CHALLENGES OF A SUSTAINABLE INFORMATION AGE

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The Internet and the ICT (information and communication technologies) are now accepted as building blocks for economics, technological and social advancement worldwide. The Information Age and the evolution towards an e-society promise substantial benefits as the availability of broadband access continues to spread around the globe. However, the infrastructure on which our e-society relies is consuming ever-increasing amounts of power. The generation of this power is producing a rapidly increasing carbon footprint. Today ICT contributes approximately 2% of humankind's carbon footprint and this contribution is growing exponentially. This raises the question of whether or not our ongoing move into the Information Age is environmentally sustainable. The Centre for Energy Efficient Telecommunications (CEET), located at the University of Melbourne, is a new research centre with a sole focus on the energy efficiency and sustainability of telecommunications networks. This article describes the areas of CEET's research and their outcomes to date.

INTRODUCTION

Today we are most certainly well into the Information Age. Just like the preceding Agricultural and Industrial Ages, the Information Age is dramatically changing the way we live our lives, both at home and at work. The on-going growth in Information and Communications Technologies (ICT) and the Internet is transforming society and generating even greater changes than any of the previous "Ages". However, very soon another "Age" will be upon us: the "Sustainability Age", if not already here, is not far into our future.

The "Sustainability Age" is that time in the evolution of our society in which we need to recognise and respond to the fact that we live on a finite planet with finite resources. We can only generate a finite amount of electrical energy and we can only dump a finite amount of pollution into our environment. Every sector of the economy must review its impact on the environment, and the ICT sector is no different.

The ICT equipment that underpins the Information Age is consuming greater amounts of electrical power than ever before, and as a result greater amounts of carbon-dioxide emissions (CO2e) are being pumped into our atmosphere. Figure 1 shows the global power consumption of the Internet projected into the future based upon current growth rates assuming no improvement in equipment energy efficiency (red dashed line), as compared with 15% improvement per year (green line) (Tucker 2011b). The 15% improvement is based on the best current trends for Internet equipment. Also shown in the figure is global electricity supply, projected into the future based on its historical growth trend of 3%. If nothing is done to improve the energy efficiency of the Internet, it will grow from consuming up to 2% of global electricity supply to well over 10% by 2025. This is not sustainable.

