DISCLAIMER: This paper was written by the author in 2009. Instead of publishing it through journals or conferences, the author has chosen to release it online. The paper questions our existing Internet architecture, setup, the huge energy consumed by existing routers and data centers, and provide the motivations for a new greener and energy-efficient Internet.

"Towards a Greener and Energy-efficient Internet"

Chai K. Toh, 2009

The Internet has now played an important if not indispensable role in our daily lives, from ordering items online (e.g. via AMAZON) to performing banking online. Internet is highly pervasive too – we use the Internet at work and at home. The Internet has become our information superhighway, and it has penetrated every corner (almost) of the globe.

John Gage's (SUN Microsystem) famous quote [3]: "The Network is the Computer" is clearly true. We indeed have moved out of our boxes (our PCs, our desktops) and have got ourselves connected to the Internet. Even MICROSOFT does not focus solely on desktop software. Networked software is found even on desktop computers. Geographically, people are separated in time (time difference) and space (different countries, etc). Internet has nicely fitted in to connect people together, narrowing these gaps.

"Are we victims of our own creation?" – How does this statement relate to the Internet? If we can recall Leonard Kleinrock's vision [1] of the future Internet: (a) everywhere, (b) always accessible, (c) always on, (d) plug in from anywhere, anytime, any device, and (e) invisible. Except (d) and (e), the other visions have all been realized.

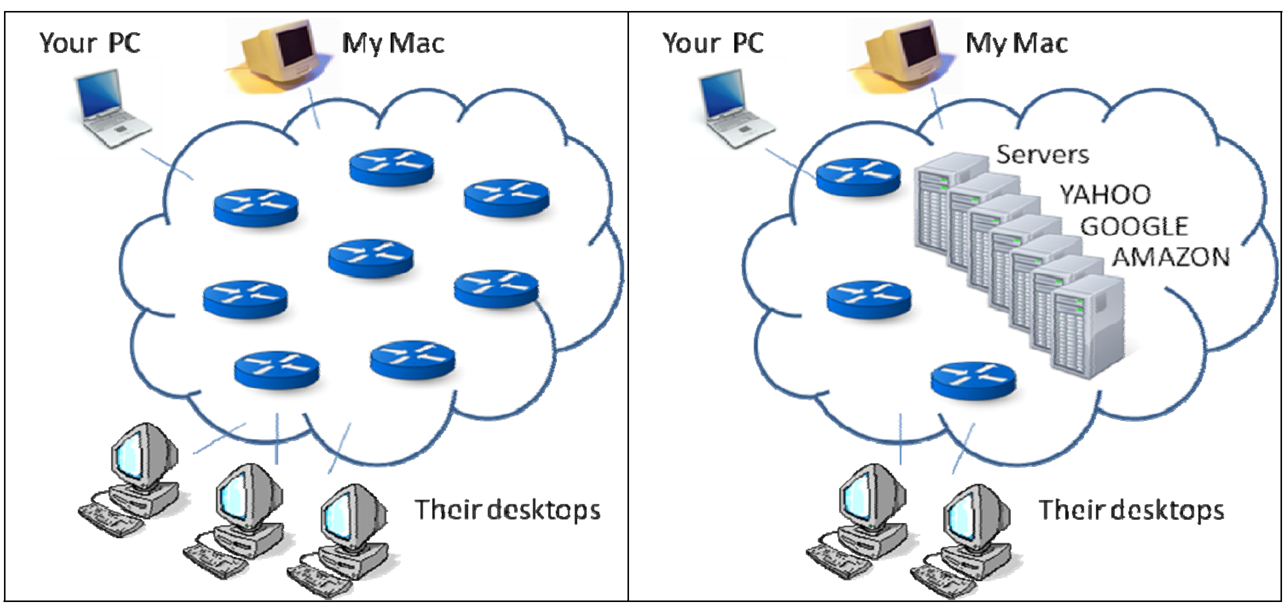
Considering the concept of "always on" – this refers to an Internet that is operating all year round – 24hr/day, 7days/week. To keep the Internet alive, routers and gateways have to remain powered on. Also, to provide uninterruptible services, many servers are power on continuously too. To keep search engines operating and accessible globally, YAHOO and GOOGLE need to have their core and redundant servers on all the time. All these imply that the Internet is a huge energy consumer! Quantitatively, it is unknown how many mega watts of energy are needed to keep the Internet alive. With increasing fuel cost and lack of sustainable cheap alternative fuel, powering the Internet can be expensive. This cost is not limited to the USA alone. Various countries in the world that connects to the Internet have to pay a price to keep Internet and its associated services alive. Hence, there are ample research opportunities to investigate how costly it is to keep the Internet up and running and how much energy is actually consumed.

