Digital Infrastructure in a Carbon-Constrained World

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I. The Double-Edged Sword of ICT and Climate Change

We enter 2009 at a turning point in the debate on global climate change. The dialogue has evolved from a scientific focus on “proving” that human activity is inducing climate change to a global policy debate about how all industries and countries can shift to carbon emission minimization to lessen the human and environmental toll of an inevitably warmer world.

Policymakers in many countries, including the United States, Australia, and Canada, have seized on the call to action and are drafting legislation at the local, state/province, and federal levels to enact substantial regulatory limits for man-made Greenhouse Gas (GHG) emissions. As these regulatory systems are implemented, there is growing interest in identifying the worst offending economic sectors while also identifying short-term activities that can help to slow down the rate of increase of GHGs in the atmosphere.

Information and Communication Technology (ICT) presents a uniquely double-edged sword regarding climate change—simultaneously providing opportunities for substantial improvement of the carbon footprint of a number of industry sectors, while requiring substantial efforts to slow down the growth of its own climate impact. This white paper provides an overview of these challenges and opportunities, provides some examples of on-going research, and lays out an agenda for American, Australian, and Canadian collaboration.

II. The Global ICT Industry’s Role in Creating Climate Change

Many efforts are underway to identify the economic sectors most responsible for global GHG emissions.[ii] In these reports emissions and sinks are computed for all GHGs and then converted to Gigatons (Gt) of CO_2 Equivalent (CO_2e). The results show that in 2006 Australia had net emissions of 0.58 Gt, while the U.S. had net emissions of 6.2 Gt. The major economic sectors generating GHGs were, in order, electricity generation, transportation, industry, commercial and residential structures, and agriculture sectors.

Although ICT is not always thought of as an economic sector, specialized studies[iii] have recently made its role clearer in the last two years. According to these studies, ICT globally produces man-made GHGs roughly equivalent to that of the aviation industry, ~2-3 percent. Furthermore, the ICT industry is rapidly growing in its emissions. The Smart 2020[iv] study concludes that the ICT sector’s emissions are expected to increase, in a business as usual (BAU) scenario, from 0.53 Gt CO_2e in 2002 to 1.43 Gt CO_2e in 2020. As with the economy in general, electricity generation is the greatest contributor to ICT GHG emissions. This rapid growth in GHG emissions from ICT will certainly draw increased scrutiny[v] from regulators and the public as pressures mounts to decrease emissions below legislated targets.

ICT Carbon Reduction Requires a System Approach. Efforts to address ICT’s carbon impact directly are complicated by the fact that much of the world’s ICT equipment is interconnected by the Internet or telecommunications systems. We must be careful of simply switching emissions from one component to another. For instance, it will become an increasing practice for a company to close down internal data centers and outsource the computing or storage to a remote “cloud” service provider. However, if the cloud provider causes as much emission as the data center did, there is no net ICT emission reduction.

Australia's Centre for Ultra-Broadband Information Networks (CUBIN)[vi] is carrying out studies to determine the emissions and their growths within the various subsectors of the Internet-connected ICT system. One can divide the Internet into edge sources that send data into the network in the form of IP packets. These packets travel over optical fibers and are switched to their destinations via routers. The packets can be thought of as equivalent to vehicles on a freeway system, where the freeways represent the fibers and the routers represent interchanges.

The highway model is a useful first-order analogy for the structure of the Internet, but the analogy does not extend to energy consumption. In the highway system, the majority of energy is consumed by the vehicles in traversing the highways. In the Internet, the majority of the energy is consumed in the routers and in associated equipment. Significant energy is also consumed in the access network equipment that connects the end user to the Internet. This means that energy consumption in the Internet is concentrated in a small number of locations rather than being distributed widely as it is in a highway system. Energy consumption causes heat to be generated in these locations, and additional energy is needed to drive the air-conditioning equipment that removes the heat.

