GreenTouch™ Celebration

The Road to 1000X Improvement in Energy Efficiency

18 June 2015 • New York City, New York

GreenTouch™

Schedule at a Glance

THURSDAY, JUNE 18

9:30–10:00	Registration and Coffee
10:00–10:05	Welcome by Host, President of Bell Labs, Marcus Weldon
10:05–10:15	Report on GreenTouch Goals and Journey by Chairman Thierry Van Landegem
10:15–10:30	Presentation of Main Results by Chair of Technical Committee and Technical Working Group Chairs
10:30–12:00	Presentations of Results and Demonstrations by Member Researchers
12:00–14:30	Lunch provided and walk through Exhibition to: • Experience Technology Demonstrations, • Discover Novel Network Architectures and Protocols, • Explore Power and Network Models
14:30	Close

Welcome to the GreenTouch Final Event in New York City

When we launched GreenTouch in 2010, the industrial community applauded our green initiative but watched on the sidelines with some skepticism: some thought we were setting ourselves an unrealistic goal; others questioned how we would make such a colorful set of members, even competitors, work together. Well, five years later, I can assure you that we did what we said we would do. And what a set of achievements can we present to you today!

Traffic in communication networks is expected to grow dramatically due to the ever-increasing number of devices and things. One of the challenges for next generation networks is the ability to support the predicted traffic in an economically viable and sustainable manner. We therefore started to work on the bold goal to improve energy efficiency in communication and data networks by a factor of 1000. Given the breadth of technologies used, no one single company was able to achieve this on its own. So we set up the GreenTouch consortium, which has today grown to about 50 members. GreenTouch is a great example of open innovation: we have been recognized by the World Economic Forum in its Green Light report as a best practice model that other industries can apply.

Today we are celebrating the successful journey in achieving our ambitious goal. And it is through the collaborative effort of all members that we reached our goal. This required alignment on a common research agenda, an agreement on a portfolio of research projects, clear rules of engagement, a framework for intellectual property assignment and usage – not always easy, and above all, a lot of hard work.

This is the first time that an end-to-end view is given of an energy-efficient architecture, technologies and protocols in the information and communications space. You will see several of these technologies demonstrated here today, including a power consumption model and a network energy visualization tool that we make publicly available to further research and innovation.

I am grateful to have been able to work with so many talented people across our membership from all over the world. I invite you to sense their almost viral enthusiasm and share it with the world!

Enjoy!

Thierry Van Landegem
Chairman of the Board, GreenTouch

The Road to Ultra Efficient Networks

Welcome to New York City for the GreenTouch Celebration of the Road to 1000x Improvement in Energy Efficiency! It is just fitting that we meet in The City That Never Sleeps to announce and celebrate the tireless efforts, the unwavering commitment and dedication, and the innovative spirit of the researchers, scientists and engineers along this five-year journey.

It goes without saying that information and communication technologies are at the heart of the digital economies and play an increasingly important part in all of our personal and professional lives. Their impact spans virtually all industrial sectors, from agriculture, transportation, and construction to education and healthcare. Ensuring a sustainable growth, both from an environmental and economic perspective, is vitally important and one of the key challenges for our industry. It was with this goal in mind that GreenTouch was founded in 2010 with the exceedingly ambitious mission to improve the energy efficiency of communication networks by a factor of 1000. A moonshot objective for the research community!

I am very proud to state that GreenTouch has been successful in its mission. And today we announce the overall results from our research projects, along with a comprehensive portfolio of technologies to achieve dramatic improvements in energy efficiency, in mobile access, fixed access and core networks. These architectures, technologies, algorithms, protocols and the underlying modeling and evaluation methods that have been developed by GreenTouch truly pave the way toward an ultra-low power, energy-efficient communication infrastructure. A sustainable infrastructure that supports future applications, services and traffic growth while consuming less overall energy than conventional networks today. We also publicly launch two interactive applications to allow all industry stakeholders to understand the GreenTouch technologies, use them as references and build on them for even greater accomplishments.

Many thanks to all the GreenTouch members for their efforts, their technical and leadership contributions, and their creativity. These results would not have been possible without every single one of them! GreenTouch has also been an extraordinary personal journey with many new friendships, collaborations and relationships formed that transcend the technical achievements.

Thierry Klein
Chairman of the Technical Committee, GreenTouch

GreenTouch Impact

The results presented in the GreenTouch Celebration today are truly impressive and show that the potential for energy efficiency improvements across the communication networks are very tangible. From the initial Bell Labs-driven vision and a preliminary set of ideas, we have moved to an entire portfolio of architectures, technologies, components and algorithms. We have developed specific methodologies to understand the energy performance of all these technologies. The culmination of the 5-year research effort demonstrates that it is possible to improve the network energy efficiency in mobile networks by a factor 10,000, in fixed access networks by a factor 254 and in core networks by a factor 316 compared to the 2010 reference scenarios defined by GreenTouch.

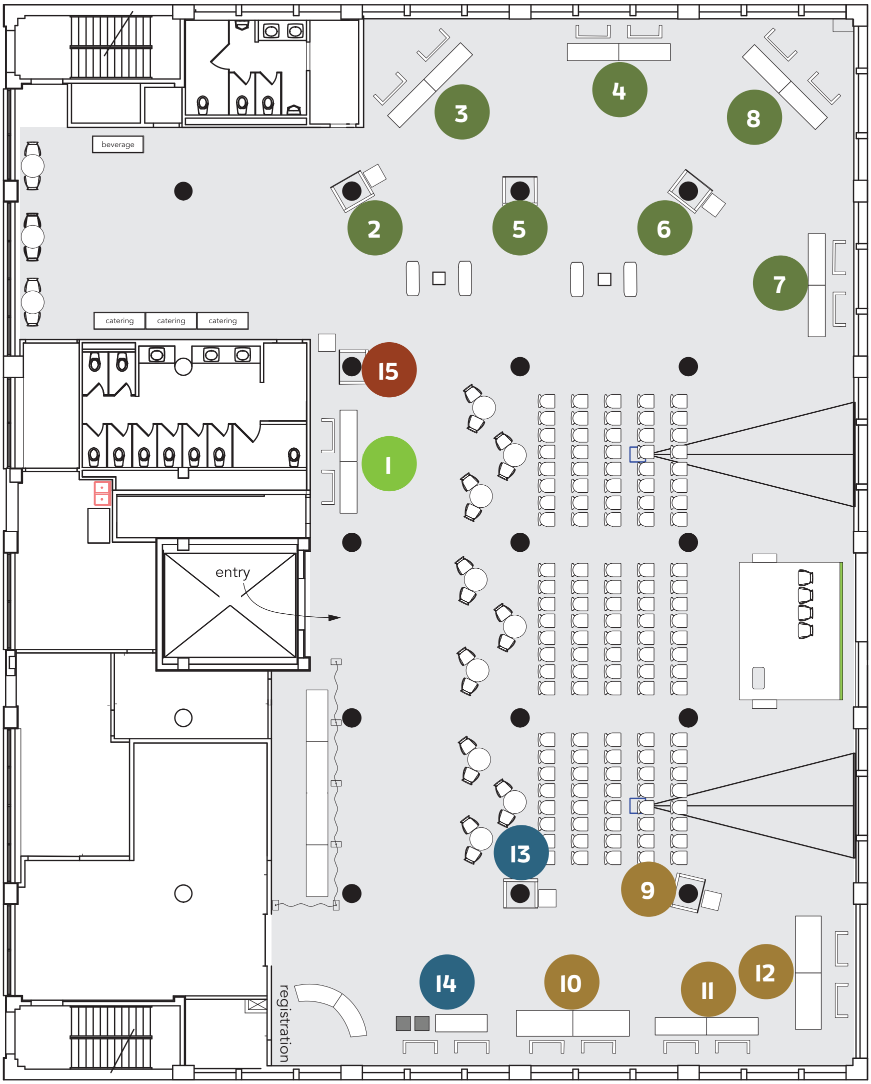
In practical terms, the GreenTouch Green Meter analysis shows that the net energy consumption of communication networks can be decreased by 98% while taking the tremendous traffic growth from 2010 to 2020 into account. Networks of the future support more traffic and consume significantly less energy than today! This energy savings potential corresponds to the equivalent greenhouse gas emissions from 5.8 million passenger vehicles.