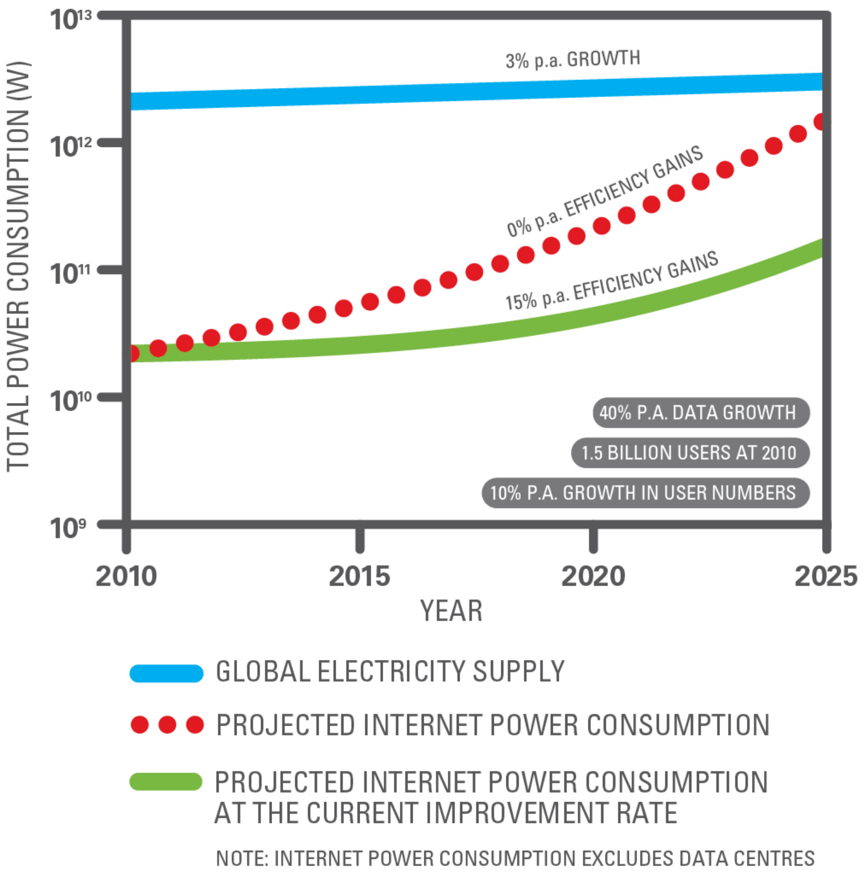


Figure 1 –The growth of power consumption of the Internet over the coming years assuming current growth rates in traffic and number of users.

Even assuming a 15% per annum improvement in energy efficiency, the Internet will consume an increasing proportion of world electricity generation. Furthermore, attaining the 15% annual improvement trend shown in Figure 1 would require replacing all Internet equipment each year by the latest generation of equipment, which is not realistic as it would place an insurmountable financial burden on telecommunications service providers. In order to realise the full potential of the Information Age, new research and innovations are required that will reduce the energy consumption of the ICT industry.

The Centre for Energy-Efficient Telecommunications (CEET) is a research centre based at the University of Melbourne that is dedicated to achieving sustainability in telecommunications. CEET was established in March 2011 and is a cooperative venture supported by Alcatel-Lucent (Australia), the Victorian State Government and the University of Melbourne. The research is primarily focused on the energy efficiency and carbon emissions of telecommunications networks, including the National Broadband Network (NBN) being rolled out by the Australian Government.

ENERGY-EFFICIENT TELECOMMUNICATIONS RESEARCH

ENERGY AND CARBON FOOTPRINT OF THE NBN

Next generation broadband networks, such as the NBN, are being deployed in nations around the world to meet future demands for high speed broadband, and drive economic growth over the coming decades. The deployment of new networks provides an opportunity to improve the energy consumption of telecommunications network by replacing old and energy inefficient equipment with state-of-the-art equipment.

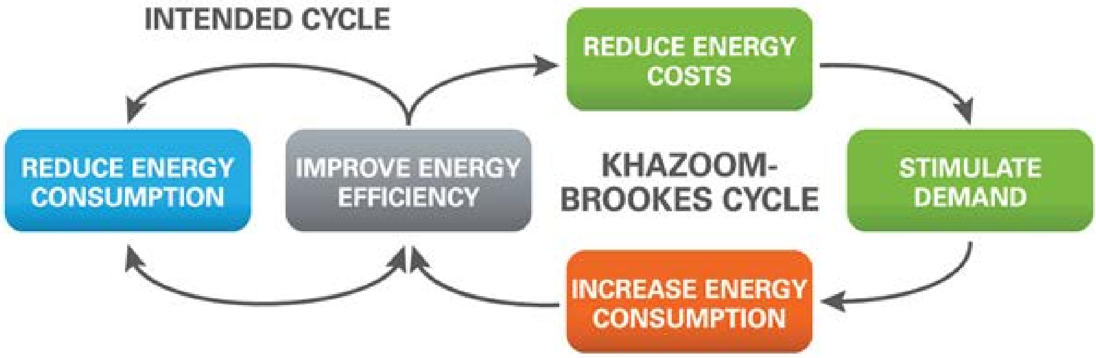


Figure 2 – Khazoom-Brookes Cycle.

Furthermore, ICT is often touted as a driver of energy efficiencies throughout the economy. In 2008 a seminal report titled "SMART 2020" (The Climate Group 2008) indicated that ICT and broadband services could be applied to help abate humankind's carbon footprint by 2020. This stimulated research into how broadband can be used to replace high carbon-footprint activities: popular examples include smart metering in the energy sector and teleconferencing to reduce travel. The report highlighted the fact that broadband can help increase economic activity while lowering a nation's carbon footprint.

