This report outlines the activities of the Centre for Energy-Efficient Telecommunications (CEET) at the University of Melbourne for the period of January 2011 to June 2016. 

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WELCOME AND ACKNOWLEDGEMENTS

This report summarises the activities and achievements of the Centre for Energy-Efficient Telecommunications (CEET) located at the University of Melbourne from January 2011 to June 2016. During this time, CEET became recognised as an international leader in energy efficiency research in telecommunications. CEET was an industry-academic partnership focused on finding ways to improve energy efficiency in the telecommunications sector. CEET’s main contributions were through its participation in the international GreenTouch consortium.

CEET was in international leader in modelling the energy and energy efficiency of telecommunications equipment, networks and services. Methods developed by CEET are now widely used in the academic and industry sectors for understanding the energy consumption in telecommunications.

The importance of energy efficiency will only increase over coming years as the Internet and broadband services transform society to become globally networked. This goal, represented by the Internet of Things and beyond, will not be attainable unless sustainability is “built-in”. Energy efficiency will be crucial at both the global and local scales. Globally, the cumulative carbon footprint of planet wide ubiquitous broadband must be minimised. Locally, the use of “off-grid” power will require energy efficient operation of infrastructure.

The members and supporters of the Centre can be proud of the contributions CEET has made to the improvement in energy efficiency and sustainability of the Internet and telecommunications. These contributions would not have been possible without the support and dedication of several organisations and people.

The support and partnership of Bell Labs, Alcatel-Lucent (acquired by Nokia in January 2016), the Victorian State Government and the University of Melbourne made the creation and ongoing operation of CEET possible. I would like to acknowledge the contributions of all the Alcatel-Lucent and Bell Labs staff that contributed and assisted CEET during its time; in particular the vision and leadership of Ric Clark, Thierry Klein, Randy Giles, Thierry Van Landegem, Peter Vetter and Tim Marshall who were crucial to CEET’s operation.

I would also thank the Advisory and Operations Committees of CEET as well as CEET’s collaborators in Bell Labs who were crucial to CEET’s research successes and its continued focus on industry relevant outcomes.

Finally, as the CEET Director, I would like to acknowledge the incredible dedication, innovation and effort put in by all the members of the CEET research team. This team includes the CEET funded Research Fellows, University of Melbourne in-kind staff and Honorary Fellows, CEET Postgraduate students and Bell Labs Collaborators. Under the leadership of Melbourne Laureate Emeritus Professor Rod Tucker, in only a few years a research team was created and attained an international reputation as world leaders in the field of energy efficient telecommunications. This was an amazing accomplishment of which all contributors to CEET can all be proud.

DR KERRY HINTON
CEET Director
Principal Research Fellow, University of Melbourne
BEGINNINGS

The Internet consumes up to 2 percent of the world’s energy supply. The increased use of connected services is resulting in increased power consumption. Therefore, minimising the energy consumption of the Internet is essential to reduce the impact of information and communications technology (ICT) on the environment.

Seeing the opportunities in this area and the depth of research talent at the University of Melbourne, coupled with a need to curb the Internet’s energy consumption to ensure sustainability, Alcatel-Lucent (now Nokia) partnered with the University of Melbourne to establish the Centre for Energy-Efficient Telecommunications (CEET).

In March 2011, then Victorian Minister for Technology, the Hon Gordon Rich-Phillips, launched CEET at Melbourne with senior executives from the University of Melbourne, Bell Labs and Alcatel-Lucent.

The Centre was a $10 million partnership between Alcatel-Lucent, Bell Labs, the University of Melbourne and the Victorian State Government. In addition to providing funding to support research, the Centre also provided connections between University researchers with industry researchers at Bell Labs from around the world.
The Centre’s research program focused on measuring and modelling the energy impact of the cloud, content delivery services, the Internet of Things, energy efficient wireless and the development of low energy access technologies. The Centre also investigated the impact of the National Broadband Network (NBN) on the national economy and energy consumption and developing energy consumption models for Internet services.

The Centre was a key member of GreenTouch, a global consortium of telecommunications organisations and Universities dedicated to showing how telecommunication networks can reduce their energy impact by a factor of 1000x. In June 2015 GreenTouch announced the roadmap for reducing the energy consumption of telecommunication networks by 98% even with the overall traffic in the network increasing 12-fold between 2010 and 2020.

During the lifetime of GreenTouch, CEET has been a key contributor to the technology roadmap by participating in 3 Working Groups on 5 key projects and contributing to white papers and technical reports. CEET representatives held positions on the Executive Board and Technical Committee and hosted the 10th GreenTouch global consortium in Melbourne in 2014.
INDUSTRY PARTNERSHIP

ALCATEL-LUCENT & BELL LABS

Working in close collaboration with Bell Labs, Victoria's Centre for Energy-Efficient Telecommunications (CEET) delivered important new insights to reduce the energy consumption of future networks, while setting new benchmarks for industry-academic research partnerships.

CEET was established in 2010 and launched in March 2011 by Alcatel-Lucent (now Nokia), the Victorian State Government and the University of Melbourne to address the substantial projected growth in energy consumption linked to surging Internet demand. Collaborating with a number of Bell Labs researchers, CEET played a significant role contributing technologies, protocols, design methodologies, modeling and architectures that increase the energy efficiency of data networks. It was also a leading contributor to the GreenTouch consortium and played a key role in putting an energy efficient Internet firmly on the global agenda.

CEET was recognised in Australia as a best practice model of academic-industry collaboration, and was awarded for excellence in innovation in industry partnerships. Alcatel-Lucent is proud of these achievements, highlighting such a great example of industry effectively working together with the academic sector in a genuine partnership for common goals.

At CEET the research team worked closely with Bell Labs to understand the complex web of resource consumption and to develop ideas and innovations to maximise the scalability, effectiveness, and energy efficiency of the interconnected environment.

As a leading contributor within the GreenTouch community, CEET played a significant role in the development of the GreenTouch Green Meter research study in the first half of 2013, which highlighted progress to achieve the GreenTouch goal of a one thousand-fold improvement in network energy efficiency. Through the University of Melbourne, CEET is a foundation member of GreenTouch and over the years CEET researchers undertook leadership roles including positions on the GreenTouch Executive Board, GreenTouch Technical Committee and chairing GreenTouch Working Groups.

NOKIA MERGER

On 14 January 2016, Alcatel-Lucent was acquired globally by Nokia.

The combined company offers a complete end-to-end portfolio of products and services, with 104,000 employees and five business groups: Mobile Networks, Fixed Networks, IP/Optical Networks, Applications & Analytics and Nokia Technologies.

Nokia is an innovation powerhouse with some 40,000 R&D professionals, a combined pro forma R&D spend in 2014 of EUR 4.2 billion and a world-leading intellectual property portfolio. Nokia is combining its own proud R&D heritage with the unrivalled history of Nokia Bell Labs, which has been awarded 8 Nobel prizes over its lifetime, together creating around 31,000 patent families.

For the purpose of this report Nokia is generally referred to as Alcatel-Lucent as CEET was established under the Alcatel-Lucent legal entity.
The ICT industry contributes around 2% to humankind’s global CO₂ production. Given the transport and construction industries generate significantly more CO₂, one can rightly ask, “Why focus on the energy efficiency of telecommunications?” ICT is currently one of the fastest growing industry sectors, with annual Internet traffic growth at around 40%. This is, in part, being driven by the ever-increasing demand for (mobile) applications and video viewing.

Energy is required to power the 24/7 global telecommunication networks. From the routers and switches to data centres, fibre-optic undersea cables to the growing number of wireless base stations.

Looking to the future, we are evolving toward a “networked planet” with industry forecasts for the growth of the Internet of Things requiring around tens to hundreds of billions of “things” to be deployed over the coming decades. Therefore the Internet and ICT are emerging as a dominant facet of human activity on the planet, and we can expect this sector of human activity to demand a significant amount of resources. If human behaviour toward broadband continues its historical trend, every time more bandwidth is made available it will rapidly be consumed and yet more will be demanded.

