GREENER INTERNET BY 2058

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3.003 Principles of Engineering Practice
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May 2008
Massachusetts Institute of Technology
Background/Issues

Trends of Internet Usage

It is at times extremely difficult to imagine that the Internet did not gain a public face until the 1990’s\(^1\). As our dependence on virtual networking continues to increase, our entire form of communication and transfer of knowledge is revolutionizing. The following graph strengthens this argument by showing the exponential increase of Internet Traffic in Japan in the last 10 years as well as projecting these trends for the following four years.

However, many fail to recognize the amount of energy consumed in what is becoming a vital aspect of our advancing society. Not only is traffic increasing, but technology is also developing at a rate at which our resources cannot sustain. The Internet’s current energy consumption is greater than 1.8% of U.S. national electrical power generation and is already expected to increase tenfold, reaching 10% of nation’s power generation by 2020 (assuming trend of Japan from Figure 1) Based on the Ministry of Economy, Trade, and Industry (METI)’s energy report from Japan, it is predicted that when online streaming videos and High-Definition technology become available online within the next decade, the total percentage of energy consumption due to internet usage will increase a thousand fold by around 2035, reaching 100% of total electrical energy generation!

\(^1\) Wikipedia
Packet Switching vs. Circuit Switching

The current mode of information transfer for the Internet is through a packet-switched network. In the packet-switching network, the data is broken into many small packets, each of which takes a different route to its destination, and is then recompiled into the original message. Packets are routed through routers at multiple nodes consisting of ISPs and millions of smaller domestic, academic, business, and government networks. There are a limited number of larger corporations that provide the routers and cable that make up the Internet’s backbone; the upstream ISPs (e.g. Verizon, AT&T, Sprint, IBM, UUNET). Smaller ISPs who handle local and regional traffic have to subscribe to these larger companies for right to access their lines of communication. The transaction between these small, rural ISPs to the IBPs is known as the middle mile. The last mile refers to the transaction between the user (e.g. that are part of the domestic, academic, business, and government networks mentioned above) and local ISPs.

Routers consist of two main functions. One buffers, or stores temporarily, the packet until a new route/line is free and the second switches the packet to that route. The buffering requires the most energy consumption relative to switching (we assume 80% of total energy for buffering and 20% for switching).

A second way to of transferring communication data, used in telecommunications, is circuit switching. In circuit switching, data is routed via a circuit switch that remains

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2 Shu Namiki
National Institute of Advanced Industrial Science and Technology (AIST)
3 http://computer.howstuffworks.com/router4.htm
4 http://computer.howstuffworks.com/who-owns-internet.htm/printable
dedicated to the same circuit during the entire transfer, and the entire message follows the same path. During the duration of communication, no other transfer can take place across that line. Although circuit switching is a more reliable form of transferring data, it increases latency as one route is occupied during the duration of one transfer.

If we continue to rely solely on packet switching and the rate of consumption of high definition media files, such as music and movies continues to grow at the rate it has been growing already, we will find that the corresponding growth required in energy production will be unsustainable. If, however, we were to switch completely to circuit switching, it would be difficult to sustain costs and resources for the implementation of enough fibers to maintain a constant latency and congestion as the current level. It would also be impractical to run a dedicated wire between more than just the most traffic intensive of paths between nodes because of the sheer number of nodes on the network. Because each path can only be utilized by one connection at a time, it could also cause greater delays in waiting for a circuit switched connection to open up, unless packet switched connections are available at the same time.

**Recommendation**

In order to optimize the figure of merit of bandwidth per power, while taking cost into count it is clear that some amount of Circuit Switching needs to be implemented due to huge amount of energy used in Packet Switching. Rather something which would provide a much more efficient solution would be a combination of packet and circuit switching through the development and implementation of multi-mode routers.

These routers would be put in the place of current routers – at the nodes of the Internet “web” but only at backbone and middle-mile Internet Service Providers (ISPs).

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These routers would be able to send files to their destination via Circuit or Packet Switching based on the variables of file type, time of day, and localized congestion.

Currently there is a huge disparity in the size of files transferred over the Internet. The vast majority of files are data files like Emails or Instant Messages that are a few kilobytes in size and require less energy to transfer. Picture files are a few orders of magnitude larger and require a proportional amount more energy; video files are a few orders of magnitude larger than picture files; and high definition videos are a few orders of magnitude larger than regular video files… These disparities set up a natural mechanism for the multi-mode routers to work. Because text files are so numerous and require so little energy to transfer they will be Packet Switched for the most part unless there is hardly any congestion in the Internet, while picture files may or may not be Circuit Switched depending on congestion or time of day, and video files will almost always be Circuit Switched except during times of very heavy congestion (middle of the day). This will greatly reduce the energy consumption of the Internet as the main energy-hogs – video files – will be Circuit Switched and use four orders of magnitude less energy. It also could send files even faster than they currently are as a direct connection can go faster because there is no buffering time!