In contrast to this, it is possible that improving efficiency leads to price reductions, which then stimulates demand and so increases production. This principle is called the Khazoom-Brookes Postulate and is widely accepted in economics (Saunders 1992). In the case of the NBN, as broadband usage increases so does the energy consumption of telecommunications networks as well as end-users, who have more broadband-enabled devices, such as TVs, tablets, home appliances and other white goods. If broadband costs are lowered, this will drive more usage, which will, in turn, require more energy to power the telecommunications network and support the demand for data. Therefore, the deployment of nationwide broadband may result in increasing economic activity to such an extent that it will increase carbon production.

To date, no detailed study on this issue has been reported. However, researchers at CEET are studying the impact on energy consumption and carbon footprint of the Australian economy, resulting from deploying the NBN with a focus on the two countervailing possibilities of increased or reduces carbon emissions. The study is accounting for the increased energy consumption of the network as demand for broadband rises and the energy consumption of broadband-enabled customer premise equipment in the various sectors of the Australian economy. It also includes energy savings resulting from the use of ICT in the domestic, government and industry sectors.

The research involves applying a Computable General Equilibrium Model (CGEM) of Australia's economy, developed in Centre of Policy Studies based at Monash University[1], to estimate the net social, environmental and economic impact of a nationwide broadband network, including the energy consumption and CO2e footprint. The model encompasses the Khazoom-Brookes Postulate to estimate the net effect of an NBN on energy consumption and related CO2 (e) emissions.

ENERGY EFFICIENCY OF FUTURE MODULATION FORMATS

Research at CEET is also focused on driving energy efficiencies in telecommunications equipment, in both the core and access networks. Research on the core network includes improving the energy efficiency of modulation formats as well as understanding the power consumed by routers.

Ubiquitous broadband generates massive amounts of data that needs to be transported between nations and continents, via the core optical fibre communications systems. As the demand for data grows, these systems must provide ever-more capacity. An optical fibre communications system consists of a highly complex group of inter-connected building blocks, as shown in Figure 3. Minimising the energy consumption of each separate block does not produce a viable, energy-efficient communications link. The system must be optimised as a totality, which makes the task of designing an energy efficient high-capacity optical link challenging.

Key to achieving high capacity in optical fibre systems has been the development of advanced modulation formats that enable very high data transfer rates using available electronics (Tucker 2011a). These advanced modulation formats enable more data to be transmitted over an optical fibre, but come at a cost of increased circuit complexity in the transmitter and receiver. They also require specialised coding and decoding of the electronic data signal before the transmitter and after the receiver, respectively (Pillai et al 2012). This increased complexity may also increase energy consumption in the system.

Research underway at CEET is determining the optimal trade-off between energy efficiency and spectral efficiency when using advanced modulation formats. This involves developing detailed energy consumption models of the various function blocks of the transmission system, including the optical link, electronic digital processing and electronic-to-optical and optical-to-electronic signal conversion. With the understanding provided by these models, a framework for energy-efficient high-capacity optical system design can be developed.