Recall from basics:

$$\text{Power (P)} = V \times I \qquad \text{(Watt)}$$

$$\text{Energy (E)} = P \times T \qquad \text{(Joule)}$$

The current consumed is represented by "I". The voltage applied can be 110V or 220V (depending on the country). Hence, the higher the current drawn, the greater is the power. Also, the longer (T) the current is drawn and the device is on, the greater is the electric energy consumed. Hence, "always on" constitutes to an infinite T, and hence energy consumed is huge.



(a) (b)

Figure 1: (a) Network-centric Internet, and (b) Data-centric Internet

To examine a step deeper, let's consider the Internet as a "cloud" or "clouds of clouds". Within the cloud we have routers. Routers themselves consume energy. Regardless of how many packets are processed each day and regardless of the number of bits per IP packet, each router consumes some minimal energy to keep it on. Also, within the cloud there are gateways and they too consume energy to operate. Connecting to the cloud are servers and end points. Servers, firewalls, end points all require energy to operate. Hence, the next thing that would bother us is how can we make the Internet "scalable" in terms of power consumption? This points us to think that we want a "greener" Internet. It also points us to consider if the "always-on" concept is wasteful and if an "on-demand" model of Internet provision would be better. This could stimulate interesting discussions among our Internet founding fathers (Bob Kahn, Vin Cerf, and Len Kleinrock).

Figure 1a shows the Internet is a cloud where users connect to it and the core of the cloud comprises an interconnection of routers. Figure 1b shows the existing trend where data servers increasingly populate the Internet cloud. The Internet is used to "compute, search, and furnish" data, not just to "relay" data. Servers and routers are both energy consumers.

Figure 2: Commercial Routers – Racks are commonly used. ISP providers have lots of such racks in their data center.

Next, let's try to gauge how much energy is actually consumed. According to [4], a typical carrier grade router consumes 3500W (for 16A at 220V). With 6 routers mounted on a rack, this would amount to 630KW. Another 1890KW is needed to cool the routers down. In total, 2.52 MW of electrical power is consumed. This magnitude is huge as a typical nuclear power plant delivers 900 – 1200 MW of power. A rack of six carrier-grade routers already consumes 2.5% of a nuclear power plant power. A data center [6][8] itself comprises not only 6 carrier-graded routers. The Internet itself is more than just a data center. Hence, it is left to the readers to image the magnitude of the total power consumed.

To further present data, the table below summarizes the power consumption of an existing carrier-grade router:

Table 1: Power of an example carrier-grade router.

MAKER	TYPE	POWER
A major router company in California, USA	• Fabric Chassis Switch Controller Card • Modular Service Card • Route Processor • Shared Port Adapters • Packet over SONET interface module • Ethernet Interface Module • WDM Interface Module • Flexible Interface Module	• 110W • 350W • 166W • 25W • 150W • 150W • 150W • 150W

The next question concerns all of us. When it comes to energy bills for powering the Internet, who actually pays for them? Internet service providers (ISPs) run the routers and hence pay for their energy cost. However, part of the cost is factored into the Internet subscription fee. AOL, for example, charges from $18 - $25 per month for Internet access in California. COMCAST High Speed Internet costs $42.95 per month [6]. If one compares the energy bill of a home (studio) with that of an ISP subscription fee, the latter actually costs less, but not negligible. From [5], the energy bill for an efficient home in CA 90025 area amounts to $899 per year, which is about $75 per month. Hence, in CA, Internet access fee alone is already 33% of our per month home energy bill. In Boston (MA 02108), the average energy bill for an efficient home [5] is $1175 per year, which is $97 per month. The extra cost is due to heating during winter. Again, this mean the ISP fee is 42.95/97 = 44.2% of the home energy bill. Undoubtedly, the cost of ISP fee is substantial in comparison with our home energy bill.