GreenTouch invites all industry stakeholders and interested parties to review the findings from the consortium and to continue to build on these results. Information is made publicly available as follows:

- GWATT Interactive Application to Visualize the GreenTouch Results: gwatt.greentouch.org
- Power Model for Wireless Base Stations: www.imec.be/powermodel
- A series of white papers and scientific papers will be published and made available on the GreenTouch webpage: www.greentouch.org
- A series of project videos are also available on the GreenTouch webpage: www.greentouch.org

Without a doubt, GreenTouch has been successful in its very ambitious mission set forth in 2010 and the announcements today cement its position as the global thought leader in Green ICT Technologies. Together these technologies pave the road towards ultra energy efficient and sustainable communication networks. The benefits of these networks span beyond the ICT sector and touch all industry sectors across the globe. Communication technologies are vital to bridge the digital divide and connect the unconnected in the world. Energy efficiency and the GreenTouch results are a key contribution and an enabler to a more productive and sustainable future for all of us.

Floor Plan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3
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5
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8
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10
11
12
13
14
15

Table of Contents

END TO END NETWORK VIEW

GWATT – An Interactive Application To Visualize the GreenTouch Results

CHALLENGE

GWATT is an online web tool developed by GreenTouch to provide an end-to-end view of the GreenTouch portfolio of technologies and solutions and to share the results and accomplishments in an easy-to-use and interactive application accessible to everyone.

BREAKTHROUGHS

GreenTouch has delivered a comprehensive portfolio of technologies, architectures, algorithms and protocols for dramatically improving network energy efficiency. Collectively the impact of all these solutions is captured in the Green Meter results for the respective network segments in mobile access, fixed access and core networks.

GWATT is a single portal that provides access to all the technologies across the solutions portfolio and summarizes the GreenTouch Green Meter results. It has been designed to help ICT stakeholders visualize the energy impact of the technologies using dynamic scenarios and multiple metrics (including energy consumption, energy cost and equivalent carbon emissions). The user is able to identify the energy hotspots in the communication networks and through different "what if" scenarios understand the impact of the GreenTouch technologies and solutions.

RESULTS

GreenTouch is publicly launching GWATT today to share its dramatic findings with the ICT industry and any interested parties. The application is freely available at: http://gwatt.greentouch.org/.

GWATT incorporates the entire portfolio of GreenTouch technologies from mobile access, fixed access and core networks based on the GreenTouch research projects, including those technologies and demonstrations being showcased at the GreenTouch Final Event in New York.

Thanks to the GWATT interactive graphical user interface, the user can check in real time how individual technologies and combinations of technologies improve network energy performance and energy cost. Different network evolution scenarios can be simultaneously constructed and their energy performance compared. The GreenTouch results are also displayed in comparison to the 2010 reference scenario and a 2020 business-as-usual network evolution.

DEMONSTRATION

A live demonstration of GWATT will be provided during the event and visitors can experience the power of the application for themselves. The three GreenTouch network domains (mobile access, fixed access and core networks) can be selected by the GWATT user. Within these domains, a technology menu is offered and users can choose any technology or combination of technologies that they are interested in. GWATT then provides a visualization of the energy efficiency gains, energy cost, energy consumption and $CO2$ savings.

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MOBILE

Green Meter Assessment of Mobile Networks

CHALLENGE

The Mobile Working Group concentrated its activities on architectures and technologies that enable the radio access network to provide – in the most energy-efficient way – full coverage and the capacity and performance that will be needed in the year 2020. But, which technologies provide such high-energy efficiency and how to calculate the energy efficiency of a mobile network?

BREAKTHROUGHS

Technologies were investigated in the Mobile Working Group by three umbrella projects: the Beyond Cellular Green Generation (BCG^2), the Green Transmission Technologies (GTT) and the Large Scale Antenna Systems (LSAS) projects. The architecture subgroup developed a methodology to evaluate the energy efficiency for a hypothetical nationwide wireless network and benchmarked all proposed approaches and technologies by using this toolset. The final mobile architecture is then created by selecting the most energy-efficient technologies separately for each deployment area, such as city centers or country sides.

The energy efficiency of mobile networks depends on the usage pattern and is measured as the electrical energy spent per transmitted data volume averaged over a period of time, i.e., in Joules per bit. The efficiency of a nationwide operator network is then obtained by averaging the energy spent over a wide range of deployment and operational conditions, from busy hours in metropolitan areas down to rural areas at night times with very low traffic demand. We analyzed network traffic patterns and defined a representative traffic model for all the use cases, including user densities as well as the anticipated, near-exponential rise in mobile data traffic between 2010 and 2020. A power model was developed to provide realistic insights into hardware power consumption for different base station architectures.

This complementary set of several models is used to predict the overall network behavior, and the energy consumption and energy efficiency for a variety of deployments across technologies and environments: for example, the massive roll-out of small cells or for futuristic base stations with hundreds of antennas or new management schemes with intelligent sleep modes. To calculate the potential energy efficiency gains for the GreenTouch technologies and solutions, a reference scenario using the best available technologies and traffic data from the year 2010 has been defined. This reference energy efficiency is then compared with the efficiency of the GreenTouch mobile architecture assuming the traffic volume and pattern for the year 2020 and the selected most energy-efficient technologies.

RESULTS

Using this Green Meter approach, we found an architecture that shows that it is possible to achieve an energy efficiency improvement of more than a factor of 10,000 in relation to the 2010 reference scenario. Even with the much higher traffic anticipated in 2020, the network energy consumption can be lowered by a factor of 110.