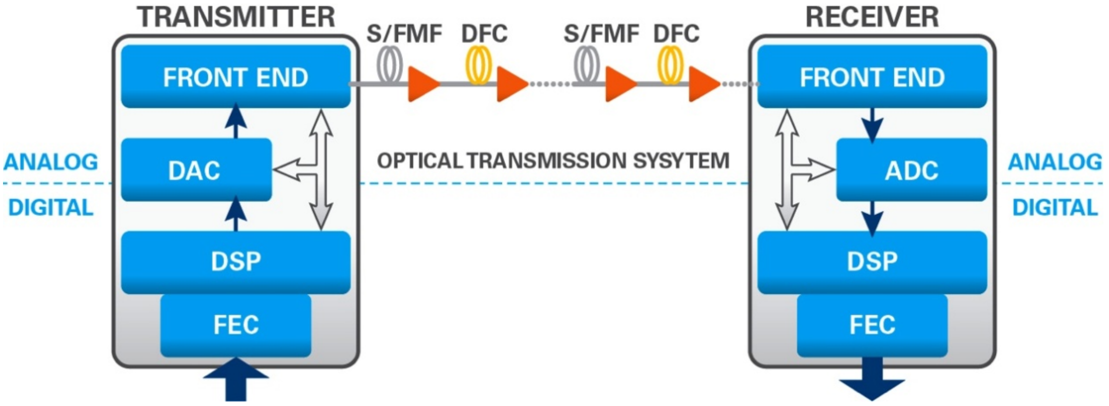


Figure 3 – Schematic diagram of an optical communications system link. To minimise power consumption, the all aspects of the link need to be considered. The use of sophisticated signal coding and error correction can improve overall energy efficiency of the link. Although the link consists of an interconnected group of operational blocks to minimise the overall power consumption of the link requires a global perspective.

ROUTER POWER MEASUREMENTS

Today access networks currently dominate the power consumption of the Internet, however this may not be true in the coming years (Baliga et al 2009). As broadband access speeds continue grow, the traffic resulting from aggregating customer traffic will generate a tidal wave of data in the Internet's core. This core traffic is steered through the network by large routers and as the amount of traffic continues to grow, we will require more and larger core routers.

To understand and then mitigate the Internet's power consumption, we need to ascertain its many contributors. Network equipment and routers in particular are major contributors. Routers tend to consume significantly greater power compared to other network equipment (Tam et al 2010). Routers require substantial computational capabilities in order to interrogate each data packet arriving from the network and determine the next step toward that packet's destination. The destination is calculated using an Internet Protocol (IP) address look-up. Other network devices provide switching functionality but do not require IP look-up processing and many other computationally intensive functions that are undertaken in routers, for example deep packet inspection, security checking, traffic data collection and routing table maintenance.

Determining detailed power consumption profiles of equipment such as IP routers, switches and cross-connects are required to construct detailed power consumption models for the

Internet. These models, in turn, can be used to develop strategies and programs to mitigate the power consumption of the Internet.

Constructing power models for network equipment requires development of measurement tools to collect the required data. This is a non-trivial task, as most network equipment is not designed to enable ease of measurement. Those that provide for power measurement use specific proprietary tools, not applicable to other vendor's equipment. Relating practical measurements to general mathematical models can also be a challenge.

CEET researchers have developed a vendor agnostic router power measurement technique that can be applied both in-service and stand-alone routers. This technique is providing crucial data for the development of sophisticated router power models.

FUNDAMENTAL LIMITS OF ELECTRONICS AND PHOTONICS

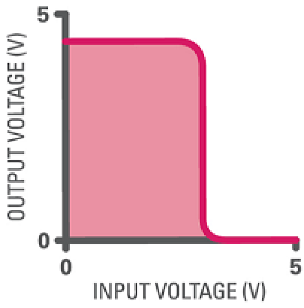
Minimising power consumption in network elements such as routers and switches is an important focus for research on energy efficiency in telecommunications. These network elements must undertake complex digital signal processing and computing activities implemented by large arrays of inter-connected digital logic gates. The energy efficiency of these network elements is constrained by a range of fundamental limitations determined by the laws of nature. These laws arise from 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 (Hinton et al 2006).

Different technologies may be subject to different constraints. One fundamental issue in the quest to "green" ICT is finding the most energy efficient technology and/or technology mix. A technology must be energy efficient and cost effective to be commercially viable. Although electronics (particularly CMOS) has been the dominant technology for digital signal processing, over recent years alternative technologies, based upon photonic interactions have attracted significant attention (Willner et al 2011).

Electronic signal processing technologies are well developed and commercially successful. The trend described by "Moore's Law" has been possible because of the continued success in reducing the power and space demands of electronic transistors. However, it is expected electronic signal processing is unlikely to attain processing speeds much beyond 100 Gbit/s, a limit that is often referred to as the "electronic bottleneck". This raises the question of coping with the ever-increasing signal processing load on ICT equipment due to the exponential growth of Internet traffic. A widely canvassed proposal is to replace electronics with photonic signal processing technologies. This idea is intuitively appealing because photonic technologies offer the promise of signal processing speeds up to 10's Tbit/s, significantly faster than CMOS. Also, photonic signal processing avoids the need for Optical/Electronic/Optical (O/E/O) conversion.