What is required is more detailed research on the carbon emissions caused by various components of the Internet—end user devices (PCs, smart phones, gaming devices), data centers, and the core, metro, and access networks. Since an increasing fraction of end users will access the Internet wirelessly, broadband wireless networks must be added into the study. Many telecommunications industry experts expect that the next big development in broadband Internet services will be Internet protocol television (IPTV), providing both broadcast and on-demand services. Video-on-demand IPTV has the potential to reduce the carbon footprint associated with travel to cinemas and video stores, but new approaches to planning of the IPTV distribution network are needed to ensure that these savings are not counteracted by energy consumption in the network itself. CUBIN is developing methods to achieve this outcome. Out of these studies and other studies will come recommendations for how to decrease the GHG emission of each part of the telecommunications network, in a way that doesn't just shift the burden to a different component of the network.

Greening Data Centers. The Gartner Group estimates that data centers with their energy and cooling demands require energy responsible for almost a quarter of global CO_2 emissions from ICT.[vii] As a result, industry[viii], government agencies[ix], federal laboratories[x], and academia[xi] have been focused on ways to measure and reduce these ICT "hot spots." Recently the Silicon Valley Leadership Group released a report,[xii] in conjunction with Accenture and Lawrence Berkeley National Laboratory, which documents 11 real-world technology initiatives and 17 case studies performed over the 16 months by data center operators, technology providers, and policy experts in conjunction with the Leadership Group's Energy Efficient Data Center Demonstration Project. It shows that dramatic reductions are already taking place as best practices are being shared and implemented on a global basis.

Calit2 at UCSD is extending this trend from the ITC data center operators to the application end users. In an NSF-funded project GreenLight[xiii], UCSD is creating the GreenLight Instrument, a set of eight instrumented racks of compute, storage, and networking hardware installed in a Sun Microsystems Modular Data Center.[xiv] This allows the measurement, monitoring, and public availability of real-time sensor outputs of equipment running a wide variety of applications and algorithms. This allows researchers anywhere to study the energy cost of at-scale scientific computing. This Instrument will enable an experienced team of CS researchers to make deep and quantitative explorations in advanced computer architectures, including alternative circuit fabrics such as multi-core[xv], Field-Programmable Gate Arrays[xvi], direct-graph execution machines, graphics processors, solid-state disks, and photonic networking.

In addition, the GreenLight Instrument will enable five communities of application scientists, drawn from metagenomics, ocean observing, microscopy, bioinformatics, and digital media, to come to understand, through this instrumentation, how to measure and then minimize energy consumption, to make use of novel energy/cooling sources coming online at UCSD, and employ middleware that automates optimal choice of compute/power strategies. This "user-in-the-loop" living laboratory again emphasizes how complex the Internet connected system is when it comes to making Green decisions.

Green Computing and Storage Clouds. Given the difficulty of dealing with energy requirements of data centers, many companies, governments, and universities are considering the use of remote data centers run by professional "cloud" services. Already many of the most used Internet services (Google, Amazon, Yahoo, MSN, etc.) have created vast data center complexes and are beginning to offer "excess capacity" as services. As long as these large-scale data centers are run off conventionally generated electrical power, their carbon footprint can be moderated as described above, but it still remains significant.

However, if the data centers are run and cooled from sources of zero (solar, hydro) or low (bio-ruels) emission energy, then much more significant GHG emission saving can be realized. Using more renewable energy has long been recognized goal by the ICT industry, but increasing the amount of renewable power as part of an energy mix is complicated by the fact that most renewable energy sources are in remote locations. Moreover today's electrical grid is not designed to be able to deliver this power to consumers because of lack of distribution capacity. It will take years, if not decades to upgrade the electrical line transmission infrastructure to deliver the renewable power that is needed by the ICT and other industry sectors.

The ICT industry, as distinct from any other industry sector, is ideally suited to have some of its infrastructure located at these renewable energy sites as long as there are high-speed optical network connections nearby. Many large data centers deployed by Google and others have already adopted this strategy, often using old aluminum smelting facilities which have high electrical current leads to hydro plants.