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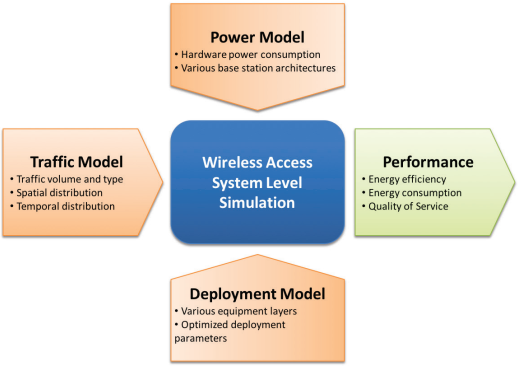

MOBILE

Power Model for Today's and Future Base Stations

CHALLENGE

The energy consumption of mobile networks is dominated by the base stations. To support increased data traffic and new services for 5G and the Internet of Things, more base stations will be required in the future. Optimizing the energy efficiency of today's and future mobile networks requires a fundamental understanding of the evolution of the power consumption and hardware capabilities of future base stations.

BREAKTHROUGHS

An advanced power model has been developed that provides realistic hardware power consumption values for a diversity of cellular base station types and operation conditions, while incorporating hardware technology trends. The power model has been extensively used by the GreenTouch Mobile Working Group. In particular it has enabled the development of innovative energy-efficient network concepts exploiting the capabilities offered by hardware technology. The network simulation results, implementing and relying on the power model as a hardware reference, are reflected in the Green Meter network energy results.

GreenTouch is convinced that this power model can become a general reference and an industry standard, as it offers a uniform and fair comparison for energy optimization of the mobile network. The clear forecasts of hardware capabilities and power consumption are suitable design guidelines for component and base station manufacturers. Network providers and operators may exploit this knowledge to develop network concepts and deployment strategies for current and future networks. To stimulate the global usage of the advanced power model, a free online web-tool version is available at www.imec.be/powermodel.

RESULTS

The key technology is an algorithmic model with a hierarchical parameter structure that enables users to clearly define the base station type and operating mode. The model provides the total power consumption of the base station and a breakdown over its components, and it delivers power and timing information on potential sleep levels. The model supports different base station types, including small cells, conventional base station types, and disruptive types such as a large scale antenna system (LSAS) with hundreds of antennas. The model also incorporates the hardware technology trends at the material, component and architectural levels to predict the base station values and capabilities between 2010 and 2020.

DEMONSTRATION

The demonstration showcases the capabilities offered by the power model through a live use of the online web tool. For example, three different base station types (such as a macro cell, a small cell and an LSAS cell) can be compared in terms of their total and component power consumptions, as well as their power scaling over different hardware technology generations. The web tool supports numerous parameter settings, which can be entered by the user through an easy-to-use graphical interface.

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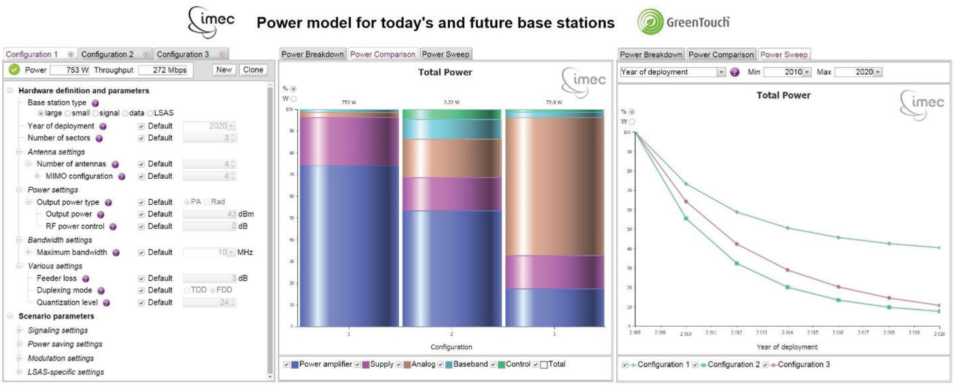

MOBILE

Beyond Cellular Green Generation

CHALLENGE

Traditional wireless network architectures are founded on the concept of cellular layout, which provides full coverage in the service area anywhere, at any time, using a set of base stations. To ensure this continuous network accessibility, most of the network remains active regardless of how many users are present and how much traffic they generate. Base stations cannot be switched off without causing connectivity issues to users that need to exchange data with the network. Their energy consumption can only be partially adapted to traffic load and hence they waste a lot of energy.

BREAKTHROUGHS

The BCG^2 (Beyond Cellular Green Generation) project goes beyond the traditional network architecture by using small cells, and by completely separating the signaling and data functions at the wireless interface. With their reduced distance between the network and user terminals, these small cells consume less energy than traditional macro cells, but we need many more of them and at any given time many of them will not be serving active users. By separating the signaling and data functions the small cells can be turned on and off when needed, making the energy consumption proportional to traffic load and the energy efficiency extremely high. A separate lightweight signaling infrastructure provides continuous network accessibility so that communication services can be requested at any time by users. It can also provide extremely useful context information on users, such as position and application profile, that can be used to optimize resources to match the traffic demands with minimum energy cost.

RESULTS

The project has evaluated the energy-saving potential of the approach through extensive simulations. Based on a detailed hardware model, three physical network architectures have been designed that map to the logical BCG^2 architecture. The first is based on a layout with two layers comprising macro data cells and a separate signaling infrastructure, the second uses three layers (adding a small cell layer for hot spots), and the third considers only small cells for the data layer and again a separate signaling layer. The network layouts and the system operation have been optimized considering traffic scenarios and selecting the most appropriate sleep mode when base stations can be turned off.

Remarkable energy efficiency gains with respect to the 2010 reference scenario have been achieved, ranging from more than 2,500x in suburban areas to more than 9,000x in urban areas.

DEMONSTRATION

The project team has also built a demonstrator that emulates the architecture using legacy technologies with the goal to show the feasibility of small-cell network management using localization information. A set of low power sensors is used for the localization system, and several access points provide the data access. The smart phones are connected through the cellular network, which emulates the signaling layer, to the back end of the system. Access points are activated and deactivated based on user positions and traffic generated. All the elements are shown on an activity map that provides in real time the status of the network and the calculated energy consumption.

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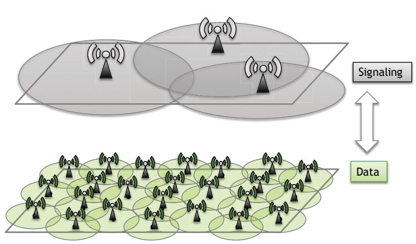
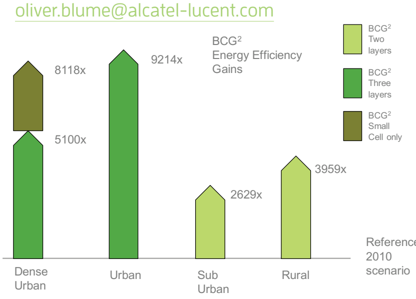


BCG^2 architecture with signaling and data separation



BCG^2 energy efficiency gains

MOBILE

Large Scale Antenna Systems

CHALLENGE

Future wireless technologies will have to accommodate three seemingly conflicting requirements: increased energy efficiency, increased throughput, and uniformly good service throughout a designated area. Present-day macro base stations serve users by means of bulky antennas that radiate power in 120-degree sectors, and within sectors each user is served over distinct time/frequency resources. Data-bearing power that is intended for a particular user is uselessly sent towards all users in the sector. A drastic departure from today's wireless physical layer may be required in order to achieve the goals of future wireless systems.