To improve the energy efficiency of network equipment (i.e., reduce the energy per bit) we need to understand where these limits lie to appreciate what further gains are available from both electronic and photonic technologies. CEET is investigating the limitations on reducing network element power consumption and size arising from the fundamental properties of electronic and photonic digital logic gates (Hinton et al 2008).

Apart from low power consumption and small device size, CMOS gates are ideal for digital signal processing. In the below Figure 4 displays the switching characteristic shapes for CMOS gate and Figure 5 likewise for a photonic gate (Highly Nonlinear Fibre, HNLF). We can immediately see that, for the purposes of implementing digital processing, shape of the electronic switching characteristic is significantly superior to the shape of the photonic switch. A question being considered in CEET is: "Is it possible for photonic technologies to attain a switching characteristic the same as electronics for similar power consumption and size?" If this is possible, the ultra-high switching speeds available with photonic devices will provide a significant step in improving the energy efficiency of the Internet.



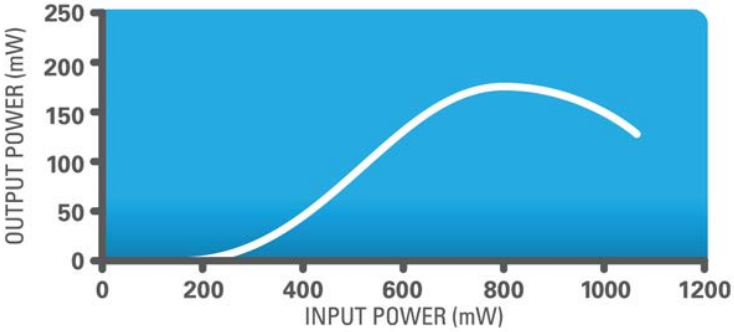


Figure 4 – Switching profile for CMOS

Figure 5 – Highly Non-Linear Fibre

The profile exhibited by CMOS is extremely well suited to digital signal processing. However, that for HNLF presents significant challenges to using these devices for high speed digital signal processing. The challenge is to determine why this is so and to find possible ways to improve the HNLF profile in an energy efficient manner.

LOW-ENERGY FIBRE ACCESS NETWORKS

CEET researchers are also considering the energy efficiency of the access network, which is currently one of the biggest contributors to power consumption in telecommunications networks (Baliga et al 2009). Fibre-to-the-Premises (FTTP), such as that being rolled out by the NBN, is widely seen as the next generation fixed access system, and has been shown to be the most energy efficient access network (Baliga et al 2009). In the case of Australia's NBN the rollout is primarily based upon a "point-to-multipoint" FTTP in which multiple customers share a single source in the local exchange. The average power consumption for current FTTP systems is in the order of 10 W/user (Baliga et al 2011). While FTTP is the most energy efficient access technology available today, reducing the power consumption of FTTP will have a significant impact on the total carbon footprint of telecommunications services.

Researching new access network architectures and technologies has shown that, with the right technology mix, other access network architectures may be more energy efficient than traditional point-to-multipoint FTTP (Sedighi et al 2012). Research underway at CEET is looking toward a point-to-point FTTP optical access network that can provide record low energy consumption in the order of 100 mW/ user for 100 Mbit/s access bitrates. A "point-to-point" FTTP has one customer for each source in the local exchange. It is expected that this new approach will open up new opportunities for alternative power supplies such as solar cells.

ENERGY-EFFICIENT WIRELESS TRANSMISSION

CEET is also undertaking research into improving the energy efficiency of wireless access networks. This is particularly important given the rise of mobile computing, and penetration of mobile devices such as smart phones, tablet, and netbooks. Wireless access networks are the least energy efficient access networks because power is transmitted in all directions, regardless of where the end is located.

There are two main ways to reduce energy consumption in the wireless network (Blume et al 2010):

a). Shorter distances between terminals and base stations reduce the required amount of transmit power.

b). Reduce energy consumption by using a larger bandwidth and trade off spectral efficiency for power efficiency.