An ICT infrastructure deployed at renewable energy sites has a number of advantages in that there is now a completely independent redundant power infrastructure for the ICT industry, as a whole, made up of the traditional one provided by electrical utilities in cities and another based on independent renewable power sources located largely outside of cities, but interconnected through optical networks. More importantly by locating network nodes at renewable power sites, network providers will have a greater certainty of price, as they will not be competing with other industry sectors for that same power.

III. Application of ICT to Lessen Climate Change

Perhaps the greatest paradox of ICT is that while the sector contributes to the GHG problems, if it can find a way to keep this footprint under check, applications of ICT offer tremendous opportunities to decrease overall emissions from other sectors. The Climate Group in their Smart2020 report estimates ICT can help enable GHG emissions reductions of 7.8 Gt of CO2e by 2020 or roughly 15% of global total "business as usual" emissions.

Some of the largest opportunities to apply ICT to carbon minimization exist through smart grids (energy consumption), intelligent infrastructure (transportation and building), and telepresence (elimination of travel), in addition to clean/green ICT (minimization of ICT footprint itself discussed above).

Smart Grids. Electrical power distribution is undergoing a digital revolution. Previously, electricity consumers have been trapped in a "blind system" in which there was no two-way communication between producers and consumers regarding power availability or costs. "Smart grids" now being deployed hold the promise to move us to a system where producers more effectively monitor power transmission and distribution, while also providing users with greater information on availability and associated real-time costs through smart meters in the home. There are also additional opportunities to address home power demand inefficiencies. Collectively, ICT-enabled smart grid activities are estimated to help globally reduce nearly 2.3 global tons of carbon dioxide worth $124 billion dollars (Smart2020).

Research opportunities exist as well as industry rollout of smart grids. Take for example the issue of external electronic power adapters. Apart from being unsightly it is estimated that these "wall warts" consume about 4 percent of all electricity in the average U.S. home (52 billion kilowatt hours). Calit2 has been working to develop a home Universal Power Adapter (UPA)[xvii] increasing the efficiency of powering consumer electronic devices while also eliminating the frustration of needing to have unique power adapters for each device. Informally known as uPower, the adapter would serve as a single power supply for one or more mobile or fixed devices or power packs. Once hooked up to the uPower adapter, an electronic appliance would use low data-rate communications to "request" the voltage it needs, and the adapter would adjust volts to operate the appliance.

Intelligent Infrastructure. ICT advances have led to an ever-increasing number of low-cost sensors deployed to make infrastructure more intelligent by allowing persistent monitoring and assisting efforts to increase efficiency.

- *Smart Buildings:* Globally, building emissions account for around 8% of all CO_2 emissions but are anticipated to experience substantial growth as India and China accelerate urbanization (Smart2020). While efforts to create more sustainable buildings are underway, such as Leadership in Energy and Environmental Design (LEED) certification, increased attention to design alone will not be sufficient. Rather, what is needed is the deployment of embedded sensors providing better real-time energy management and allowing for the creation of smart autonomous management systems that can decrease lighting, power, and cooling.
- *Intelligent Transportation:* The US accounts for nearly 45% of all vehicle miles driven in the world. Road congestion domestically is estimated to decrease productivity by 3.7 billion hours and waste 2.3 billion gallons of fuel[xviii]Embedded roadway sensors can provide input delivered back to consumers through the Web, handheld devices, or intelligent vehicle navigation systems that can help eliminate congestion. For instance, Calit2 has developed an intelligent traffic management system[xix] deployed

in San Diego, Silicon Valley, and San Francisco that allows thousands of users each day to receive automated alerts when their primary routes become congested. Traffic.calit2.net also aggregates daily data from these drivers on their commute time that is then shared with the community, allowing them to make data-driven decisions on when is the best time daily for them to leave for their commute to avoid traffic congestion spikes. Meanwhile, Calit2 is partnering with the Intelligent Transportation System,[xx] which houses a distributed on-line database system for Orange County transportation management using cooperating roadside and in-vehicle communication devices.

