Greening Potential Estimation of Data Network Equipment

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***Abstract*—Green Internet is becoming a major concern recently. The main concept of it is to improve energy efficiency in the Internet for reduction of unnecessary energy consumption. Generally, energy consumption of data network equipment in the Internet is unknown although they use a substantial amount of energy. In this area, there is a lack of deeper related studies with a special focus on wired networking and it still remains to be many challenges. This paper aims at exploring an impact of data network equipment for greening the Internet. We first introduce backgrounds and motivations of green networking. Secondly, we estimate energy consumption, costs, and energy savings potential of data network equipment in detail. Thirdly, we assess impacts of it based on IP traffic type and propose new viewpoint on energy efficiency focused on the quality of service (QoS). Lastly, we propose the future works for green networking from the perspective of QoS.**

***Index Terms*—Energy efficiency, green networking, QoS, data network equipment**

I. INTRODUCTION

TODAY, a huge numbers of electronics are used and most of them have network connectivity. As setting up ubiquitous computing environments ubiquitous various devices tend to embed computing and networking functionalities. Thus the Internet has been expended quickly with growing greenhouse gas (GHG) emissions and electrical requirements from it. However, these GHG emissions and energy consumption are becoming key factors of limiting expansion of the Internet.

To overcome these problems, greening of the Internet has begun to be studied with the goal of improving energy efficiency of the current Internet. There are various approaches found on energy-saving mechanisms and power management criteria for greening the Internet, but they have mainly focused on edge devices such as end-user computers and data-centers. However, the energy consumption associated with network functionality is a big issue that we need to focus on, due to growing IP traffic from excess network-connectivity. This issue usually referred to as ***green networking*** [1], which energy managing mechanisms exploiting network-specific features like ad-hoc network have to be added to the wired data network for boosting the network energy efficiency.

The use of the Internet is a part of daily life, but a volume of energy used for providing network connectivity is largely unknown. In particular, there are few reliable and practical figures of greening potential of wired data network equipment for greening the Internet.

The Internet will eventually be constrained by energy density limitations rather than by the bandwidth of the physical components because of its high dependency on electronics. So energy efficiency improvement of the current Internet is a critical issue. But, a subtle trade-off between energy saving and performance exists because energy efficiency must be treated together with increasingly diversified demands of services and sophisticated the quality-of-service (QoS) support.

This paper aims at estimating energy consumption and savings potential in the today's wired data network equipment, understanding impacts of them and providing comprehensive view on green networking. In particular, we are devoted to enterprise network equipment. The paper is organized as follows. Section II states detailed background of the concerns and reasonability of study on greening networking. Section III includes an estimate of energy consumption, costs, and savings potential for wired data network equipment that primarily switches and routes IP packet from a source to a destination. Section IV further gives estimates of impacts of network equipment depending on traffic type in an aspect of energy efficiency considering for QoS and presents directions for future works related to our estimations. Finally, the conclusions are drawn in section V.

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II. PROCEDURE FOR PAPER SUBMISSION

Today, the reduction of energy consumption is the world's major concern. Residential and commercial buildings account for approximately 32% of global energy use and almost 10% of total direct energy-related CO_2 emissions. Energy demands from the buildings sector will be more than double by 2050 [2]. Much of this growth is fuelled by the rising number of residential and commercial buildings in response to the expanding global population.

In the building sectors, the huge potential of improvements in energy efficiency remains untapped, and it will have the largest impact on energy savings and CO_2 emission mitigation through energy-efficiency technologies. By the International Energy Agency (IEA) 2DS (2°C scenario) [2], which assumed policy action consistent with limiting the long-term global temperature increase to 2°C, buildings sectors can contribute to 2DS objectives about 18% of CO_2 reduction shares by 2020. The Information and Communication (ICT) devices occupy over 50% [3] of the electronics used in buildings, and the amount of greenhouse gas (GHG) emissions from their energy use is significant as in Fig. 1. In 2005, CO_2 emissions produced in the ICT sector amount to 98.3MtCO_2e (carbon dioxide equivalent) or 1.9% share of the total EU-25 CO_2 emissions and these are projected to double by 2020 as each 187.7MtCO_2e or 4.5% in BAU (Business As Usual) scenario assuming no significant efforts to reduce emissions. However, in ECO-scenario adopting energy-saving solutions, CO_2 emissions are expected to decline to 132.1MtCO_2e or about 3%, this is the amount decreased by about 30% of BAU-scenario.