CEET researchers and investigating ways to trade off spectral efficiency for power efficiency. Reducing the transmitter power can be accomplished using stronger error control coding on the transmitted signal, which allows the receiver to operate with a much lower received power, and hence a low signal-to-noise ratio (SNR). Operating with a very low SNR requires a re-think of wireless receiver design from the ground up. Such systems differ from conventional systems, as a significant amount of error-control coding is necessary to recover the transmitted data when the received SNR is very low. It is this coding that reduces the spectral efficiency and, according to Shannon's information theory, allows for higher energy efficiency (Heliot et al 2012).

To attain significant energy efficiency gains using coding at a low-SNR receiver requires proper synchronisation in terms of timing, clock frequency, carrier frequency and phase. Each of these tasks is absolutely critical, and the failure of any one will result in failure of the receiver to recover the transmitted data. This work is investigating the theoretical foundations to maximise energy efficiency of a wireless point-to-point link by analysing and understanding its low-SNR receiver limitations.

WIRELESS BASEBAND MODELLING FOR LIGHTRADIO™

CEET researchers are also investigating trends in mobile base stations and how these can assist in driving energy efficiencies. Large and powerful base stations serving areas of a few square kilometres have largely delivered cellular phone services. In selected high-traffic areas including central business districts and shopping complexes, these have been augmented by lower power base stations serving limited areas. A traditional base station radiates power in all directions within each coverage area serviced by the wireless antenna, irrespective of the location of the customers. This approach wastes significant amounts of power.

A very recent trend in the wireless base station technology has been the development of compact modular wireless transmitter/receivers for base stations, of which the Alcatel-Lucent lightRadio™ cube is an example (Segel & Weldon 2011). These modules can be used singly to provide wireless coverage in a limited area such as a shopping centre or sports ground, or used in groups to build a more traditional base station. Importantly, when using several of these small radio modules together, by slightly shifting the relative signal timing (or phase) between the modules it is possible to shape the resulting wireless signal beam and deliver a stronger signal power to customer locations in parts of the coverage area. As the phasing between modules is changed, so the location of the best signal coverage can be dynamically adjusted. This technology is commonly described as an Active Antenna Array.

Active Antenna Arrays can both improve quality of service and energy efficiency. To attain these outcomes, CEET is developing models to determine the potential for each of these technology developments to lower the energy consumption of wireless access networks while delivering equivalent service capabilities. The work is building on current-technology modelling by adding an analysis of new wireless technologies and Active Antenna Array systems. The model also includes the use of pooled and shared base station control functions and accounts for the different demographic and network usage patterns in the USA, Europe and Asia-Pacific areas.

CLOUD COMPUTING, CONTENT DISTRIBUTION & INFORMATION LOGISTICS

In considering the energy consumption of telecommunications networks it is important to consider the elements of the network, as well as how the network is used. Different applications have differing energy consumption profiles. CEET researchers are currently undertaking research into the energy efficiency of cloud services.

Cloud computing offers the promise of providing organisations and consumers with on-demand computing, storage, and software services that can be accessed from any location at any time (Mell & Grace 2011). All that is needed is a network connection and a device such as a laptop, tablet or mobile phone. This has led to explosive growth in demand for cloud based services for a wide range of businesses and social applications (Cisco 2011). Cloud computing relies on large data centre facilities that house many thousands of computers (called "servers") that provide remote processing and storage for cloud users.

A frequently stated benefit of cloud services is that they are ”greener” than performing tasks on a local desktop PC (Accenture 2010; WSP 2011). Studies that have produced this finding typically focus on cloud computing in corporations. In this scenario, cloud computing is likely to be a green alternative to desktop computing, which requires IT infrastructure that typically consists of a number of desktop PCs connected to an “in-house” network and one or more local servers. Replacing this infrastructure with a cloud service enables employees to use low-power client devices networked to a large well-managed data-centre that provides significantly more processing power than several local “in-house” servers at a fraction of the price and power consumption per user (Liu et al 2009). Despite this, data centres can consume mega-watts of power and, depending upon their power source, may have quite a significant carbon footprint (The Climate Group 2008). This has lead to an active and ongoing debate about over the “greeness” of cloud services (Greenpeace 2010). This debate has focussed on the power consumption of data centres, not the network and equipment needed to connect cloud users to the data centre.