- **Projected need in 2058 is 98% circuit switching**
- **Threshold for circuit switching (98% of file sizes are larger than this) is approx. 9 GB**

**Analysis/ Assumptions**

There are three different principal ways to work towards sustainable energy consumption within Internet/virtual communication networks:

1. Network Design
2. Individual Site performance
3. Alternative Energy Sources

Individual Site Performance refers to the energy efficiency of the physical routers mainly addressing the maintenance and cooling of buildings and physical materials of the routers. Further, alternative energy sources such as solar, wind, and biofuels all provide aid in our depleting energy sources. We have chosen not to concentrate on these two aspects as our fellow colleagues cover them in detail since they are also two vital aspects concerning transportation and server farms. Thus, we have chosen to focus on Network Design.

There are an additional two components to Network Design. One deals with the technical design of the Internet packet switching routers and the other with the model/architecture of the Internet. Currently, there is no well-known breakthrough of technology that hopes to improve energy efficiency of routers. Multiple studies are being undertaken concerning optical packet switching (keeping the signal in an optical state
throughout the entire transfer rather than converting the signal from optical to electric to optical during the switching), which hopes to make switching more efficient. However, there is no evidence that this new form will consume any less energy. Therefore, we have chosen to remodel the Internet with the current level of energy efficiency and thus also create an improved “base” for possible future developed energy efficient technology.

We are also assuming that these multi-functional routers can be created. These routers need to detect the size of files in order to choose if they are to be packet switched or circuit switched. Currently, at the IP level, no one can detect what the content of each packet handled by IP routers are. They are only able to differentiate between the type of file, i.e. if it is html, ftp, or P2P. Thus assumptions have to be made, that correlate file type with file content. For example, if “you claim most of the P2P contents are of video, then you could conclude that the majority of the Internet traffic is already video related.”

This leads to our other assumption concerning distribution of file sizes. We have taken the following data from CISCO’s Global IP Traffic Forecast and Methodology 2006-2011 in order to compile data necessary for our calculations.

This table represents an overview of break-up of file types transferred in a sample Internet Traffic, namely Global Consumer Traffic between 2005 and 2011.

We assumed that those sub-segments highlighted in a red rectangle are smaller files ranging from 1kB to 100kB whereas the rest fall under the area of 10GB to 15 GB as

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6 Shu Namiki- e-mail 4/30/08
they comprise mostly of larger media files. The smaller files are web, email, and commercial file transfers (excluding P2P and music files such as iTunes) and VoIP is voice over the Internet (eg. Skype and other telecommunications). The following table summarizes the data given above.

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<tbody>
<tr>
<td>1kB-10kB</td>
<td>23.84%</td>
<td>24.57%</td>
<td>22.48%</td>
<td>20.95%</td>
<td>19.92%</td>
<td>19.31%</td>
<td>23.33%</td>
</tr>
<tr>
<td>10GB-15GB</td>
<td>76.16%</td>
<td>75.43%</td>
<td>77.52%</td>
<td>79.05%</td>
<td>80.08%</td>
<td>80.69%</td>
<td>76.67%</td>
</tr>
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The trend shown in the table indicates that the percentage of larger files is mostly increasing (with the exception of 2011). With the expected increase in traffic due to HD videos and media files we therefore assumed that in 2058, smaller files would be 10% of total traffic and 90% would be larger files. Thus, according to our calculations regarding the amount of traffic needed to be circuit switched, the threshold for circuit switching is just below 10 GB, so approximately 9 GB.

Calculations

The primary mathematical model that defines our problem and incorporates our proposed solution is what we dubbed our Figure of Merit (F.O.M.)

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F.O.M. = \frac{\text{Bandwidth}}{\text{Power Consumed}} = \frac{\text{Gigabits}}{\text{Watt}},
\]

an expression which we are attempting to maximize.

In quantifying the amount by which the current packet switching needs to be transformed into circuit switching within the next 50 years, a few key assumptions were
made and constraints were set. In summary, the following steps were taken to calculate the percentage of current packet switching that needs to be converted to circuit switching:

Assumptions:
(1) The amount of energy consumed through the Internet should remain proportional to the total amount of energy available in the United States.
(2) At a node, 80% of energy consumed is due to buffering, whereas 20% is devoted to switching.
(3) There are 100 packets and 100 switches included in an average packet switched file transfer.