Humankind’s demand for ever-higher bandwidth services is currently insatiable. We have seen an exponential growth in internet traffic and the demand for broadband services.

This ever-growing demand for bandwidth requires ever-increasing amounts of infrastructure which will consume increasing amounts of power as well as both non-renewable and renewable resources.

The exponential growth in internet traffic is not sustainable in the longer term using non-renewable energy resources. Therefore we cannot continue with “more of the same” because this will require ongoing exponential growth in the production of goods and services into the foreseeable future.

We need to take action now to ensure the growth in production of goods and services, including ICT, are sustainable. In fact, a requirement for sustainable growth is even greater for ICT than most other industries. This is because ICT is growing significantly faster than all other industries. Currently, the ICT industry has a relatively small carbon footprint and low global power consumption; it is therefore not a significant burden on energy resources. This gives us time to act. However, if nothing is done, ICT’s relative and absolute carbon production and power consumption will grow to become a significant contributor to our overall carbon footprint.

It is therefore important that we act now while ICT is a small contributor. We need to take the opportunity to “build-in” sustainability to make it an integral component of the future ICT industry. Trying to retrofit sustainability into the industry after it has grown to be a dominant contributor to carbon production will be far more costly. Thus, acting now while ICT is still developing is a key to future success. Additionally, the ICT industry has the opportunity to take a leadership role and “show the way” on how to evolve to become more sustainable. Sustainability is not a voluntary option for the future; it is an essential requirement for all human endeavours.

Ultimately, we will need to transform all industries to become more sustainable. Thus by developing a sustainable ICT industry, we can potentially provide a model from which other industries can learn. The ICT industry is still relatively young, and is populated by innovative people; therefore it has an opportunity to evolve in a new direction and lead the way.

CEET has developed an international reputation as a leader in the field of energy efficiency of telecommunications networks and services. As such, CEET played a key role in influencing this new direction.
Since its inception, CEET had a focus on industry relevant research. This focus was supported by ongoing consultations and cooperation between CEET and its Bell Labs collaborators. CEET was also deeply engaged in the GreenTouch consortium which provided CEET with additional industry and academic collaborators. CEET’s research program reflected these industry and academia interactions.

Through its collaboration and innovative program of research CEET became internationally recognised as a world leader in the field of energy-efficiency research in telecommunications. Below is a brief summary of the major research activities and outcomes generated by CEET during its tenure.
Energy Modelling of an Internet Service

The reporting of carbon emissions by large corporations is becoming a requirement in a number of countries from around the globe. Many companies are now undertaking energy audits to fulfill their corporate reporting requirements, particularly with regard to corporate sustainability reporting to stakeholders.

Corporations that are heavy users of ICT infrastructure and services will have to include the energy consumption of these activities in their reports. Typically these services are provided by telecommunication service providers. Therefore these providers will, in turn, need to measure the energy consumption of the products and services they provide to their customers. To provide these reports, telecommunication companies require a systematic energy audit framework to quantify the energy consumption of the equipment in their network that provides services to each of their corporate customers.

The research team formulated several energy metrics and a methodology to capture the energy consumption of end-to-end Internet services. Most Internet users interact with the Internet via a service. For example, Facebook, Google Docs, Netflix are all services that utilise equipment deployed as part of the Internet’s physical infrastructure. The future Internet of Things will also use a service-based paradigm. Assessing the energy consumption of a service is more difficult than for equipment. This project has developed a methodology to undertake this task. 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.

Through this project, and GreenTouch, the team collaborated with China Mobile. China Mobile is the leading telecommunications services provider in Mainland China. China Mobile claims the world’s largest mobile network and the world’s largest mobile customer base.

Since December 2013, China Mobile has built the largest 4G network in the world. China Mobile’s 4G network has approximately 1.1 million base stations, covering a population of over 1.2 billion. China Mobile now has more than 300 million 4G customers, with a net addition of over 200 million 4G customers in 2015.

CEET has collaborated with China Mobile to develop power models of Over The Top (OTT) applications provided via mobile networks.

This project was supported by GreenTouch.

PUBLICATIONS


Low Energy Point-To-Point (P2P) Optical Access Technology

Point-to-point (P2P) optical links provide a dedicated fibre from the exchange to each customer. P2P plays a significant role in providing Internet services to businesses and are envisioned to connect high-data-rate devices in the home in the future. A key component in a P2P access network fibre link is a pair of optical transceivers: one located at the central office and the other at the customer’s premises. Conventional P2P transceivers are designed with little 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 P2P optical links are relatively inefficient in energy usage.

In this project the research team analysed the trade-off between power consumption and additional packet delay. The results of this analysis were presented at the GreenTouch members meeting at Shanghai in May 2013.

In collaboration with Bell Labs, CEET researchers developed a new low energy P2P link technology that incorporated a new hardware design and a custom-built optimised ASIC with a new effective sleep mode algorithm. The new technology, once implemented, could provide a 30-fold increase in energy efficiency compared to the current (2014) state-of-the-art optical transceiver. The new transceiver can be coupled to adaptive powering schemes for further energy efficiency gains. It is expected to save energy costs for Internet Service Providers, and will benefit both businesses and consumers who want a high-capacity, secure and direct fibre connection. The technology was demonstrated at the November 2014 GreenTouch members meeting in Melbourne.

This project was supported, and co-funded, by GreenTouch.

CEET researchers also provided local Alcatel-Lucent technologists with guidance on energy consumption aspects of access technologies. In particular the energy saving opportunities for Passive Optical Local Access Networks (POLANs) based on Gigabit PON (GPON) and P2P network architectures.


PUBLICATIONS


PATENTS


U.S. Patent Application entitled Method and Apparatus for Managing Data Transmission in a Communication Network Publication No.: US20130098279 A1 Filed by ALU: September 2013, Inventors: Je Li (CEET), Chien Aun Chan (CEET), Ka-Lun Lee (CEET), Nagaraj Anthapadmanabhan (ALU-Bell Labs)

Reduction Next-Generation Networks
Energy Consumption

Telecommunications networks are transforming into structures that use packet-based switching. These networks are known as a “Next Generation Networks” (NGN). As part of this evolution extra equipment needs to be installed to manage the network, adding to network power consumption. However, if this new technology can make the network “energy aware”, this can provide an overall saving of energy in these Next Generation Networks.

This project explored the power consumption of NGNs through the analysis of its components - the physical layer and protocols, by researching how traffic grooming and multiplexing have the potential to impact energy consumption within the network.

The project team undertook a detailed analysis of the power consumption in a NGN and legacy IP over WDM network to determine how energy efficiency improvements may be implemented as part of the evolution toward NGNs. The traffic grooming and multiplexing capabilities of each layer and how these capabilities can impact on energy consumption within the network were investigated.

The researchers developed power models for several types of NGNs that employ GMPLS/ASON. Network power consumption of these networks based on simulations of a range of mesh network architectures was calculated. The power savings relative to legacy IP over WDM network with the same network architecture were calculated and strategies on how to improve network energy efficiency in NGNs were determined. It was shown that significant power savings are possible when using NGNs.

A power consumption model for the network and Internet protocols was developed that accounts for the deployment of IPv6 and encompasses the impact of using label based routing in the core network. The model was used to explore the relative merits of IPv4, IPv6 and label based routing in terms of power consumption in a network node. It was found that, for larger packet sizes, IPv6 is approximately 2% less energy efficient than IPv4. Further, the model showed that the details of implementing protocols in a network node could have a dramatic impact on the energy efficiency of that node.

The project was completed in 2012. The findings of this project assisted research in other CEET projects including research into Cloud Computing and Content Distribution and the Internet Services Energy Star Rating project.