Now does our current Internet pollute the environment? Besides being a major energy consumer, the Internet generates a lot of heat as a result of "always on" operation. Most routers, gateways, servers, PCs, etc., have cooling abilities. Heat sinks are used to keep microchips within permissible operating temperatures. Ventilators are also used to prevent these devices from overheating and melt down. INTEL Active Monitor [2] is a utility that monitors system's temperatures, power supply voltages and fan speeds. The user is alerted when abnormal conditions arise, such as extremely high temperatures or fan failures. However, to date, there is no data to show that this heat generated by the Internet contributes to "global warming"! Geographically, countries in the northern and southern hemispheres can provide natural cooling to their Internet boxes. Countries in the tropics actually require air conditioning (which actually consumes more energy) for their network centers. 1 W of heat created requires at least 3W to cool it down [4]. Hence, an increase in power consumption by 1W will result in a total increase of at least 4W. Hence, cooling is expensive and power consuming. Material wise, most routers and gateways are electronic chips and components on PCB boards. The chassis is made mostly from metal or plastic. In fact, in some companies, electronic parts are actually recycled – where copper and gold can be extracted from PCB boards.

In the pursuit for a "greener and energy-efficient" Internet, we need to relook at:

1. **Always-On Concept:** Is this necessary and sustainable for the future?

2. **Router & Switch Construction:** Can we make them less power hungry?

3. **Ethernet Construction:** The IEEE P802.3az Energy Efficient Ethernet Task Force [10] was formed to design a greener Ethernet. Work is still in progress currently.

4. **Server Construction:** Can we make them less power hungry?

5. **Server Replication:** Do we need that many replicated servers?

6. **Internet Software:** Energy per bit – does our protocol operations consume power excessively? Are retransmissions, packet size, and protocol layering considered harmful?

7. **Application Software:** Is our application software consuming CPU cycles unnecessarily?

8. **Social Reliance and Habits:** Shouldn't we power down our PCs when they are not in use? Shouldn't we balance our reliance on Internet? Shouldn't Internet access and service provision be on-demand based?

9. **Alternative Power Sources:** Can we seek alternate energy sources to power our Internet? There are works on converting motion and movements to electrical energy for personal area networks (PANs) but these are too weak to power our routers. So far, there is a lack of suggestions on alternative ways of powering our Internet. On continual reliance on electricity can result in a bottleneck in the future.

In our quest for scalability for the Internet, there are other issues beyond the desire for a longer IP address. There are economics issues – for example, affordability (low price) increases pervasiveness and hence grows the Internet. If the Internet is to grow further, its energy demand must be addressed.

Paul Baran's packet switching concept created a stir in the 1960s. Paul presented a detailed architecture for a distributed, survivable, packet switched communication network. Since then, switching methods have evolved over the years for the better – from packet switching, cell switching, to optical switching.

Current fast packet switches are electrical based, i.e., they are constructed from gate-based on-off switching fabric. Needless to say, electrical switches consume energy but they offer better control and programmability.