Fig. 2 shows GHG emissions footprint of networks from 2002 to 2020. In 2011, this amounted to 22 % of the total ICT footprint and represents 5% compound annual growth rate (CAGR) by 2020. Overall, wired networks' emissions are estimated to grow at a 4% CAGR from 2011 to 2020 to reach 0.14 GtCO_2e. The GHG emission footprint from wired network equipment is to amount to approximately 11 % of the total ICT footprint and approximately 0.25% of total GHG emissions [5]. This is a non-neglected level, so the current wired network infrastructure needs to challenge for energy efficiency.

IPCC 2007 climate change report [6] presents top-down studies that indicate substantial economic potential for the mitigation of global GHG emissions over the coming decades. As shown in TABLE I, in 2030, global economic mitigation potential estimated and assessed the economy-wide potential of mitigation options. TABLE I assumed two scenarios, SRES A1B and SRES B2 (SRES: IPCC Special Report on Emissions Scenarios). They assumed that GHG emissions in SRES A1B are about 68 GtCO_2e and them in SRES B2 is about 49 GtCO_2e in 2030. They are measured economic potential to US$ by different GHG mitigation rates. In TABLE I, on assumption that GHG emission is 68GtCO_2e/year and GHG mitigation rate is 13~27% (9~18 GtCO_2e/year) in 2030, it is possible to save 20 US$/t$CO_2$e.

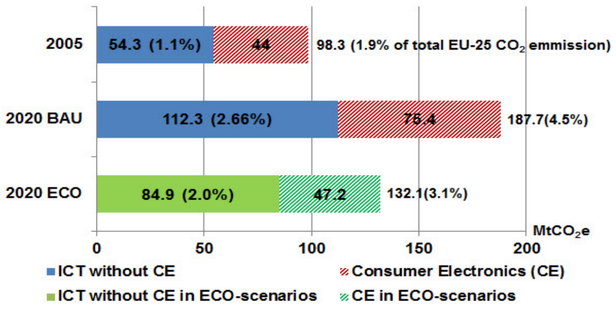


Fig. 1. GHG emission and savings potential (EU-25) of ICT : source [4]

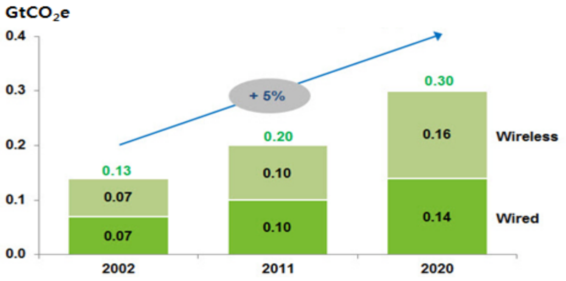


Fig. 2. Global mobile and wired networks emissions [5]

With reference to [5][6], we estimated economic potential of GHG emission mitigation of network-connected equipment to US$ from 2020 to 2030. Assuming 2% CAGR in BAU, GHG emissions of global network-connected equipment are expected to emit about 1.55 GtCO_2e in 2030. According to [5], if network-connected equipment is introduced to other sectors, global GHG abatement potential enabled by these technologies is between five and seven times larger than network-connected equipment's own footprint. Therefore, global GHG emissions is likely to reduce annually about 7.8~10.9 GtCO_2e, using TABLE I, we can estimate economic savings potential at approximately 156~218 billion US$. The energy consumption of network-connected equipment in the USA reflects the world's trend because the USA accounts for the largest amount of the world's (40% of world, in 2008 [7]).

Appliances take a great share of building electricity use, and are also of growing importance in the service sector in the form of office equipment. Globally, network connectivity is being added to appliances which would not previously have had such functionality, and demand for the availability of traditionally network-connected equipment is increasing.

In the USA which occupies the largest proportion of global electricity consumption (27%, 2008 [3]), as shown in Fig. 3, buildings accounts for over 70% of the total electricity consumption in 2006, and electronics account for about 11% of

TABLE I GLOBAL ECONOMIC MITIGATION POTENTIAL IN 2030 ESTIMATED FROM TOP-DOWN STUDIES [6]

Carbon price (US$/t$CO_2$e)	**Economic potential (GtCO_2e/yr)**	**Reduction relative to SRES A1B (68GtCO_2/yr)%**	**Reduction relative to SRES B2 (49GtCO_2e/yr)%**
20	9-18	13-27	18-37
50	14-23	21-34	29-47
100	17-26	25-38	35-53