PUBLICATIONS

THESES
Cloud computing and content delivery services are transforming many industries and organisations. Enterprise customers and home users are increasingly being offered the opportunity to move from running applications on stand-alone computers to using cloud-based services. A major advantage of cloud-based services is their ubiquity as a platform for cooperative work. With cloud services, data is readily available to all team members without the need for managing multiple copies spread across multiple stand-alone PCs. Additionally, the take-up of content delivery services is growing rapidly. Content Delivery Network (CDN) traffic is forecast to constitute more than half Internet traffic by 2017, up from 34% of Internet traffic in 2012. For the individual, cloud services and CDNs provide a platform for easy sharing of content across multiple devices and sharing with friends. Examples of content delivery include Internet Protocol Television (IPTV), video on demand (VoD), audio and photo sharing distribution and e-magazines.

In this project CEET researchers developed energy consumption models for a range of cloud and CDN interactive, on-line services. We found that, although cloud and CDN almost certainly improve the energy efficiency of services for corporations and enterprises, they may not be the most energy efficient platform for providing these services to consumers.

In April 2013 CEET released the white paper The Power of Wireless Cloud which analysed the impact on energy consumption of the growing popularity of accessing cloud services via wireless devices. The report highlighted the need for industry move the conversation away from data centre energy to a focus on the real issue, more efficient wireless networks in the wireless cloud environment.

PUBLICATIONS


F. Jalali, Hidden Energy Consumption of Photo Sharing in Online Social Networks, 14th Annual Grace Hopper Celebration of Women in Computing (GHC14), Phoenix, USA, October 2014.


F. Jalali, Home Servers Can Save Energy for IoT Applications, 15th Annual Grace Hopper Celebration of Women in Computing (GHC15), ACM Student Research Competition (SRC), Houston, USA, Oct. 2015. (Poster Presentation)


THESES


WHITE PAPERS

The Power of Wireless Cloud
An analysis of the impact on energy consumption of the growing popularity of accessing cloud services via wireless devices.

Published in 2013.

Measuring and modelling the energy consumption of Content Delivery Networks (CDNs) and the Cloud
Energy Efficiency of Ultra High Capacity Optical Communication Systems

Telecommunications enables information to be moved from one point to another. Today this is mostly done using optical fibre communications. An optical communications link consists of 5 basic “building blocks”: (1) encoding the information for transmission (2) transmitting the information into the link as an optical signal (3) the optical fibre link which may include amplifiers and other optical devices (4) receiving the optical signal and (5) decoding the signal to extract the information. Each of these components consumes energy but minimising each one separately will not provide a functioning link.

The CEET team looked at how to minimise the overall power consumption of the link accounting for the interactions between the 5 blocks. They successfully built energy consumption models for a range of different functional blocks used in a transmission system; including electronic-to-optical and optical-to-electronic signal conversion, electronic digital processing (at the transmitter and receiver) and optical amplification along the optical link. Using these models, the researchers performed end-to-end energy consumption analysis of a transmission system and have compared energy efficiency of various advanced modulation formats.

Decentralised Optimisation and Game Theory

The Internet is, in reality, is a very complex network of networks with many thousands of players involved in its operation. For example; the Internet Service Providers we use to connect to the Internet, the telecommunications carriers that provide the communications links around the globe, the companies that provide services via the Internet and the data centre operators are all players in the global Internet. With so many different parties involved in the Internet’s operation, one issue that we must consider when we investigate technologies and techniques for improving the energy efficiency of the Internet is how the effectiveness of one player’s improvement strategy may be reduced by the actions of another player within the Internet zoo of participants.

To address this issue, CEET has constructed energy consumption models for the cloud and content delivery eco-systems which recognise the fact that these eco-systems include multiple players who may or may not have an interest in energy efficiency. Using these models CEET is developing optimisation tools to analyse and optimise the energy consumption of large-scale distributed CDNs in which the players need to juggle energy efficiency with other business imperatives, such as several key ‘quality of service’ metrics.

PUBLICATIONS


THESES

At its heart, the Internet is an incredibly complicated network of inter-connected computers. The Internet uses switches and routers to direct traffic between these computers. As the amount of traffic flowing through the Internet grows, the power consumption of these switches and routers will eventually dominate the power consumption. Therefore, it is important to understand the power consumption behaviour of the switches and routers. Although the manufacturers of this equipment have power models for their products, there are no vendor-agnostic models.

The research team developed a measurement technique that provides a power consumption model for any manufactured switch or router. Such a model is of great significance because it enables a unified approach to estimating and understanding the power consumption of the heart of the Internet. This project was supported by GreenTouch.

PUBLICATIONS


The IoT can be simply described as the connection of sensors, actuators, embedded devices and everyday physical items (i.e. Toasters, Fridges) to data processing facilities via communication networks (i.e. the Internet) which provide services for the benefit of users. It is expected that most of these devices will be wirelessly connected using communication protocols like ZigBee, Bluetooth, Wi-Fi and 433MHz. Industry estimates are that the IoT will encompass between 50-200 Billion connected devices by 2020.

The Internet of Things (IoT) is seen as the next evolutionary step for the Internet. The IoT will involve billions of small devices connected to the Internet to provide a myriad of new services to enhance our daily lives. Although this is a vision, we need to ensure the IoT is sustainable. The IoT will require many new devices to be deployed around the globe and is forecast to generate Exa-bytes of additional traffic per month. This will require additional energy to collect, transport and analyse this data.

The IoT project within CEET focused on the gateways and network. This included the identification of relevant IoT application use-case scenarios, modelling and quantifying the gateway and network energy cost of the identified use-cases through experimentation and measurements, and determining energy-efficient alternative deployment strategies to ensure the IoT is sustainable in the long term.

Having identified the key use-case scenarios (e.g. Home Automation & Security, E-health, Smart Buildings, Connected Vehicles) that may form the basis of an IoT deployment, the focus of this project has been identifying the energy cost of these use-cases. Initial experiments using off-the-shelf devices (e.g. temperature sensor, security camera) in a simple home automation system test-bed indicates an additional aggregated data throughput between 2 Kbit/s and 4 Mbit/s depending on device activity (e.g. duty-cycle) and type (sensor/camera). This is in addition to the usual data throughput of the average home with internet connections and is measured at the IoT gateway. As part of this project, an energy consumption model for a home automation and security system has been developed to analyse the energy consumption of future home automation products and services.

**PUBLICATIONS**

Modifying devices for energy efficiency in wireless access networks

Wireless access networks are energy inefficient compared to other access technologies, such as Passive Optical Access Networks. Increasing numbers of mobile subscribers and the demand for mobile broadband connectivity will see the energy consumption of wireless mobile networks rise constituting an increasing component of the energy consumption of the telecommunications sector.

Many research groups and companies are investigating ways on how to improve wireless energy consumption and almost all are focussing on factors such as the cell size and the operation of base stations. At CEET we have taken a different approach by investigating how modifying the handset can improve energy efficiency.

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 neighbouring 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 and increases the interference on neighbouring cells. A receiver that can perform better in such scenarios would both reducing base station energy and reduce interference on neighbouring cells.

CEET has shown that, by re-designing the handset receiver, energy savings of around 10% are possible. At CEET we have redesigned the handset to provide a quality connection even with a signal that has a much lower “Signal to Interference Noise Ratio” (SINR). This is the ratio of desired signal power to unwanted interference power. This innovation enables the power output of the base stations (which dominate the power consumption of mobile networks) to be reduced without a loss of service quality. Energy is saved and users can experience higher data rates and a more reliable mobile experience.

This project was supported by GreenTouch.

PUBLICATIONS

D. Kudavithana, Jamie Evans, Brian Krongold, Energy Efficiency Comparison of Coherent QPSK vs Differential QPSK, Australian Communications Theory Workshop (AusCTW), Sydney, Australia, February 2014. (Poster Presentation)


THESES


Determining and defining Energy Efficiency

The global effort into making telecommunications sustainable has historically focused on several “metrics”. These are “energy per user” or “power per user” and “energy per bit”. These quantities enable comparing different networks and technologies because they “normalise” for the size of the network. (By size, we mean the number of users or the amount of traffic in the network.) Metrics are crucial to designing strategies for improving energy efficiency. Depending upon the metric, different aspects of the network’s operation will be highlighted for the development of improvement strategies.