BREAKTHROUGHS

The Large Scale Antenna Systems (LSAS) approach eliminates sectorization and utilizes a large number of physically small, low-power, individually controlled antennas to create a multiplicity of user-selective beams of data. Doubling the number of service antennas improves the selectivity and permits the total radiated power to be cut in half with no effect on the quality of service. Aggressive multiplexing serves all users over all time/frequency resources, which yields the desired spectral efficiency, and therefore throughput gains. Effective power control ensures uniformly good service for the users, even at the edge of the cell.

The LSAS project has achieved notable technical successes: a power model, a semi-analytical multi-cell performance simulation, and optimization algorithms for system design that minimize total power consumption while meeting desired service requirements. The power model accounts for the inefficiency of generating transmit power; the power consumption of internal electronics, which is proportional to the number of service antennas; and the power required for LSAS-critical signal processing. The semi-analytical simulation enables rapid performance evaluations. The optimization algorithms resolve a fundamental tradeoff that more antennas reduce the required radiated power, but increase internal power consumption.

RESULTS

For a variety of deployment scenarios, ranging from dense urban to rural, we have determined the optimal number of antennas and radiated powers for maximizing total energy efficiency. Daily average energy efficiency improvements for LSAS over the 2010 reference scenario range from 1,600x for rural deployments to 14,000x for dense urban deployments.

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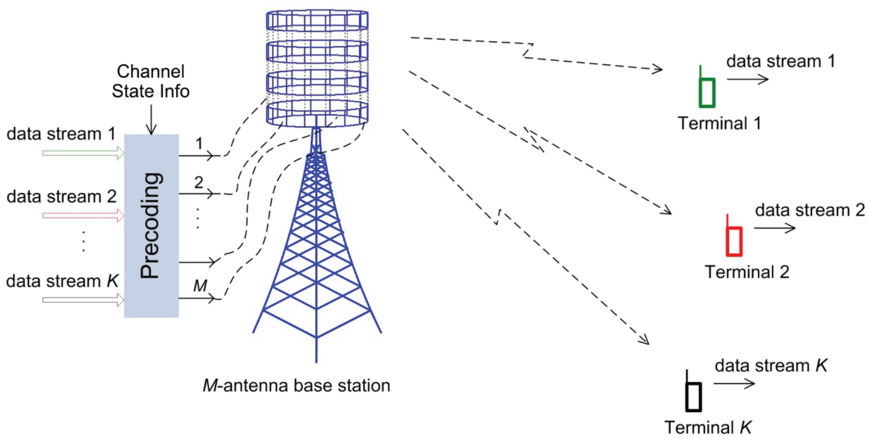

MOBILE

Green Transmission Technologies

CHALLENGE

Shannon's ground-breaking capacity theorem suggests that there is a fundamental tradeoff between energy efficiency (EE, defined in bits per second per Watt) and spectrum efficiency (SE, defined in bits per second per Hertz). The theory suggests adapting the system's operating point from the high SE region to the high EE region whenever possible while satisfying the quality-of-service of all users. Though straightforward in concept, it is not trivial to implement in practice. Transmit power is only a part of the total power consumption in real systems, and the power required for baseband processing and the radio frequency chains needs to be taken into account. A large number of users are sharing all the resources, such as bandwidth, power, time, antennas, etc., and interfering with each other, which makes the EE-oriented optimization flexible but complex. Smart integration of the various proposed solutions becomes a challenging task.

BREAKTHROUGHS

In a bandwidth-rich environment, bandwidth expansion has been shown to lead to a corresponding reduction in the transmit power but it pushes the system to work in very low signal-to-noise-ratio conditions. Dedicated signal processing algorithms to maintain the stability and reliability for such transmissions are one of the key breakthroughs of the Green Transmission Technologies (GTT) project. On the other hand, in bandwidth-limited situations, the network EE optimization problem is formulated under the EE-SE tradeoff framework, and various GTT solutions are proposed to best utilize all available resources. These strategies include Dynamic MIMO (Multiple Input Multiple Output) with antenna sleeping, which selects between single-user beamforming and multi-user multiplexing with the optimal number of active antennas. Interference alignment is another technology that is investigated to eliminate the strongest interference produced by a large set of neighboring base stations. Finally, at the network architecture level, a collaborative distributed antenna system is considered that enables low interference virtualized access through intelligent clustering and optimal power allocation.

RESULTS

The GTT project has developed a methodology and a unified simulation platform to integrate all the different technologies. Hierarchical modeling with two layers is used to decouple the network layer deployment with the physical layer transmission technology design. Each (combined) solution gives a physical-to-network performance mapping curve and the best solution is selected for any given environment. Together, the GTT technologies offer an improvement in energy efficiency between 5200x (for rural environment) and 7300x (for urban environment) compared to the 2010 GreenTouch reference architecture. Additional gains can be achieved when the GTT technologies are coupled with the Beyond Cellular Green Generation (BCG^2) concept of separating the control and data plane functionalities.

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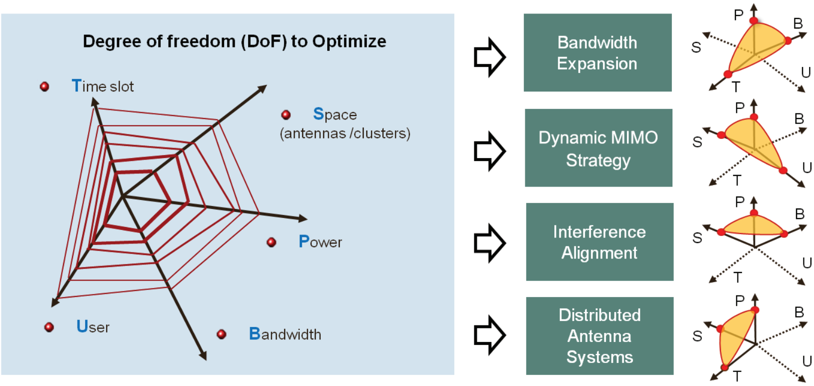

MOBILE

Enhanced Wireless Receiver to Mitigate Poor Channel Quality and Interference

CHALLENGE

Mobile wireless users can suffer from degraded performance due to having a poor channel link with a base station and/or interference from transmissions in neighboring cells. Users see this in the form of a "low number of bars" on their screens, dropped or poor quality calls, and very low data rates. Base stations compensate for users suffering from a poor channel link or interference by transmitting at higher signal powers to these users. This adversely adds to the energy cost of the base station, but also increases the interference on neighboring cells.