Calculations:

- As depicted above, U.S. total electricity generation is projected to increase by 160 Gigawatts per decade. Thus, over fifty years, we are projecting an 800 Gigawatt increase in U.S. electricity availability.
- Current Electricity generation is about 1070 Gigawatts

*We are projecting a 73% increase in total electricity generation in the U.S.

- Internet energy consumption is predicted to increase 100-fold over the next fifty years:

- Now we incorporate our idealized model to establish a relationship between total energy available, the energy required to support both packet and circuit switched systems, and consequently the theoretical threshold
for the amount of packet-switching that should be permitted fifty years from now:

- Variable definitions:
  - $E_p$ and $E_c$ give energy consumed by packet and circuit switching in relation to the other, respectively, as a proportion which is necessary to determine an overall proportion of circuit switching required.
  - $E_{p+c} = \text{Ratio of the percent increases of total energy available and projected needed percent increase of energy utilized through the internet: } (\% \text{ change of energy available})/(\% \text{ change of energy needed for the internet})$
  - $(E_p+c) = (1-x)E_c + x(E_p)$
    Where $E_c = (8\times10^{-5})E_p$
    And $E_{total}$ increases by 73%
  - Which yields: $(0.015)(50000) = (1-x)(4/50000)E_p + E_p x$
  - So **Projected need in 2058 is 98% circuit switching**
  - The projected **Threshold for circuit switching (98% of file sizes are larger than this) is approx. 9 GB**
    - This will serve as the cut-off between files that will be sent through packet or circuit switched systems

**Consequences**

The main consequences of our solution are cost/resources and implementation. Optical fiber will have to be continually added to the Internet to be able to keep up with its increased usage (on an exponential curve). It will probably have to be added at an even faster rate than required with just Packet Switching as this new technology will undoubtedly require some time to perfect and congestion could be a problem with limited bandwidth. Although at this time a 98% conversion to circuit switching may seem unfeasible but it is a possible solution for 2058- telephone lines work on circuit switching and were completed in approximately a 50-year period—but it would require a tremendous amount of optical fiber, money and time.

The second large issue with this new Internet model is the logistics of implementation. As there is no centralized owner of the Internet it is not easy to implement changes. But the beauty of this solution is that the architecture is already set up for it to succeed with minimal work while still achieving the desired result of decreased power use while maintaining performance. While there is no centralized

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7 Calculated by using a ratio of 100 packet switching nodes to 4 circuit switched nodes, and circuit switching only using 20% of energy to packet switch
8 Professor Lionel Kimerling, Massachusetts Institute of Technology
owner, there are a limited number of very large corporations that provide the routers and cable that make up the Internet’s backbone. These larger ISPs can use this control as means to implement circuit switching. They can charge a larger amount of money for packet switched routers in smaller ISPs than for circuit switch routers. Furthermore, organizations that oversee Internet Infrastructure and protocols such as Internet Society, Internet Engineering task Force (IETF) Internet Architectural Board (IAB) can also enforce rules of limited energy consumption.

Besides implementation, congestion is probably the largest concern. The reason packet switching was adopted first adopted in the late 1970s was because circuit switching takes over a fiber so that nothing else can use it and bandwidth is wasted. However, back then files were so small that they used a tiny portion of the bandwidth. Nowadays some files are much larger and capable of using a sizeable portion of bandwidth of the fiber. So, with these files there really is not as much lost bandwidth efficiency in circuit switching and there is a tremendous amount of energy saved. Therefore, if the files are switched properly—large files via circuit switching, small files via packet—a system of multi-mode routers would be just as bandwidth-efficient as packet switching and much more energy efficient.

A possible solution to minimizing congestion could be implementing monetary incentives for Internet users to transfer larger media files during less trafficked times of the day. For example, now that iTunes has made it possible to rent movies online, downloading of video files will largely increase. iTunes can charge more for the movie between the times of 9 am and 10 pm than if the user were to order during the night. This would encourage users to download their files while they are sleeping, consuming less energy.

To conclude, a system of multi-mode routers which route files via circuit or packet switching based on their size, the time of day, and the localized congestion would greatly increase the energy-efficiency of the Internet while maintaining the bandwidth-efficiency and performance. As mentioned earlier, the Internet will be, if it is not already, the heart of communication and its energy issue is largely overlooked. Just as with many other examples, our resources cannot sustain our technological development and we must therefore look ahead in order to provide the resources for future generations to take advantage of the technological advancements they will be making.