The results of CEET’s work to date indicate that applying a single metric to individual networks, network elements and services will produce significantly different results. Furthermore, when the same metric is used by a network operator, the strategies it suggests for improving energy efficiency of the network may conflict with the strategies the same metric suggests to service providers using that network.

PUBLICATIONS

Optical amplifiers are now an essential component in long-haul high-capacity optical links. The EDFA is the most widely used optical amplifier technology today and the DRFA is growing in popularity due to its ability to preserve the optical signal quality over very long-distance links. However, the DRFA requires significantly more power to operate than the EDFA, resulting in a trade-off between amplifier power and signal quality.

In this project CEET developed energy consumption models for each of these amplifiers in an endeavour to understand this trade-off and determine which of these amplifiers is the most energy efficient for high-capacity optical links.

The models account for the various noise processes in each amplifier as well as the power inefficiencies of the pump lasers and pump processes. Furthermore, the models also include the use of Forward Error Correction (FEC) and its power requirements. (FEC is a technology that adds additional bits to the data stream and uses these bits to remove errors at the receiving end.) The inclusion of FEC is essential because it is an integral part of long-haul, high-speed optical link technology today and into the future. FEC comes in several forms with differing power requirements. A simpler form ("hard decision" FEC) consumes less power but cannot correct as many errors as a more sophisticated form ("soft decision" FEC), which requires more power but can correct more errors. The results show that for links that require soft decision FEC, DRFAs provide better energy efficiency (lower energy/bit/km) than EDFAs. However for links that only require hard decision FEC, EDFAs provide better energy efficiency. The choice of soft or hard decision FEC thus depends on a range of link design requirements.

This project was co-funded and supported by an ARC Discovery Grant.

PUBLICATIONS

THESES

Minimising power consumption in network elements such as routers and switches is an important focus for research on energy efficiency in telecommunications. These network elements must undertake complex digital signal processing and computing activities implemented by large arrays of inter-connected digital logic gates. The energy efficiency of these network elements is constrained by a range of fundamental limitations dictated by the laws of nature. These laws are described by quantum mechanics, statistical physics, entropic limitations, information theoretical constraints and relativistic processes, to name a few. All technologies, which include those used in ICT and the Internet, are subject to these constraints.

In this project CEET investigated the limitations on reducing network element power consumption and size set by the fundamental properties of electronic and photonic digital logic gates.

The research team developed models that describe the power-length trade-off for all-photonic signal processing based on Highly Non-Linear Fibre, Periodically Pollthed Lithium Niobate and Semiconductor Optical Amplifiers were developed. These models describe this trade-off in terms of the fundamental constants of nature and other parameters that are not readily modified. These models show that CMOS technologies can attain much smaller sizes and lower power consumption values than will ever be attainable by these all-optical technologies. This means electronic CMOS technologies will provide the most energy efficient network elements for the future Internet.

PUBLICATIONS

THESES

Authors
K. Hinton
P. Wang
P. Farrell
Bipin
S.G. Pillai
Energy-Efficient Data Storage in the Zettabyte Era

With the increasing use of the cloud, data storage in global data centres is growing rapidly. In general, more and more data is being stored, both locally and in the cloud, because storage technology has become very cheap. IDC (a technology analyst company) has estimated that in 2013 about 4.4 zettabytes (4.4x10^21 bytes) of data was stored in all media. It has forecast that the quantity of data stored will increase by ten times to 44 zettabytes (ZB) in 2020. While other forecasts vary in quantity, all assume exponential growth in data storage. The energy consumed by data storage is therefore increasingly significant in the overall energy use of ICT.

CEET investigated whether current data storage technologies will manage the expected data in an energy-efficient way. The researchers found that major changes are needed in the management of data in storage and in users’ expectations about the ready availability of online data in order to contain the energy used by data storage. This suggests that previous forecasts of energy use for data storage have been optimistic.

It was found that the continued physical power/storage density improvement across all technologies will unfortunately not contain the energy used for storing ten times the amount of data, let alone fifteen times, if the proportion of data stored in data centres (rather than end-user devices) grows from today’s 40% to 60% of all data in 2020.

This would mean a substantial change in expectations for domestic users of the cloud today, where the expectation is that all data in the cloud is immediately available online. For business users, good information lifecycle management, where data is moved to offline storage or discarded when it is no longer of use, can help to mitigate the need for ever greater data storage. All these changes will be required if data storage is to remain sustainable in the zettabyte era.

The results of this research were presented at a CEET public event, Towards a Sustainable Connected World on the 20 November 2014 in conjunction with the Melbourne GreenTouch Members Meeting.

PUBLICATIONS
Ubiquitous broadband has been described by the Global e-Sustainability Initiative (GeSI) as a vehicle for reducing the carbon footprint of society. Examples include downloading music and books rather than purchasing a “hard copy”. However, ubiquitous broadband is also seen as providing an opportunity to increase productivity. These two factors have resulted in a debate about whether or not national broadband will be another example of “Jevon’s Paradox”. Jevon’s Paradox describes the situation in which an improvement in (energy) efficiency does not result in a reduction in (energy) consumption but rather an increase. This is because the increase in efficiency results in a reduction of costs and so stimulates more demand to the extent that the efficiency improvements are over-run by the increase in demand.

CEET studied whether or not Jevon’s Paradox applies to the deployment of the Australian National Broadband Network (NBN). At CEET we asked the question of whether the deployment of a national broadband network alone would be enough to reduce carbon production by replacing old “high carbon” industries with “low carbon” digital industries.

Our research has shown that the additional energy consumption resulting from the economic stimulus generated by a well-designed national broadband network will overwhelm the energy savings resulting from consumers and industry moving to energy efficient alternatives. This means that deploying ubiquitous broadband is not, of itself, enough to secure energy (and carbon emission) reductions. Policies and practices that leverage off the availability of nationwide broadband, such as those described by GeSI, are also required to realise the carbon-reducing potential of a national broadband network.

In September 2015, CEET released the white paper Economic Benefit of the National Broadband Network: Benefits of the NBN to the Australian Economy. In this report we show that, in the long term, real GDP can be boosted by about 1.8% and real household consumption (a measure of national welfare) by about 2.0%. When we take into account the need to repay the cost of the NBN, GDP increases slightly but the benefit to real household consumption is reduced to 1.4%. Most of the benefit comes from telehealth and teleworking.

PUBLICATIONS


WHITE PAPERS

Economic Benefit of the National Broadband Network
Benefits of the NBN to the Australian Economy Published in 2015.
A Mobile Access Network Simulator

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. Optimising 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. To gain this understanding, GreenTouch developed an advanced power model that provides realistic hardware power consumption values for a diversity of cellular base station types and operation conditions, while incorporating hardware technology trends.

CEET made significant contributions to the development of this model. 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 energy efficiency improvements. 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.

A Diurnal Traffic Model for Internet service traffic types

It was not feasible to determine the energy efficiency improvements attained from the GreenTouch core network technologies and innovations by direct measurement on the Internet core network. The Internet is too large and complex for such a task. Therefore GreenTouch relied on several core network simulations, which were based upon experimental measurements and deployed network architectures. A key input for the simulations was the 2-hourly diurnal cycle traffic used to represent the Internet traffic of developed (so called “Group 1”) nations in 2010 and 2020. Although traffic forecasts were developed by GreenTouch for the total monthly traffic (in Petabytes per month), these values had to be converted to link-by-link capacities (in Gbit per second) for 12 two-hourly time periods spanning a day.

CEET provided this model by using a combination of known traffic models plus typical measured diurnal traffic statistics. The CEET model provided the required traffic values for the dominant traffic types used in the core network Green Meter calculations.

PUBLICATIONS


Beam Steering And Co-ordinated Multipoint Wireless Transmission

This research was motivated by the potential power savings that can be attained by using a coordinated narrow-beam forming technology in mobile base stations. This technology could form the basis of a new Coordinated Scheduling/Beamforming strategy for Long Term Evolution (LTE).