A receiver that can perform better in such scenarios will be of great value by both reducing base station energy and reducing interference on neighboring cells (which in return helps reduce the energy expended by those neighboring base stations). The challenge lies in designing and validating such a receiver to perform better when its signal quality is low.

BREAKTHROUGHS

Mobile receivers need to synchronize themselves to the received data signal and estimate and equalize the effects of the channel link. The key innovation of this project is a redesigned receiver structure that operates better with lower signal quality. It differs from conventional handset receivers in two ways. Firstly, a residual phase-estimation function is used to improve initial synchronizing of the receiver along with a faster acquisition time. Secondly, an iterative channel estimation-equalization approach uses a feedback loop from the soft data decoder output to improve performance and track the channel as it changes over time.

RESULTS

The redesigned receiver provides energy savings of almost 9% at the base station versus a conventional receiver. The more reliable receiver reduces a base station's need to retransmit data to users with low signal quality. Hence, energy is saved and such users experience higher data rates and a more reliable mobile experience.

DEMONSTRATION

The demonstration is an experimental validation of the new receiver technology. It consists of two Universal Software Radio Peripheral (USRP) boards connected to laptops: one acts as a transmitter and the other as a receiver. Data packets are sent wirelessly between the USRP boards, and a low transmit power forces a low signal quality at the receiver. Results are processed on a laptop to compare the performance of the new receiver technology to a conventional one.

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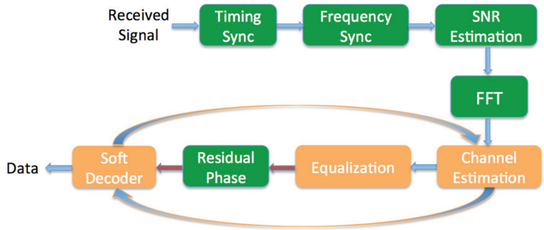

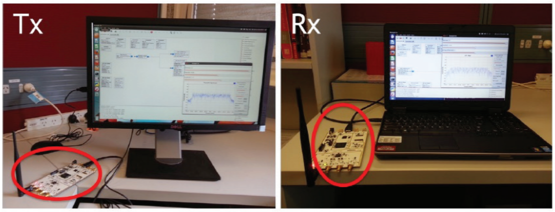

MOBILE

Interference Alignment in Cellular Networks for Energy Efficiency Improvement

CHALLENGE

An important part of the energy consumption of mobile networks is proportional to the radiated energy, which relies on the frequency bandwidth and the transmission power. Current networks aim to support high data rates to end users by increasing the spectral efficiency in bps-per-Hertz of the network, at the expense of the energy efficiency of the network. A more energy-efficient transmission scheme is to increase the system bandwidth and to allocate the entire available spectrum to each base station. Such an approach, however, leads to significant interference increase and performance degradation for mobiles located at the cell edges. The key challenge is to find the appropriate balance between reducing the interference and maximizing the spectrum utilization to reach an optimal spectral efficiency – energy efficiency tradeoff.

BREAKTHROUGHS

This challenge has been addressed in the past, for instance using frequency/code planning in 2G/3G networks or with cooperative multipoint antennas in 4G. The aim of this project has been to derive a more flexible scheme leveraging the current technology but achieving greater overall energy efficiency. The proposed approach exploits interference alignment to reduce inter-cell interference without complex coordination. A new precoding algorithm is developed to create an appropriate interference map for each mobile user. This map is then exploited by novel base-station scheduling algorithms that ensure that cell edge users perceive an almost interference-free signal, leading to greater spectral efficiency and performance.

RESULTS

The performance of the proposed scheme has been evaluated through exhaustive simulations in different network and load scenarios. In comparison to a reference scenario without interference alignment, the simulations highlight that the cell capacity can on average be increased by a factor of two and that the spectral efficiency of cell edge users can be increased up to a factor of four. When translated into system-level benefits, it has been shown that the interference alignment approach could reduce the network energy consumption by up to 15%.

DEMONSTRATION

The demonstration gives a proof of concept and focuses on the main challenges related to interference alignment: the knowledge of the interference footprint and the scheduling algorithms to make use of the interference information to maximize the spectral efficiency. A wireless network is emulated on CorteXlab (http://www.cortexlab.fr), a controlled hardware facility located in Lyon, France with remotely programmable radios and multi-node processing capabilities. During the live demonstration, a control laptop is remotely connected to the facility, deploying software on the radios and launching an interference alignment scenario and collecting real-time performance feedback. The efficiency gain of interference alignment is then shown for various experimental conditions that can be tuned from the control laptop.

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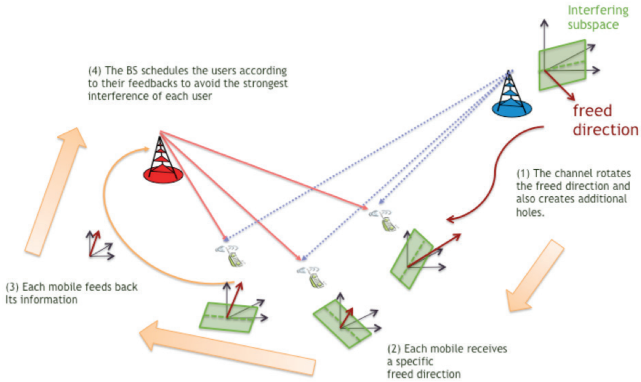

FIXED ACCESS

Green Meter Assessment for Fixed Access Networks

CHALLENGE

Fixed access traffic constitutes more than 85% of the total IP traffic in access networks. All subscribers have broadband access devices at their homes, thus contributing a significant portion to the overall network energy consumption. Moreover, the traffic volume predicted for 2020 is more than seven times larger than the 2010 traffic. The challenge is to define the network architecture integrating key new technologies to improve the energy efficiency of fixed access and metro aggregation networks. We also aim to develop a mathematical model that captures energy savings measured at the component level and has the ability to compute the overall system-level energy savings.

BREAKTHROUGHS

Both residential as well as business access networks are investigated. The GreenTouch residential access network is based on a new access technology known as Cascaded Bit Interleaved Passive Optical Network (CBI-PON), which allows the power consumption to scale in proportion to the actual traffic passing through the network. In addition, we use the concept of virtualization, which allows moving some of the functions of the residential gateways to the central office and takes advantage of pooling and sharing of resources to realize energy savings. We also use point-to-point fiber optical links within the local home network, and the capability to put different components in a low-power sleep state.

In the GreenTouch business access network, we use a point-to-point access technology, where the optical transceiver has been fundamentally re-designed to achieve the lowest power consumption. In addition, we again use point-to-point fiber-optical links within the premise, and the sleep mode capability.

RESULTS

The Fixed Access Green Meter methodology brings together this portfolio of technologies and assesses their individual and collective impact on energy savings. In particular, our results demonstrate that the energy efficiency can be improved by 254x for the residential access network and by 30x for the business access network relative to the 2010 reference scenarios.