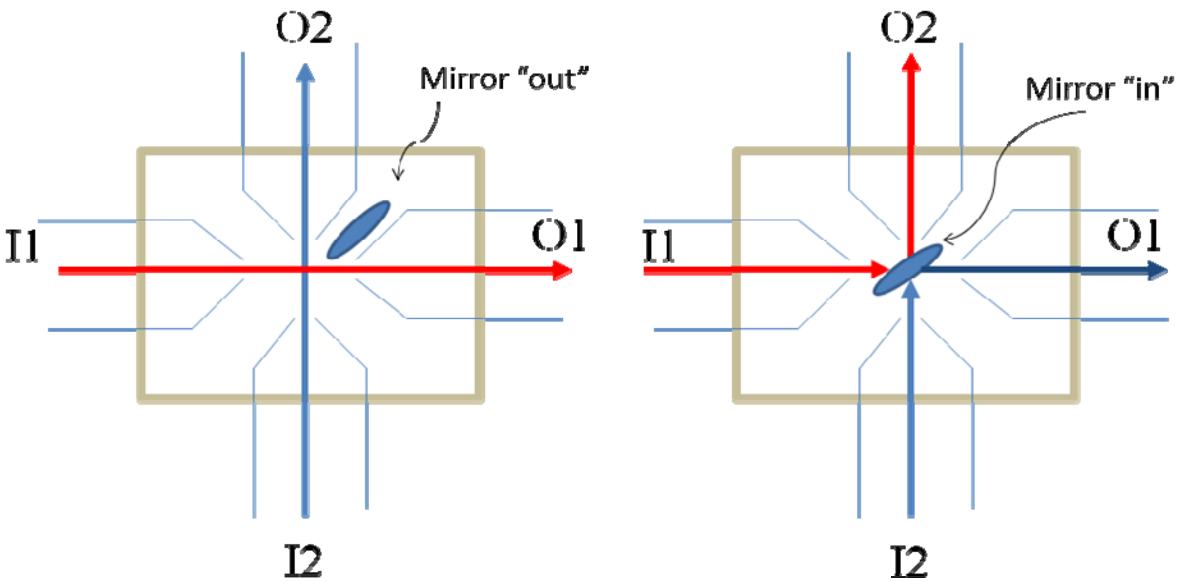


Figure 3: MEMs Switch

Recent work on "green switch" [9] suggested that opportunistic sleeping and the use of shadow ports to buffer ingress packets help to reduce power consumption of an electrical network switch.

Optical switching, on the other hand, involves switching light waves. Optical networks using light sources may appear to be more energy efficient but realizing a passive optical network globally is still far from its reality. Wavelength switching is fundamentally different from electrical-based packet switching. The former typically uses glass reflectors to alter light paths. Data information is embedded into the light beam, distinguished by different wavelengths. For example, MEMs (Micro-Electro Mechanical Systems) switches contain tiny mirrors and their angles can be carefully controlled to direct light signals to respective output ports (Figure 3). MEMs are semiconductor-made micro-mechanisms. In optical networks, light can be split into various wavelengths, and wavelength division multiplexing (WDM) can carry signals at very high speeds.

All-optical switching refers to transmission and switching information in the form of light signals only, with light-to-electrical signal conversion occurring only at the pre- and post-processing ends. If the Internet core is done solely with all-optical switching, a lot of energy can be saved in contrast to existing scenario of electrical switches. It remains yet to be seen if ever our electrical routers will be replaced with all-optical switches in the future for better energy efficiency of the Internet.

Finally, Table 2 shows the trends in terms of bytes sent, access, data type, and energy consumed for the Internet over time. As the number of Internet users continue to grow, energy demands from the Internet must decrease.

Table 2: Trends

Bytes Sent:	Kbytes	Mbytes	Gbytes	Tbytes
Access:	Modem	Cable	Broadband	Next Generation
Data:	Email/Fax	Documents/ WWW	Libraries/ Search Age	Maps/Google Earth/ Medical Imaging
Energy:	Less	More	More	More → Less !

Summary: Energy crisis is now felt in various parts of the globe. Fuel costs have increased over the years. The search for better energy alternatives still continues. The Internet is pervasive and increasingly relied upon for business, banking, travel, education, and private needs. The continual growth in the number of Internet users implies growth in network size and network traffic. The “always-on” concept means our Internet has to be operational round the clock. The Internet is a major energy consumer and this issue has to be addressed. We have to start thinking and striving for a “greener and energy-efficient” Internet soon.

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