Telepresence: Networked high definition systems can create the impression that two rooms at different spots on the Earth's surface are "joined" into a single virtual/physical room, nearly as good as "being there," while having the associated benefit of eliminating the carbon footprint from travel. For instance, Cisco is an early leader in the deployment of these technologies - their over 300-Telepresence[xxi] units worldwide have resulted in the elimination of nearly 40,000 face-to-face meetings with environmental impacts equivalent to taking over 15,000 vehicles off the road.[xxii]

Calit2 and partners at the Electronic Visualization Laboratory[xxiii] at the University of Illinois, Chicago, have been exploring the telepresence use of streaming digital media combined with high-resolution data. Through the OptIPuter project[xxiv], funded by the National Science Foundation, Calit2 has been developing the capability of using slightly or uncompressed[xxv] high definition video over an extensive global fiber infrastructure network[xxvi] that is providing a prototype for the next generation of telepresence and international research collaborations. One year ago, in collaboration with the Melbourne University in Australia, an OptIPortal (high resolution tiled display wall) built in Australia was used to allow for a landmark broadband communications demonstration[xxvii] featuring scientific researchers and the Australian American Leadership Dialogue. There are now seven of these OptIPortals in Australia and another forty worldwide.

IV. Proposed Australian, American, Canadian Green ICT Testbed

UCSD and UCI are among the Greenest U.S. campuses. UCSD has undertaken a large number of initiatives to move it rapidly toward a carbon neutral campus[xxviii]. UCI recently won the Best Overall category award in the annual Flex Your Power program[xxix], California's statewide energy efficiency campaign. This means that Calit2 has a strong foundation on its two home campuses to undertake a wide range of Green initiatives.

Since a key thematic element of Calit2 projects is international engagements, we sought out both Canada and Australia to be partners in establishing an international Green IT testbed. As a first step, on October 27, 2008 a MoU was signed between UC San Diego, University of British Columbia, and Prompt Inc.[xxx] during the third Summit of the Canada-California Strategic Innovation Partnership in Montreal, Canada. In one of the first efforts of its kind, these universities in Canada and California are pledging to work together to reduce GHG emissions on their campuses while developing a 'green cyberinfrastructure' – information technology that improves energy efficiency and reduces the impact of emissions on climate change.

In the near term, the institutions agreed to develop methods to share GHG emission data in connection with International Organization for Standardization (ISO) standards for information, computer and telecommunications equipment (ISO 14062), as well as baseline emission data for cyberinfrastructure and networks (ISO 14064). These protocols will become much more widely used as those reducing ICT GHG emissions wish to obtain energy credits in "cap and trade" systems. The Calit2 GreenLight data center will be connected to Canadian end users over the CENIC[xxxi]/Pacific Wave[xxxii]/CANARIE[xxxiii] dedicated optical fiber networks. CANARIE in Canada is studying establishing several research data centers near hydro, wind, and solar powered energy sources, so that a variety of Green Cloud alternatives can be experimented with. Meanwhile, efforts are underway at Calit2 to use DC fuel cell technologies to experiment with feeding modular data centers locally with zero carbon emission energy sources.

Calit2 will build on its now extensive relations[xxxiv] with Australian universities, CSIRO, and AARNet to extend in 2009 the UCSD/Canadian Green IT testbed to sites in Australia. Approximately half of the energy consumed by the Internet goes into the core network routers in the core nodes. Therefore, large improvements in network energy efficiency can be obtained if each packet travelling through the Internet passes through as few routers as possible. The primary method to minimize router hops is to employ optical bypass, by which traffic is groomed into wavelengths and/or wavebands which can be diverted around certain routers, avoiding the need for full electronic processing in every router. CUBIN proposes to study this using the dedicated optical infrastructure made available by the AARNet/CENIC testbed.