DEMONSTRATION

Physical demonstrations of some of the constituent technologies (Bi-PON, virtual home gateway, and the redesigned point-to-point optical transceiver) are being showcased.

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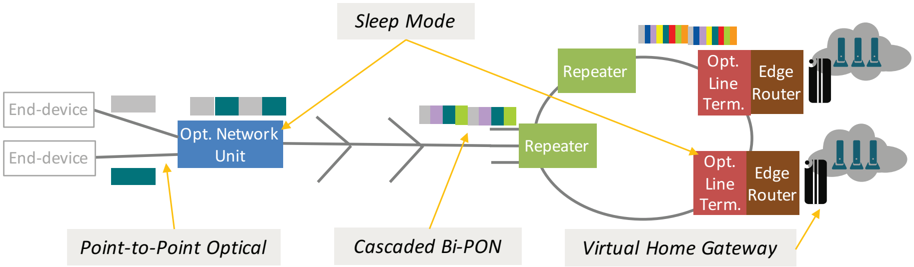

Residential access network

FIXED ACCESS

Cascaded Bit-Interleaving Passive Optical Network

CHALLENGE

Future telecom services are anticipated to require lower latency and wider range of bandwidth demands. To support a higher instantaneous bandwidth demand, service providers are forced to upgrade their networks with higher-capacity equipment. As power consumption of conventional network equipment is directly proportional to its maximum line rate and loading, rather than the actual traffic that the subscriber is receiving, the metro and access networks will suffer from low energy efficiency. This inefficiency will further be multiplied by the large number of user terminals. As a result, the total power consumption of the metro and access networks will become a challenge for telecom service providers.

BREAKTHROUGHS

We introduce a novel concept of "power consumption follows user traffic load." It is enabled by the key innovation of a bit-interleaving PON (Bi-PON) protocol. The Bi-PON protocol allows the ONU digital back end in the customer premise equipment to run at a much lower rate, taking advantage of the fact that only a fraction of the aggregate downstream traffic is intended for any given ONU. This enables a drastic reduction of the ONU power consumption. We also extend this Bi-PON concept to a Cascaded Bit-Interleaving PON (CBI-PON). In CBI-PON, data is organized in such a way that any network node (intermediate repeater or end termination node) can efficiently process only the portion of data that is relevant to that node. Hence, it significantly reduces the total power consumption across the entire network.

RESULTS

To realize this concept and experimentally evaluate the power consumption of the proposed protocol, we designed a unique sub-sampling clock and data recovery circuit together with an ultra-low power and bufferless protocol processor and transceiver circuit. With reference to the baseline network in 2010, a savings factor of 5x at the aggregation point and 4.5x at the ONU in digital processing and switching functions can be achieved.

DEMONSTRATION

A system demonstration of a single-stage Bi-PON is shown with live video traffic. We show real-time power consumption measurements of two Bi-PON ONT proof-of-concept implementations, one in FPGA and one in ASIC, with comparison to a conventional XGPON ONT.

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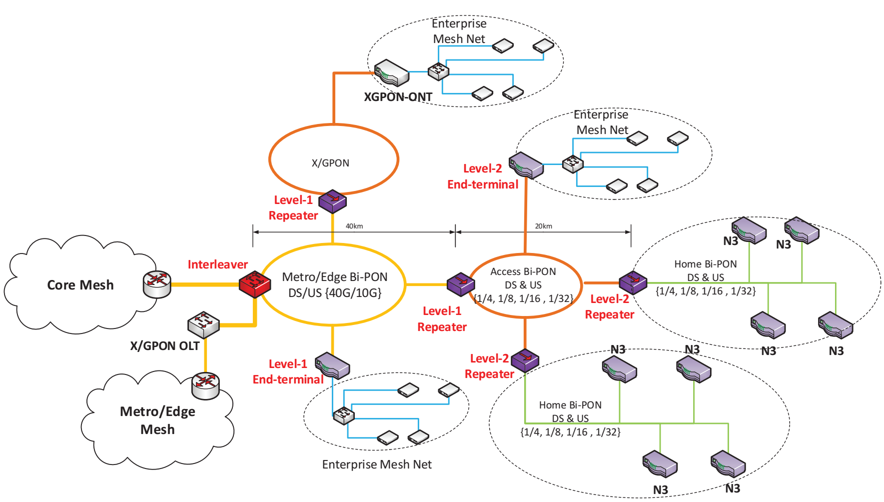

FIXED ACCESS

Virtual Home Gateway

CHALLENGE

Most connected homes rely on in-home equipment such as a home gateway or set-top box. These boxes allow consumers to benefit from Internet access through a set of dedicated services supported by network operators. Multimedia, data, voice and television streams all pass through the home gateways. Today, this equipment is usually always on (24 hours a day), and it consumes a lot of electrical power (from 15 to 30W per gateway), whether it is being used or not.

BREAKTHROUGHS

The GreenTouch Virtual Home Gateway project tackles this issue using a disruptive approach. Instead of keeping these energy-consuming, unshared gateways in the home and always powered on, we replace the in-home boxes with smaller interface equipment and virtualize their service functionalities into "containers" that are hosted inside the network operator's infrastructure. In other words, we move the service functions from a box inside the home to the cloud.

RESULT

This more efficient sharing of resources leads to a reduction of the power consumption of the residential access network by 19%

The Virtual Home Gateway project has demonstrated that this level of reduction is indeed feasible. A lab demonstration that can host 1000 virtual home gateways on a single server consuming 110W has been built to validate the underlying concept. The virtual home gateways are all active and handle video transmissions and forwarding to 1000 clients. The effective per-user power consumption of 165mW for a virtual home gateway, accounting also for cooling for the server, has to be compared to the equivalent home gateway data processing (excluding switching) power consumption of about 1.2W in today's networks.

The scalability issue has also been addressed through a distributed server architecture that hosts the virtual home gateway functionalities on multiple servers in a cloud environment. These servers can be efficiently shared and turned on and off as needed by the traffic demands. Using this approach, the optimal quality of service is provided to all the subscribers while activating only the minimum required number of servers with the overall minimum amount of energy.

DEMONSTRATION

Several hundred virtual home gateway instances are running on the demonstration hardware and connecting to the home clients. In the live demonstration, the potential energy savings are shown along with the ease of managing the virtual home gateways in a distributed fashion.