CEET assessed the potential for gains in wireless network throughput and energy consumption through the use of a range of other technologies being developed in GreenTouch. Of immediate interest is the potential of steered narrow-beam transmission. Instead of spreading a base station’s power across a wide geographic region a steered beam enables the power to be directed in a narrower beam toward an end user. This yields benefits in giving the user a better signal, reducing interference with signals to other users, with an overall improvement in network capacity. This leads to a gain in capacity for a given radio equipment power consumption, but this gain needs to be balanced against the extra network control needs and the associated energy costs.
CEET was awarded an Australian Research Council (ARC) Federal Government Linkage grant with Alcatel-Lucent Australia in 2015 to investigate how best to minimise energy consumption from next-generation telecommunications systems, such as 5G wireless networks.

A growing problem for telecommunication network providers and their users is how to minimise the energy consumption of their networks. This is important in terms of reducing their operational expenditure (OPEX), as well as meeting the energy demands of the continued growth in network traffic.

An important aspect of this problem is how to monitor and audit the energy consumption of a given telecommunications network. In recent years, a variety of models have been developed for modelling energy consumption in networks. However, these energy models assume a reasonably static network architecture, and are designed for off-line accounting of energy usage. As a result, they are not suitable for existing telecommunication network architectures, which will use highly dynamic network architectures.

Modelling Energy Efficiency of Next-Generation Networks

A major challenge for modelling energy consumption in these next-generation networks is how to monitor these dynamic networks in real-time and in a financially viable manner, so that the network configuration can be dynamically optimised to minimise energy consumption in response to changing traffic conditions.

The focus of this project is to develop modelling techniques for energy consumption in next-generation telecommunication networks. This is important in reducing their operational expenditure and meeting the energy demands of future growth in network traffic. Project outcomes are intended to enable real-time management of energy usage, and the assessment of the financial benefits of different investment strategies in network infrastructure.

This research is led by Professor Christopher Leckie from the Department of Computing and Information Systems in the Melbourne School of Engineering.

This project is supported and funded by an ARC Linkage grant from January 2016 until December 2017.

PUBLICATIONS

CONTRIBUTIONS TO GREENTOUCH™

During the lifetime of GreenTouch, CEET has been a key contributor to the technology roadmap and Green Meter. GreenTouch is a global 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.

The GreenTouch consortium announced its final results in June 2015. CEET’s contributions to GreenTouch include:

- The Energy Metrics For Users
- Construction of a Diurnal Traffic Model for Internet Service Traffic Types
- Demonstration of a Low Energy Point-To-Point (P2P) Optical Access Technology
- Demonstration of a Low Signal-To-Noise Ratio Wireless Receiver
- Construction of a Mobile Access Network Simulator As Part of the Mobile Communications Green Meter Tool
- Construction of the Core Network power consumption model for the Green Meter Tool

Other contributions to GreenTouch by members of CEET include:

- Rod Tucker was a member of the GreenTouch inception. He has also contributed to the Core and Access Network technical groups work.
- Bipin Pillai was a member of the GreenTouch Technical Committee during 2014 and also contributed to the Core Network technical work group.
- Kat Franks provided marketing and event support to GreenTouch.
- Kerry Hinton was a member of the Technical Committee and Chair of the Wireline Core and Access Network Work Group.
- Chien Chan was a member of the GreenTouch Services, Policies and Standards Work Group.
- Rob Ayre, Jeff Cheong, Qasim Chaudhari and Brian Krongold were members of the Mobile Work Group.
- Alan Lee and Jack Li were members of the Access team of the Wireline Core and Access Networks Work Group.
- Peter Hormann and Leith Campbell provided GreenTouch with a presentation on energy consumption trends for data storage at the November 2014 meeting.

Apart from being a contributor to GreenTouch, as a member of GreenTouch, CEET benefited from:

- Collaboration with leading experts from around the world
- Involvement in fundamental research in exciting new areas
- Access to network models and studies examining key energy related issues
- Information on network power consumption, traffic growth and energy trends
- Opportunities to bring innovative new ideas to reality.

GreenTouch has contributed to a large number of industry events, conferences, workshops, and trade shows to share its vision and results as well as to encourage others to contribute to the mission of dramatically improving network energy efficiency. In addition, GreenTouch members have presented and published numerous scientific and technical contributions in peer-reviewed conferences and journals. GreenTouch has also organised several events, bringing together leading experts from industry, academia, and policy organisations (from GreenTouch as well as non-GreenTouch organisations) to discuss energy efficiency and to enable stronger collaborations. CEET has either participated in, or contributed to, almost all of these activities.

GreenTouch held two Members Meetings each year in a number of locations including the Netherlands, South Korea, USA, Germany, China, France, Italy, and Australia. CEET hosted the November 2014 meeting at the University of Melbourne. GreenTouch announced its final results and technology roadmap during a celebration event hosted by Bell Labs / Alcatel-Lucent in New York City on June 18, 2015.
RECOGNITION

In September 2014 CEET was recognised by the Victorian government for their achievements by winning the 2014 Victorian International Education award for Excellence in Innovation in Industry Partnerships. The Victorian Government initiative supports leaders in Victoria’s international education sector and recognises those delivering and benefiting from Victoria’s world class education.

In November 2013, CEET Honorary Fellow and former CEET Director, Melbourne Laureate Emeritus Professor Rod Tucker received the 2013 GreenTouch 1000X Award for Technical Excellence and Promotion of the Technology for Future Wireless Networks as well as for his leadership in the creation, organisation and promotion of the GreenTouch consortium and pioneering research contributions to the field of energy efficiency in telecommunications.

In presenting the award, Thierry Klein, Chair of the GreenTouch Technical Committee, commented that “Professor Tucker has conducted fundamental research on energy efficiency that was instrumental in setting up the GreenTouch consortium and formed some of the early foundations. His leadership and the technical contributions that he has made, along with the team at CEET, are an inspiration to all GreenTouch members and the industry at large.”

Alcatel-Lucent was recognised for their work in energy efficient telecommunications research through the partnership and investment in CEET by winning the 2012 ACOMMS Environmental Responsibility Award. This award recognises the important research activity being undertaken at CEET to increase the energy-efficiency of global telecommunications networks and highlights the leadership of Alcatel-Lucent and Bell Labs in forging fruitful collaborations between industry and academia.
The Business/Higher Education Round Table (B-HERT) is a not-for-profit organisation that was established in 1990 to strengthen the relationship between business and higher education. They are the only organisation with members who are leaders in higher education, business, industry bodies and research institutions.

On 8 November 2012, then Minister for Tertiary Education, Skills, Science and Research, Senator the Hon Chris Evans presented CEET and Alcatel-Lucent the prestigious 2012 Business/Higher Education Round Table award in Outstanding Achievement in Collaboration in Research & Development.
TEAM

From the beginning of 2011 until the middle of 2016 a number of Researchers, Postgraduate Students, Staff, Honorary Fellows, Visiting Academics and Collaborators contributed to the Centre for Energy-Efficient Telecommunications (CEET).

To the left is an image of contributors to CEET from the University of Melbourne in its first year of operations. A number of dedicated and outstanding people contributed to CEET’s research program over the years. The following pages lists those who made CEET possible.