V. **Greening the Internet Economy**

In November 2008, CUBIN hosted the *Symposium on Sustainability of the Internet and ICT* bringing together leaders from industry, not for profits, and academics for a two day workshop hosted by the University of Melbourne. In January 2009, Calit2 is hosting with the California Public Utilities Commissions a the *Greening of the Internet Economy* workshop bringing a similar American stakeholder community together to examine carbon limit legislations impact on ICT, data center power efficiency, smart buildings, smart grid, intelligent transportation, and ICT enabled carbon minimization efforts. Building on the success of these two community events we propose establishing an *International Greening the Internet Symposium* to be held annually with hosting alternating between the United States, Australia, and Canada. Technical efforts should be undertaken across the three countries to create "virtual conference audience sites" to allow for the greatest international participation and to reduce the carbon footprint of attendance.

In summary, 2009 will be a watershed year for the ICT industry with a highly increased role in society's efforts to deal with global change. We believe that the university communities have a key part to play.

International partnerships that have been developed over the last few years and which adhere to the mutuality principle, such as the Australian American Leadership Dialogue and the Canada-California Strategic Innovation Partnership, provide an unprecedented opportunity to facilitate creation of Green ITC testbeds to accelerate innovations to help solve this global challenge.

For followup on this paper see Jerry Sheehan, Calit2 jerry@ucsd.edu

About Calit2: The California Institute for Telecommunications and Information Technology (www.calit2.net), a partnership between UC San Diego and UC Irvine, houses over 1,000 researchers organized around more than 50 projects on the future of telecommunications and information technology and how these technologies will transform a range of applications important to the economy and citizens' quality of life. See www.calit2.net

About CUBIN: CUBIN is a Special Research Centre established in January 2000 under the Australian Research Council's Special Research Centres program. CUBIN aims to be a national and international focus for research into future generations of telecommunications. CUBIN focuses on fundamental theory and practical approaches to the design, implementation and management of ultra-broadband networks. The Centre is building close links with industry and with major Australian and overseas university research groups. To assist in fostering collaborations, the Centre sponsors national telecommunications workshops and has established a visitor scheme for Australian and overseas researchers.

About CANARIE: CANARIE Inc., based in Ottawa, is Canada's advanced network organization. It facilitates the development and use of its network as well as the advanced products, applications and services that run on it. The CANARIE Network serves universities, colleges, schools, government labs, research institutes, hospitals and other organizations in a wide variety of fields in both the public and private sectors. By promoting and participating in strategic collaborations among key sectors, and by partnering with peer networks and organizations around the world, CANARIE Inc. stimulates and supports research, innovation and growth, bringing economic, social, and cultural benefits to Canadians. The national organization was created in 1993 by the private sector and academia under the leadership of the Government of Canada. CANARIE Inc. is supported by membership fees, with major funding of its programs and activities provided by the Government of Canada through Industry Canada.

About AARNet: AARNet Pty Ltd (APL) is the company that operates Australia's Academic and Research Network (AARNet). It is a not-for-profit company limited by shares. The shareholders are 38 Australian universities and the CSIRO. AARNet provides high-capacity leading edge Internet services for the tertiary education and research sector communities and their research partners. AARNet serves more than one million end users who access the network through local area networks at member institutions. For further information, please visit: www.aarnet.edu.au.

About AALD: Founded in 1992, the annual bipartisan Australian American Leadership Dialogue alternates between Washington DC and a major Australian capital city. In recent years, the Leadership Dialogue has also accessed the best institutional infrastructure on the west coast of the USA, in order to engage some of their best and brightest about the next phase of nation building in both countries.