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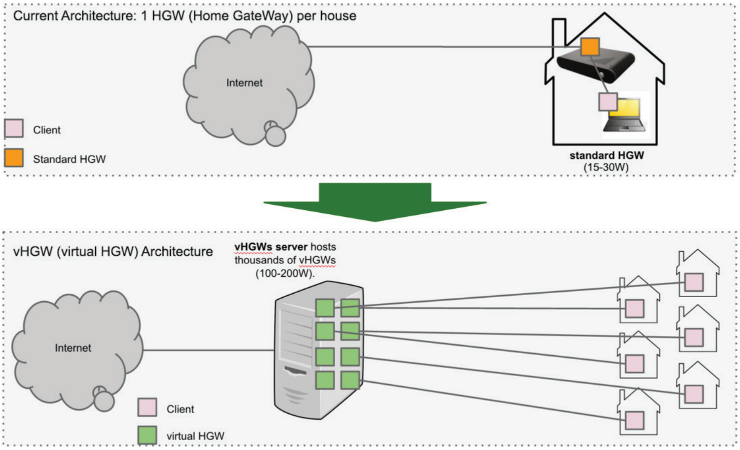

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Point-to-Point Optical Transceiver

CHALLENGE

Optical access networks are mainly based on either point-to-multipoint or point-to-point technologies. Point-to-point optical links play a significant role in providing Internet services to businesses and are envisioned to connect high-data-rate devices in the home as well. A key component in a point-to-point access network fiber link is a pair of optical transceivers: one located at the central office and the other at the customer's premises. Conventional point-to-point optical transceivers are designed with limited consideration for the power consumption. Each transceiver is continuously operating at a high and fixed optical power. The electronic-to-optical signal conversion efficiency is relatively low. As a result, conventional point-to-point optical links are relatively inefficient in energy usage.

Our modeling estimates that in a conventional point-to-point fiber access network the pair of transceivers consumes a quarter of the total power consumption of the link. Therefore, a significant improvement in the overall access network energy efficiency can be attained by reducing the power consumption of the optical transceivers.

BREAKTHROUGHS

A new energy-optimized optical transceiver has been designed for point-to-point links with a data rate up to 1 Gb/s. In particular, an innovative hardware design and an intelligent control mechanism have been introduced with the explicit goal to improve the overall energy efficiency of the transceiver design. A new low-power custom-built ASIC has been developed that minimizes the circuit power consumption. The vertical cavity surface emitting laser (VCSEL) and photodiode (PD) are wire-bonded to the ASIC transceiver, thereby reducing the circuit parasitic and providing better circuit performance. This tight system integration also removes the power-hungry interconnects. A second important feature of the new transceiver is an adaptive power control algorithm to dynamically optimize the power consumption based on the link distance and the actually experienced link loss.

RESULTS

The project has developed and tested an experimental prototype of the new optical transceiver. A nominal power consumption of 27mW has been measured in the lab, which could be further reduced to as little as 12mW with the full benefit of the adaptive power control algorithm. This ultra-low power consumption compares to 460mW that has been measured for conventional state-of-the-art optical transceivers, representing a 17x to 38x improvement in the component energy consumption.

DEMONSTRATION

The demonstration setup shows a point-to-point communication link between two terminals connected by a 20km fiber connection. HD video is continuously streamed between the transmitter and the receiver and the corresponding power consumption is displayed in real-time. Both the conventional and the new energy-optimized optical transceivers are included in the setup and their respective power consumptions are measured. The video is displayed to show that actual content is being sent from the transmitter to the receiver at a fraction of the power consumed by current commercially deployed equipment.

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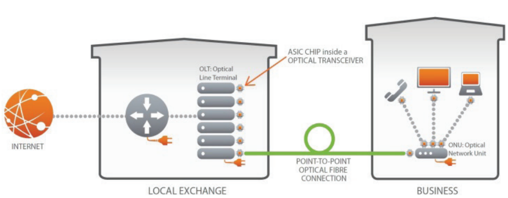

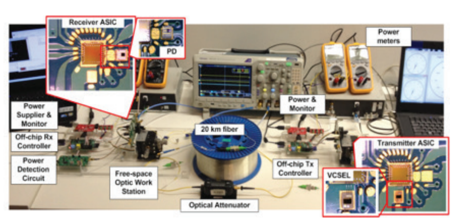

CORE NETWORKS

Green Meter Assessment for Core Networks

CHALLENGE

Over the 10-year period from 2010 to 2020, the traffic in the core of the Internet will increase by almost 10-fold. With the current industry trends for network energy efficiency improvements, the energy consumption of the core of the Internet is increasing at an annual rate of 8.5% and would more than double over the 10-year period. Global electricity production historically increases at 3% per annum. Without increasing the rate at which core network energy efficiency improves, the long term growth of the Internet is not sustainable. The industry needs new strategies for energy efficiency improvement.

BREAKTHROUGHS

The "business as usual" roadmap of improvements (primarily attributed to Moore's Law) will only lead to a four-fold improvement in core network energy efficiency. This is not sufficient to keep pace with the predicted traffic growth in the Internet. The Wired Core and Access Network Working Group has investigated a number of technologies specifically targeted at core network energy efficiency improvements, including the following new innovations:

1. Improving the IP routers by matching packet processing more carefully to packet sizes, leveraging optical interconnects in router ports and tuning the signal processing in transponders to the actual link length,
2. Improving the energy efficiency of network protection by optimizing the deployment and intelligently managing the protection equipment only when it is required,
3. Coordinating sleep modes and router bypass in accordance with the diurnal cycle of traffic patterns to place electronic equipment into a low-energy state during times of low traffic and bypassing electronic processing in routers whenever possible,
4. Dynamically allocating the most appropriate line rate of 40Gb/s, 100Gb/s, 400Gb/s and 1000Gb/s based on the distance and capacity of each network link to ensure that the power consumption of transponders is proportional to data rate,
5. Optimizing the network topology through the dynamic allocation of direct connections between nodes,
6. Implementing optimized distributed cloud storage and network equipment virtualization to minimize the storage, processing and transmission resources in the network.

RESULTS

GreenTouch has combined the experimental validation of some of the roadmap features with a detailed computer optimization of a representative nationwide network to bring together all the roadmap innovations. This optimization provides an estimate of the individual and cumulative energy efficiency gains provided by the different technologies. In particular, this Green Meter study shows that it is possible to increase the energy efficiency of the Internet's core network by 316-fold compared to the 2010 reference scenario. This efficiency improvement will result in a 96% decrease in core network energy consumption.

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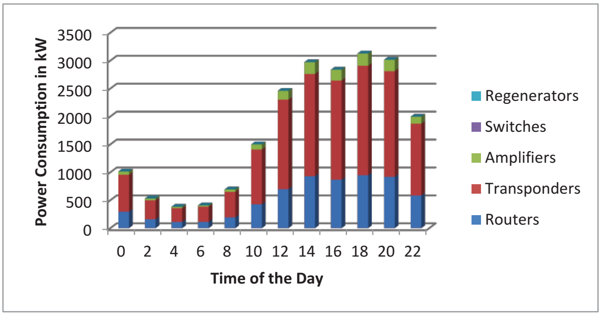

CORE NETWORKS

Energy-Efficient Content Distribution

CHALLENGE

Content distribution networks have typically not been optimized to minimize power consumption but rather to minimize delay. In many cases, content (such as video files, music files and pictures) has even been delivered from one central data center in the network. Content represents over 90% of the current traffic in core networks, and therefore any improvements in the energy efficiency of content distribution and associated reductions in the power consumption will have a significant impact on the overall energy efficiency of the core networks.