UNIVERSITY OF MELBOURNE

CEET FUNDED RESEARCHERS & STAFF

1. Rod Tucker
   Melbourne Emeritus Laureate Professor, Former CEET Director

2. Kerry Hinton
   CEET Principal Research Fellow and CEET Director

3. Alan Lee
   CEET Senior Research Fellow and CEET Deputy Director

4. Arun Vishwanath
   Former CEET Senior Research Fellow

5. Behnam Sedighi
   Former CEET Senior Research Fellow

6. Bipin Pillai
   CEET Senior Research Fellow

7. Chien Aun Chan
   CEET Research Fellow

8. Jack Li
   CEET Research Fellow

9. Jeff Cheong
   Former CEET Senior Research Fellow and CEET Honorary Fellow

10. Joanna Gajewski
    Former CEET General Manager

11. Kat Franks
    CEET General Manager

12. Mohammad Rezaeian
    Former CEET Research Fellow

13. Qasim Chaudhari
    CEET Research Fellow

14. Rob Ayre
    CEET Senior Research Fellow

UNIVERSITY OF MELBOURNE IN-KIND RESEARCHERS & STAFF

1. André Gygax
   Academic, Department of Finance

2. Andrew Greentree
   Former Principal Research Fellow, Department of Physics and Honorary Fellow

3. Bill Moran
   Former Professor, Department of Electrical & Electronic Engineering

4. Brian Krongold
   Associate Professor, Department Electrical & Electronic Engineering

5. Chris Leckie
   Professor, Department of Computing & Information Systems

6. Darryl Veitch
   Former Professor, Department of Electrical & Electronic Engineering
TEAM

Elaine Wong
Associate Professor, Department of Electrical & Electronic Engineering

Kate Cornick
Former Director, Industry Engagement and Innovation and Former CEET General Manager

Jamie Evans
Professor, Department of Electrical & Electronic Engineering

Margreta Kuiper
Associate Professor, Department of Electrical & Electronic Engineering

Mortuza Ali
Former ARC Research Fellow, Department of Electrical & Electronic Engineering

Peter Farrell
Former Associate Professor, Department of Electrical & Electronic Engineering

Simone Gambini
Former Lecturer, Department of Electrical & Electronic Engineering

Stan Skafidas
Professor, Department of Electrical & Electronic Engineering

Tansu Alpcan
Senior Lecturer, Department of Electrical & Electronic Engineering

Thas Nirmalathas
Professor and MNSI Director, Department of Electrical & Electronic Engineering

William Shieh
Professor, Department of Electrical & Electronic Engineering

Leith Campbell
CEET Honorary Fellow, Department of Electrical & Electronic Engineering

Peter Hormann
CEET Honorary Fellow, Department of Electrical & Electronic Engineering

Gary McLaren
CEET Honorary Fellow, Department of Electrical & Electronic Engineering

An Li
PhD Graduate, CEET Top-Up Scholarship

Ashrar Matin
PhD Student

Chrispin Gray
PhD Student, CEET Top-Up Scholarship

Daniel Angley
PhD Graduate, CEET Top-Up Scholarship

Dinuka Kudavithana
PhD Graduate, CEET Full Stipend Scholarship

Fatima Jalali
PhD Graduate, CEET Full Stipend Scholarship

Hamid Khodakarami
PhD Graduate, CEET Full Stipend Scholarship

Michael Feng
PhD Graduate, CEET Top-Up Scholarship

Olivia Zhu
PhD Student, CEET Top-Up Scholarship

Peter Wang
Masters Graduate

Rashid Quddes
Did not complete, CEET Full Scholarship

Sofia Lambert
Visiting PhD Student, iMinds, Ghent University, Belgium

Tansu Alpcan
Senior Lecturer, Department of Electrical & Electronic Engineering

Yan Ming
Visiting Academic, Communication University of China

Anne-Cécile Orgerie
Visiting Academic, Inria Reso, Laboratoire de l’Informatique du Parallélisme, France

Chunlei Zhang
Visiting Academic, Lanzhou Jiaotong University, China

Colin Campbell
CEET Honorary Fellow, Department of Electrical & Electronic Engineering

Philip Adams
Monash University

Terrie Walmsley
Purdue University

Alvaro Dominguez Llera
Visiting Masters Student, Universidad de Granada, Spain

Marco Savi
Visiting PhD Student, Politecnico di Milano, Italy

Sascha Süßspeck
PhD Student, CEET Full Stipend Scholarship

Tony Lin
PhD Graduate, CEET Full Stipend Scholarship
TEAM

ALCATEL-LUCENT & BELL LABS

COLLABORATORS

1. Andrea Francini
   Member of Technical Staff, Nokia Bell Labs, NJ, USA
2. Antonia Maria Tulino
   Crawford Hill, Nokia Bell Labs, NJ, USA
3. Dan Kilper
   Former Member of Technical Staff, Bell Labs, NJ, USA
4. Dusan Suvakovic
   Researcher, Nokia Bell Labs, NJ, USA
5. Gilbert Buty
   Environmental Standards Manager, Nokia, Villarceaux, France
6. Grant Underwood
   Solution Architect, Nokia Australia
7. Gregory Wright
   Crawford Hill, Nokia Bell Labs, NJ, USA
8. Hungkei (Keith) Chow
   MTS/Project Lead, Fixed Access Program, Nokia Bell Labs, NJ, USA
9. Jaime Llorca
   Member of Technical Staff, Nokia Bell Labs, NJ, USA
10. Kyle Guan
    Research Scientist, Nokia Bell Labs, NJ, USA
11. Man Fai Lau
    Researcher, Embedded Systems, Nokia Bell Labs, NJ, USA
12. Marc Weinstein
    Former Business Modeling Manager, Nokia, NJ, USA
13. Nga Dinh
    Former Member of Technical Staff, Bell Labs Seoul, South Korea
14. Noriaki Kaneda
    Murray Hill, Nokia Bell Labs, NJ, USA
15. Oliver Blume
    Team Leader, Energy Efficient Small Cells, Nokia Bell Labs, Stuttgart, Germany
16. Peter Vetter
    Head of Fixed Networks Research Program, Nokia Bell Labs, NJ, USA
17. Peter J. Winzer
    Crawford Hill, Nokia Bell Labs, NJ, USA
18. Philippe Carre
    Program Manager, Nokia Bell Labs, Villarceaux, France
19. Philippe Richard
    Senior Director, Nokia Bell Labs, Villarceaux, France
20. Prasanth Anthapadmanabhan
    Member of Technical Staff, Nokia Bell Labs, NJ, USA
21. Reinaldo Augusto Valenzuela
    Director, Nokia Bell Labs, NJ, USA
22. Ronghuan Tu
    Integration Test Team leader, Nokia Australia
23. Shanthi Fernando
    IP Engineer, Nokia Australia
24. Thierry Klein
    Head of Innovation Management for Verticals, Nokia
    Former Network Energy Research Program Leader, Bell Labs Nokia
25. Tim Marshall
    Head of Marketing and Corporate Affairs, Oceania Nokia
26. Timo Pfau
    Former Member of Technical Staff, Nokia Bell Labs, NJ, USA
27. Theodore Sizer
    Vice President of the Wireless Research Program in Nokia Bell Labs, NJ, USA
28. Ulrich Barth
    Head of Smart Wireless Networks, Nokia Bell Labs, Stuttgart, Germany
An Advisory Committee and an Operations Committee governed CEET. Each committee consisted of an equal number of members from Alcatel-Lucent and the University of Melbourne.

The Advisory Committee assisted CEET with achieving its goals and maximising its influence and impact. This included nurturing the partnership between the University of Melbourne, Alcatel-Lucent, Bell Labs and the Victorian State Government.

The Operations Committee overviewed and made decisions on CEET’s research program; research staff and fostered research collaborations between CEET and Bell Labs.

The Centre would like to thank the members of the Advisory and Operations Committees for their time and contributions to CEET over the years.

GOVERNANCE

ADVISORY COMMITTEE

Alcatel-Lucent
- Randy Giles
- Ric Clark
- Debasis Mitra
- Simon Harriss
- Alice White
- Rai Pullinen
- Thierry Van Landegem
- Warren Lemmens

University of Melbourne
- Charlie Day
- Doreen Thomas
- Iven Mareels
- Liz Sonenberg
- Peter Taylor
- Rob Evans
- Stan Skafidas
- Thas Nirmalathas

OPERATIONS COMMITTEE

Alcatel-Lucent
- Charlie Williams
- Dan Kilper
- Dominique Chioroni
- Max Bryan
- Mickey Vucic
- Peter Vetter
- Tim Marshall
- Thierry Klein

University of Melbourne
- Alan Lee
- Kat Franks
- Kate Cornick
- Kerry Hinton
- Rod Tucker
- William Shieh
LAUNCH OF THE CENTRE FOR ENERGY-EFFICIENT TELECOMMUNICATIONS (CEET)
28 March 2011

On Monday 28 March 2011, CEET was officially launched by the Victorian State Government’s Former Minister for Technology, Gordon Rich-Phillips, at the University of Melbourne. To mark the occasion, Jeong Kim, Former President of Bell Labs, attended the event as a keynote speaker along with Rod Alferness, Former Chief Scientist Bell Labs, Andrew Butterworth, Former Managing Director Alcatel-Lucent Australia and David Tudehope, Chief Executive, Macquarie Telecom.