[i] The presentation can be downloaded from www.calit2.net/newsroom/presentations/lsmarr/index.php

[ii] EPA U.S. Greenhouse Gas Inventory (www.epa.gov/climatechange/emissions/usgginventory.html)
Australia National Inventory by Economic Sector 2006 (www.climatechange.gov.au/inventory/2006/economic-sector.html)

[iii] Gartner Symposium/ITxpo April 2007 (www.gartner.com/it/page.jsp?id=503867)
International Telecommunication Union (ITU) ICTs and Climate Change (12-2007) (www.itu.int/dms_pub/itu-t/oth/23/01/T23010000030002PDFE.pdf)

[iv] Smart 2020-A report by The Climate Group on behalf of the Global eSustainability Initiative (GeSI) (www.theclimategroup.org/assets/resources/publications/Smart2020Report_lo_res.pdf)

[v] See for instance, An Inefficient Truth by the Global Action Plan (www.globalactionplan.org.uk/upload/resource/Full-report.pdf)

[vi] CUBIN is a Special Research Centre established in January 2000 under the Australian Research Council's Special Research Centres program at the University of Melbourne. www.ee.unimelb.edu.au/research/cubin/index.html

[vii] www.gartner.com/it/page.jsp?id=530912

[viii] See for instance:
www.dell.com/hiddendatacenter?ST=green%20data%20center&dgc=ST&cid=33433&lid=787077
http://h71028.www7.hp.com/enterprise/cache/331475-0-0-0-121.html
http://www-05.ibm.com/il/greenit/downloads/index001_guide.pdf

[ix] EPA Report on Server and Data Center Energy Efficiency Aug 2, 2007 (www.energystar.gov/ia/partners/prod_development/downloads/EPA_Datacenter_Report_Congress_Final1.pdf)

[x] See for example: Pacific Northwest National Laboratory Energy Smart Data Center Project (http://esdc.pnl.gov/)

[xi] See for instance:
http://news-service.stanford.edu/news/2008/october15/sustech-101508.html
www.citris-uc.org/files/07-Paul-Wright-Case-Study-on-Data-Centers.pdf

[xii] Silicon Valley Leadership Group Report on Data Center Energy Forecast July 29, 2008 (https://microsite.accenture.com/svlgreport/Documents/pdf/SVLG_Report.pdf)

[xiii] http://greenlight.calit2.net/

[xiv] www.calit2.net/newsroom/release.php?id=1342

[xv] www.calit2.net/newsroom/print_page.php?id=1378

[xvi] www.calit2.net/newsroom/release.php?id=1425

[xvii] www.calit2.net/newsroom/article.php?id=1327

[xviii] Smart 2020—the United States Report Addendum (www.theclimategroup.org/assets/resources/publications/Smart2020UnitedStatesReportAddendum.pdf)

[xix] http://traffic.calit2.net/

[xx] www.its.uci.edu/its/research/its.html

[xxi] http://Cisco.com/TelePresence

[xxii] Cisco Systems, private communication.

[xxiii] www.evl.uic.edu

[xxiv] www.optiputer.net

[xxv] iHDTV (www.washington.edu/ihdtv/) has been pioneered by the University of Washington's Research Channel (www.researchchannel.org)

[xxvi] The Global Lambda Integrated Facility (www.glif.is)

[xxvii] www.evl.uic.edu

[xxviii] www.gogreentube.com/watch.php?v=NDc4OTQ1

[xxix] www.today.uci.edu/news/release_detail.asp?key=1859 UCI's progressive energy and water efficiency programs were highlighted for reducing campus electrical demand by up to 15,000 kW and saving nearly four million gallons of water annually.

[xxx] Prompt, Inc. (www.promptinc.org) is a non-profit corporation that fosters research and development, building university-industry partnerships to increase the competitiveness of Quebec 's information and communications technology (ICT) sector

[xxxi] Corporation for Education Network Initiatives in California (www.cenic.org)

[xxxii] Pacific Wave (www.pacificwave.net)

[xxxiii] Canada's advanced network (www.canarie.ca)

[xxxiv] www.calit2.net/newsroom/release.php?id=1421