However it is not just the data centre that consumes power in cloud computing: end user devices, the broadband access network and the core infrastructure all drive energy consumption. As noted above, the access network consumes significant power. Therefore the recent push to extend cloud services to individual consumers via their mobile phone and/or tablet is driving the energy consumption of cloud computing.[2] [3] [4] The energy consumption relating to the transmission costs is only going to get worse as demand for consumer cloud services grow in popularity and diversity, as is predicted in the very near future (Juniper 2010).

CEET research has shown that this scenario is very different to the use of cloud services in a corporation. A study of cloud-based word processing applications introduces overhead bytes that can be as high as 1000 times as the original text data bytes. The results are shown in when using cloud-based word processing applications, each keystroke typically generates a maximum size packet of approximately 1500 bytes in addition to around 1500 bytes data for document synchronization between the client and the cloud server. Thus composing a text document online using a cloud-based enterprise suite can be somewhat less energy efficient than composing on a low power user device.

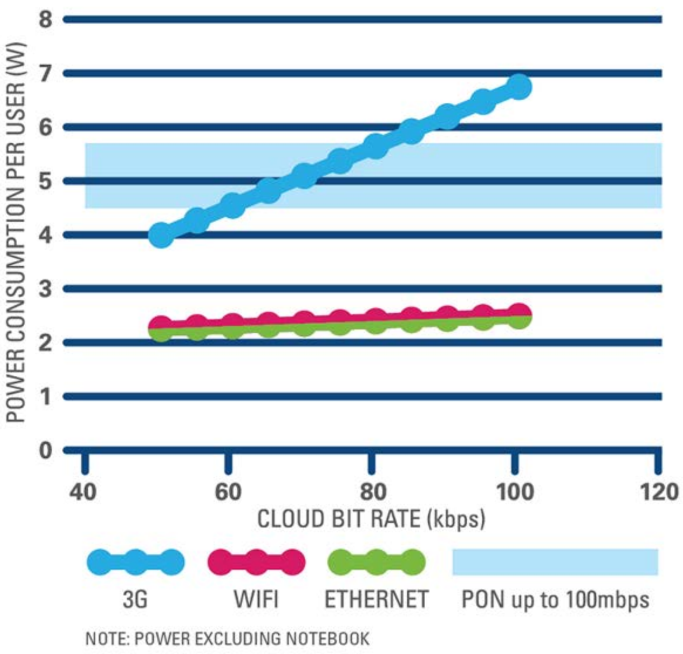


Figure 6 – Plot of power consumption per user when accessing cloud based word processor for different access technologies. It shows that when a wireless (3G) connection is used the power consumed is roughly the same as for a Passive Optical Network operating at 100 Megabits/second, even though the wireless cloud service is operating at less than 1/1000 of this speed. Overall, accessing a cloud service via a mobile network is very energy inefficient compared with other technologies. These findings indicate that the greatest challenge to the sustainability of cloud services is the expectation of an “any-where, any-time, any-service” cloud.

CONCLUSION

It is becoming increasingly clear that the Information Age of tomorrow will be significantly different to the vision that existed in the 1990s when the Internet grew from an academic tool to a dominant part of the world economy. The embryonic days of the Internet did not envision the plethora of services and technologies that we see today from mobile access to cloud services, social networking, high definition IPTV and tablets to name a few.

Today's younger generations see these services and their supporting technologies as the "norm". They are now looking toward and/or creating the next generation of information based services. No matter what these may be, they all will consume power. They will all require equipment to be deployed around the planet and will all have a carbon footprint. The challenge if the Information Age is to ensure it is sustainable for the benefit of future generations worldwide.

The research being undertaken in CEET, along with many other similar institutions around the globe, provides a crucial building block for this future.

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