Announced at the launch by Rod Tucker, former Director of CEET, were the CEET projects in the research areas of Modelling, Transmission and Fundamentals.

PUBLIC GUEST LECTURES

CEET hosted the following public guest lectures by Bell Labs in 2011:

- Debasis Mitra, former Vice-President of the Chief Scientist’s Office of Bell Labs, presented a lecture on ‘Models for Optimisation of Industrial Research Management’
- Dan Kilper, former member of the technical staff at Bell Labs, presented a lecture on ‘Energy-Efficient Networks’.
EVENTS

TOWARDS A GREEN INTERNET
3 October 2011
CEET hosted the public lecture and panel session “Towards a green Internet: Do we need new power stations to support future broadband use?” at the University of Melbourne on Monday 3 October 2011. The event was attended by academicians, students, industry representatives and the general public. The event helped raise awareness about the importance of green telecommunications and green initiatives companies have been undertaking internally to reduce their carbon footprint.

Speakers at the event included:
- Marcus Weldon: Former Global CTO, Alcatel-Lucent
- Philip Kong: Former Green Practice Leader, Hewlett-Packard Enterprise Services Australia and New Zealand
- Mike Sandiford: Director of the Melbourne Energy Institute (MEI)
- Rod Tucker: Former Director of CEET

The event was proudly co-hosted by MEI, Alcatel-Lucent and the Institute for a Broadband Enabled Society (IBES).

BELL LABS SHOWCASE
3 November 2012
Alcatel-Lucent and CEET presented the global innovations of Bell Labs and Chief Scientist, Alice White, at the University of Melbourne on the 3 November 2011. This event was part of the Bell Labs showcase tour which included Parliament House, Australian National University and the University of Sydney. The showcase tour included lectures and demonstrations of the latest Bell Labs innovations and CEET’s research program. Topics and speakers included:
- An Innovation View of the World by Alice White, Former Bell Labs Chief Scientist
- Immersive Applications of the Future by Jan Bouwen, Residential Applications Research Director
- The Emerging Directions of Wireless by Tod Sizer, Head of Wireless Research
- Optical Innovation by Sebastien Bigo, Head of Optics
- Low-Energy Fibre Access Networks by Alan Lee, CEET Senior Research Fellow
- Improving the Energy-Efficiency of the Internet by Rod Tucker, Former CEET Director
THE AUSTRALIAN ENERGY-EFFICIENT INTERNET SUMMIT
18 September 2012

The Australian Information Industry Association (AIIA), Alcatel-Lucent and the Centre for Energy-Efficient Telecommunications (CEET) hosted the Australian Energy-Efficient Internet Summit on the 18 September 2012 at the University of Melbourne.

The Summit highlighted the energy-related challenges facing the ICT and telecommunications sector, and its customers, and explored collaborative approaches for improving the energy efficiency of the Internet.

Bob Hayward, a keynote speaker at the event stated, “Collaboration across the IT and telecommunications sector can help delay or even avoid the impending growth in energy consumption by ICT as the world becomes more digital. At the same time we must never forget that using ICT almost always reduces the overall environmental impact throughout the economy. For example, procuring digital services online is a far better environmental outcome than the alternatives.”

Recognising the complex interconnected nature of the network and ICT environment, the Summit brought together equipment and system vendors, operators, service and application providers and academics to explore how different network elements contribute to network energy consumption and the various approaches that could be taken to improve their efficiency.

The event MC was Tim Marshall from Alcatel-Lucent Australia. Speakers included:

- Seán O’Halloran, Former President and Managing Director, Alcatel-Lucent Australia
- Bob Hayward, Former Board Director, AIIA
- Thas Nirmalathas, Professor, The University of Melbourne
- Kerry Hinton, CEET Director

The event included “A greener future for our internet ecosystem” panel with Professor Chris Leckie from the University of Melbourne as MC. Panelists included:

- Craig Baty, Former CTO, Fujitsu
- Matt Healy, Regulatory & Government at Macquarie Telecom and a Director of OzHub
- Peter Hormann, Former Enterprise Architect for Energy Efficiency at Telstra
TRANSFORMING ICT NETWORKS FOR A SUSTAINABLE FUTURE
23 May 2013
CEET hosted Dr. Thierry Klein, former Head of Green Research, Bell Labs and Chairman of the Technical Committee, GreenTouch who presented a public lecture at the University of Melbourne on the 23 May 2013.
During this presentation, Dr. Klein reviewed current trends in communication and data networks and discussed the latest research to improve energy efficiency and reduce power consumption in mobile, wireline access, packet data and optical networks. He provided an overview and a status update of the GreenTouch consortium.

THE WIRELESS 5G FUTURE
11 June 2014
CEET hosted Dr. Chih-Lin I, Chief Scientist of Wireless Technologies China Mobile Research Institute who presented a public lecture at the University of Melbourne on the 11 June 2014.
China, the world’s largest mobile market entered the 4G era at the end of 2013. 2020 is now widely considered to be the year of 5G Mobile with 5G becoming the hottest key word in the wireless industry. One common consensus is that next generation of wireless systems will face a 1000x traffic load increase that raises the questions:

- How can we increase network capacity dramatically while keeping the total cost of ownership at a reasonable level?
- What user needs must be met by 5G?
- How will wireless technologies and mobile infrastructure be integrated?
- Are there any particular needs from a mobile operator’s point of view?
- How will mobile operators stay on the centre stage in the future?
- What’s the likely roadmap towards next generation mobile network?

This talk gave insights into the above questions, shared China Mobile’s views as well as selected technology updates.

THE DIGITAL UNIVERSE - INVADED BY SENSORS
9 July 2014
CEET hosted Matt Zwolenski, CTO Australia & NZ at EMC who presented a public lecture at the University of Melbourne on the 9 July 2014.
The evolution towards the Internet of Things will have massive implications for education and business as we adapt to new models and technologies. In this talk EMC discussed key research findings, trends towards next generation applications and what skills tomorrow’s technologists will need to be armed with.
The world’s leading academic and industrial internet efficiency researchers met in Melbourne for the 10th GreenTouch global consortium members meeting. The event was hosted by CEET at the University of Melbourne between the 17 - 20 November 2014.

The agenda for the GreenTouch Members Meetings consisted of intense operational and technical session-working group sessions along with current project status reports and demonstrations.

GreenTouch Chairman, Thierry Van Landegem, stated: “Today’s telecommunication networks are optimised for cost and performance, not energy efficiency, and a solution that combines all these factors will require a re-imagined approach to global network design, architecture, network optimisation and management. The University of Melbourne is a world centre of research excellence and CEET, as a founding member of GreenTouch in 2010, has been instrumental in driving and contributing to our exciting and urgent agenda. I am hopeful the meeting can put into place the final steps for GreenTouch’s ambitious 2015 goal.”

An energy-efficient, P2P network that would be used inside of homes to connect home electronics gear—such as Internet TV and wireless routers—to wired in-house networks.

TOWARDS A SUSTAINABLE CONNECTED WORLD
20 November 2014

CEET hosted a public forum as part of the GreenTouch Members Meeting proceedings on the 20 November 2014 at the University of Melbourne.