BREAKTHROUGHS

This project introduces a new analytic optimization framework to minimize the power consumption of content distribution networks. This has resulted in new network architectures where content is delivered to end users from distributed clouds or data centers that are close to the users. Such distributed clouds reduce the transmission paths through the network to access content and therefore reduce power consumption. Our optimization has established the minimum number and the location of the clouds required, the best placement of content in the respective clouds based on content popularity, and the energy-optimal routing strategies to access the content from the clouds. Practical algorithms have been developed that can be implemented in our distributed clouds and used to access content in real time. In addition to hosting content, the clouds can be used to carry out processing functions in virtual machines in an energy-efficient manner for applications that include gaming and data processing. The placement of these virtual machines in the distributed network has also been included in our optimization framework.

RESULTS

The Wired Core and Access Network Working Group has constructed a methodology to assess the portfolio of technologies for the core data networks and to show that total energy efficiency gains of 316x in 2020 compared to the 2010 reference scenario can be achieved. The energy-efficient content distribution approach presented in this project contributes itself just over 2x towards this 316x improvement.

DEMONSTRATION

We have implemented our energy-efficient content distribution algorithms in a hardware demonstrator to emulate the topology of a nationwide core and data center network. The demonstration represents a core network with 14 nodes, where each node is represented by a server for hosting content and carrying out processing and by a router for data forwarding. A centralized content distribution strategy that serves users from one central location has been implemented as a reference scenario, along with our optimized algorithms for localized data centers and content placement and distribution. The analytical models, the implemented algorithms and the hardware demonstration produce results that are in close agreement and show significant reduction in network power consumption compared to the reference scenario.

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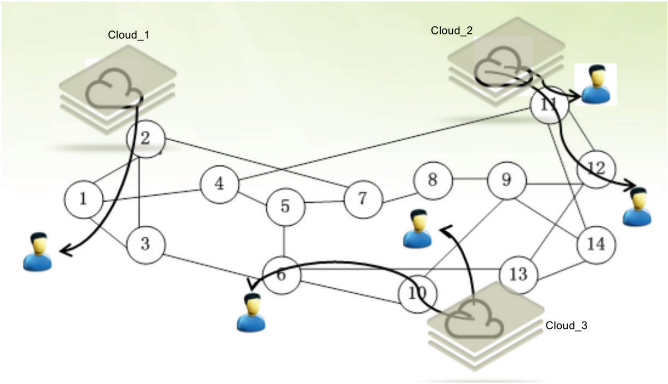

SERVICES, POLICIES AND STANDARDS

Overview of GreenTouch Standardization Activities

CHALLENGE

It is well recognized that standards are one important way to promote research results and to accelerate their transfer into innovative marketable products and services. In some circumstances, they are also a necessary pre-condition for a large deployment and the successful commercialization of a technology. Standards should take into account the maturity of the ecosystem, the position of the candidate technology in the standardization lifecycle, the objectives of the research projects, possible open issues, and the research project maturity.

BREAKTHROUGHS

GreenTouch has recognized the need to understand the important trends in the industry and to position the research work of the consortium within the broader ecosystem. The Services, Policies and Standards (SPS) Working Group was set up with the following four main objectives in mind:

- Identify the macro traffic trends, network characteristics and traffic details, and assist the GreenTouch projects and working groups when designing their network models,
- Provide an appropriate platform to understand and influence standards central to realizing the GreenTouch innovations and architectures,
- Provide unbiased, pre-competitive information and guidance to further the GreenTouch mission in policy arenas,
- Establish a channel for operators and service providers to clearly communicate the importance of energy efficiency improvements for future networks.

RESULTS

The main accomplishments of the SPS Working Group span the entire lifecycle of the GreenTouch projects.

- Traffic volume projections and growth rates have been developed for the entire 2010¬2020 timeframe based on historical trends, near-term forecasts and extrapolations. Our research shows that, from 2010 to 2020, traffic will increase in mobile networks by a factor of 89 and in fixed access by a factor of 7 and in core networks by a factor of 10. The traffic projections are instrumental to the evaluation of the network energy consumption and the Green Meter results on energy efficiency improvements.
- The Energy Metrics for Users (EMU) project has formulated energy metrics and a methodology to capture the energy consumption of end-to-end Internet services. This methodology has been submitted as the unique candidate standard in ITU-T SG5 (ICT & Climate Change), providing a metric to assess the potential reduction of the ICT service carbon footprint.
- GreenTouch has also been engaged with the broader policy ecosystem to increase awareness of the developments made within the consortium. In particular, GreenTouch provided traffic information and growth projections to GeSI (Global e-Sustainability Initiative) for inclusion in the SMARTer 2020 Report and participated in workshops at the International Energy Agency. A position paper outlining the requirements for energy data collection in radio access networks has been developed and circulated to encourage an industry-wide methodology.

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About GreenTouch

Our Global Vision

GreenTouch is a consortium of leading Information and Communications Technology (ICT) industry, academic and non-governmental research experts dedicated to fundamentally transforming communications and data networks, including the Internet, and significantly reducing the carbon footprint of ICT devices, platforms and networks.

Our Foundation

Two factors motivated the formation of GreenTouch in early 2010. First, energy consumption in ICT networks is increasing in part due to exponential network growth, especially with the explosion of wireless data traffic. Network growth is outpacing equipment efficiency, which is slowing as limits to historical capacity and scaling laws loom. This trend could adversely affect the Internet and the broad energy efficiency benefits that ICT networks and associated smart technologies enable. The second motivation is the urgent need to meet the global challenge of reducing greenhouse gas emissions. Every industry must play its part, and ICT, at the forefront of technology, can be a leader here.

To dramatically reduce the energy consumption of today's ICT networks, a radical new approach was needed. Meeting the challenge depended on collaborative efforts that take advantage of innovation and expertise from around the world. GreenTouch brought together this expertise in a consortium whose members -- leading industry enterprises, entrepreneurs, and researchers from across the ICT community -- worked in concert to invent the technologies that can achieve sustainable networks in the decades to come.

GreenTouch has also been stimulated by recent research that identifies a gap between rapid network growth rates today and historical equipment efficiency improvements -- a gap that promises to increase over the decades ahead. Technologies in use today, even considering best-case projected energy efficiency improvements, are not expected to be sufficient to check the rate of energy consumption over the long term. At the same time, key technology energy limits associated with existing underlying components of ICT networks (optical, wireless, electronics, routing, architecture, etc.) are still many orders of magnitude below current operating levels.

The vision of GreenTouch has been to create ICT networks and technologies that enable a sustainable Internet, and to serve as an open, collaborative platform that allows our members to make best use of their expertise in order to deliver a fundamental redesign of networks – one that dramatically improves their energy efficiency and reduces their overall carbon footprint – for the benefit of our members, the ICT sector, and the entire world.

www.greentouch.org

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GreenTouch™ Celebration

The Road to 1000X Improvement in Energy Efficiency

18 June 2015 • New York City, New York

GreenTouch™