The Internet of Things offers the promise of enormous benefits to human kind and significant contributions to improve our environment through the ubiquitous and intelligent use of information and communication technologies. However to realise this future, some central questions need to be addressed to ensure the Internet of Things itself will be sustainable at such a large scale. This event looked at several foundational issues relating to a connected world. The event MC was Rod Tucker and speakers included:

- Telstra’s Environment Strategy by Pauline Gregg, General Manager - Environment, Chief Sustainability Office, Telstra
- IBM, Internet of Things and Big Data by Arun Vishwanath, Research Scientist, IBM Research-Australia
- Wireless Innovations for a Future Connected World by Ulrich Barth, Head of Smart Wireless Networks, Bell Labs
- Data Storage Energy Efficiency in the Zettabyte Era by Peter Hormann, Honorary Fellow, CEET
- Key Challenges in Creating a Sustainable Networked Internet of Everything by Thierry Klein, Chairman of the Technical Committee of GreenTouch consortium
PRESENTATIONS

KEY PRESENTATIONS

• GreenTouch Members Meeting, 6 - 8 April 2011, Seoul, South Korea. Speakers: Rod Tucker and Kerry Hinton

• GreenTouch Members Meeting, 14 - 17 November 2011, Seattle, USA. Speakers: Rod Tucker, Kerry Hinton, Arun Vishwanath, Bipin Pillai, Alan Lee, Rob Ayre

• GreenTouch Members Meeting, 14 - 17 November 2011, Seattle, USA. Speakers: Rod Tucker, Kerry Hinton, Arun Vishwanath, Bipin Pillai, Alan Lee, Rob Ayre

• GreenTouch Members Meeting & TIA Showcase Network Innovations in Green ICT, 5 – 7 June 2012, Dallas, Texas, USA. Speakers: Rod Tucker, Kerry Hinton, Chien Aun Chan, Alan Lee, Brian Krongold


• IEEE ICC 2012: Workshop on Smart and Green Communications & Networks (SGCNet), 15 August 2012, Beijing, China. Keynote Speaker: Rod Tucker

• Australian IPv6 Summit 2012 17 – 19 October 2012, Melbourne, Australia. Speaker: Kerry Hinton

• GreenTouch Members Meeting 5 - 8 November 2012, Stuttgart, Germany. Speakers: Rod Tucker, Kerry Hinton, Bipin Pillai, Jeff Cheong

• ANZAAS, The Australian & New Zealand Association for the Advancement of Science, 21 November 2012, Melbourne, Australia. Speaker: Rod Tucker

• Smart Power for Smart Communication Networks 2013, 6 March 2013, Brisbane Australia. Wireless access, cloud computing, M2M & IPv6: Burn, baby, burn! Speaker: Kerry Hinton

• CommsDay, 10 April 2013, Sydney Australia. Launch of CEET’s first white paper: The Power of Wireless Cloud. Speaker: Kerry Hinton

• GreenTouch TREND workshop at INFOCOM 2013, 19 April 2013, Torino, Italy. Speaker: Kerry Hinton

• GreenTouch Members Meeting 13 – 16 May 2013, Shanghai, China. Speakers: Rod Tucker, Kerry Hinton, Arun Vishwanath, Alan Lee, Brian Krongold

• Google Summit: How Green is the Internet? with former US Vice President Al Gore, 6 June 2013, California, USA. Speaker: Kerry Hinton

• 2020: Smart Cities, Zettabyte Data and 200 billion things, A TelSoc Special Panel, 3 September 2014, Melbourne, Australia. Panelist: Rod Tucker

• GreenTouch Members Meeting 4 - 7 November 2013, Paris, France. Speakers: Rod Tucker, Kerry Hinton, Jack Li, Qasim Chaudhari, Chien Aun Chan

• GreenTouch Members Meeting 5 – 8 May 2014, Milan, Italy. Speakers: Rod Tucker, Kerry Hinton, Bipin Pillai, Brian Krongold, Alan Lee

• GreenTouch Members Meeting 17 – 20 November 2014, Melbourne, Australia. Speakers: Rod Tucker, Kerry Hinton, Bipin Pillai, Brian Krongold, Alan Lee, Chien Aun Chan, Qasim Chaudhari, Jack Li, Rob Ayre, Jeff Cheong

• Towards a Sustainable Connected World, 20 November 2014, Melbourne, Australia. Speakers: Peter Hornemann

• GreenTouch Members Meeting 16 – 18 June 2015, New York, USA. Speakers: Rod Tucker, Kerry Hinton, Brian Krongold, Alan Lee, Jack Li
Telstra is an Australian telecommunications and information services company who offers a range of communications services. Telstra believes that information and communications technology (ICT) has the potential to unlock environmental benefits with the industry having a central role to play in enabling a low-carbon future.

CEET, in conjunction with Telstra, presented an Advanced Studies Unit Energy-Efficient Networking during Semester 2 of 2012.

The course offered graduate Engineering students at the University of Melbourne lectures, project work and a field visit to introduce them to the principles and practices of energy efficient technologies for telecommunications. The Advanced Studies Unit was unique in that students in the course undertook team based project work under the guidance of network engineers provided by Telstra. The close collaboration between CEET and Telstra provided the students with hands on experience of working on real-world projects and solutions for a commercial telecommunica-tions company.

CEET also worked with Telstra to undertake a power audit of a range of customer premises equipment. This audit formed part of Telstra’s sustainability agenda.

Media

Media Articles & Media Mentions


Alcatel, Melbourne University, Victoria govt launch CEET TelecomPaper, 28 March 2011


CEET aims to introduce energy rating system for telecom services CommsDay, 29 March 2011

Australia expands green internet capacity ECOS Magazine, 31 March 2011

Greening the Telecom Sector EBN, 31 March 2011

Inefficiencies that will plague the NBN Business Spectator, 5 April 2011

Sustainability in telecommunications Sustainability Matters, 12 April 2011

Top Australian University for Electronic Engineering Electronics News, 14 April 2011

The net is getting dirtier Technology Spectator, 5 May 2011

Cleaning up the net Technology Spectator, 9 May 2011

Carbon Tax Signals Change For Telco Industry WhaTech, 15 July 2011

On the Frontiers Engineering, Greening the internet The Saturday Age, 16 Sept 2011
Wireless cloud to consume more and more energy
Technicolor computing, 7 July 2013

Cloud energy consumption estimates challenged by study
CloudPro, 16 July 2013 http://www.cloudpro.co.uk/cloud-essentials/56484/cloud-energy-consumption-estimates-challenged.html
Bigger frames make Wi-Fi a power miser: boffins
How many networks do you want to run to enable the Internet of bits?
The Register, 12 August 2013 http://www.theregister.co.uk/Print/2013/08/12/cut_wifi_power_consumption_using_bigger_frames_boffins/

Conversations 4: Will the cloud run out of steam?
Interview with Kerry Hinton (Podcast)
Corrupted Nerds, 13 August 2013 http://corruptednerds.com/video/100004/

Digital Economy Requires Massive Amount of Electricity

Links 17 Aug: Your iPhone Uses More Energy Than Your Refrigerator

New report outlines how network technology must increase efficiency to meet rising energy demands

Datacenter Power Still Largely Driven by Coal
Slashdot, 19 August 2013 http://slashdot.org/topic/datacenter/power-still-largely-driven-coal-

Constant access to wireless networks has an environmental cost

Always-On Wireless Devices: a 30M Ton Carbon Problem
Environmental Leader, 22 August 2013 http://www.environmentalleader.com/2013/08/22/always-on-wireless-devices-a-30m-ton-carbon-problem-

Does Your iPhone Use As Much Electricity As A Fridge? (No Way!)

G20 and CEET on the energy efficiency problem for the Internet of Things

New GreenTouch Innovations to Reduce Energy Consumption in Wireless Access Communications Networks by 46 Percent

GreenTouch wants to move your home network to the cloud

Energy-efficient point-to-point optical transceiver, virtual home gateway are latest from GreenTouch

Can we create an energy efficient Internet?

New hardware to boost efficiency of Internet devices

Can we create an energy efficient Internet?

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ACKNOWLEDGMENT

This work was supported by the Australian Research Council’s Discovery Projects funding scheme (project number DP110102957).


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