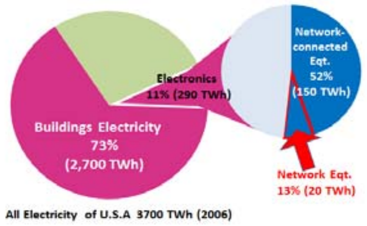
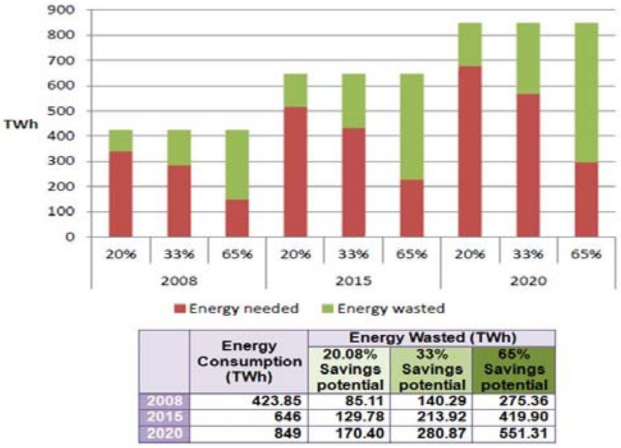


Fig. 3. Electricity consumption of the USA (2006), source : [3]

building electricity use. Electricity consumption of network-connected equipment forms about 52% of electronics and about 0.6 ~ 0.7% of the total buildings'.

Reference [7] presents global energy consumption of network-connected equipment in buildings (e.g., PC, Printer, Phones, TV, game console, audio receiver, media player, STB, router, gateway etc.) and savings potential of them. This is estimated by the degree of market penetration of energy efficiency technologies (e.g. 20.08 ~ 65%) as shown in Fig. 4.

It is estimated that in 2008, total energy consumption by network-connected equipment was 423.85TWh and it accounts for 2.3% of the global electricity consumption (18,603TWh). Based on market trends, this is projected to increase to 646TWh in 2015 and 849TWh in 2020-double the 2008 level. The green parts in Fig. 4 implies that how much energy saving is possible by energy efficient technologies. The lower- end estimate of wasted energy is around 20%, as a result of excess connectivity and/or the use of sub-optimal technologies instead of cost-effective improved technology. This 20% of energy could be saved by means of implementation of power management and power-level reduction policies. The maximum estimate (technical potential) is around 65% of energy, assuming all network-connected products and components are 1W power state lower, and implementation of effective power management policies are on them. The amount of energy wasted by excessive connectivity is estimated between 85TWh and 275TWh in 2008, rising to between 130TWh and 420TWh in 2015, and between 170TWh and 551TWh in 2020, an amount that is superior to the entire electricity consumption of all network-connected equipment in the USA in 2008 (about 169TWh).



	Energy Consumption (TWh)	Energy Wasted (TWh)		
		20.08% Savings potential	33% Savings potential	65% Savings potential
2008	423.85	85.11	140.29	275.36
2015	646	129.78	213.92	419.90
2020	849	170.40	280.87	551.31

Fig. 4. Projected energy consumption and wasted by network-connected equipment worldwide, source : [7]

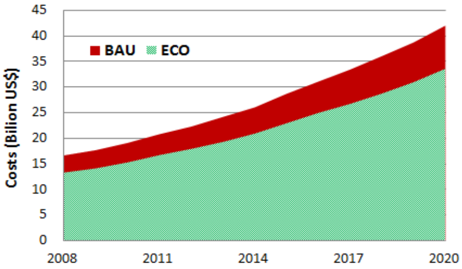


Fig. 5. The USA energy costs for network-connected equipment

We made an effort to look at a scale of expenditure on energy use of network-connectivity equipment in BAU and ECO scenarios. With reference to [7][22], we presented roughly an estimate of the costs of network-connected equipment in the USA between 2008 and 2020 (Fig. 5). We supposed that the energy consumption of network-connected equipment grows annually at 7.3% from 2008 to 2015 and at 6.3% from 2016 to 2020 the same as [7] and ECO scenario has 20% energy savings potential (as the lower limit) over BAU. As a result, it is possible to save 3~9 billion US$ every year from and accumulated saving is about 71 billion US$.

This energy consumption is caused by the absence of effective power management of network-connected equipment. Greater quantities of new network-connected products are entering the market and products are spending more time in higher power modes due to network-related requirements and a lack of effective power management strategies. Power consumption in lower power modes is also increasing because network interfaces require more power in standby modes in order to maintain a network link and networks are tending towards faster speeds and higher bandwidth, which increases power in the absence of effective power management. So, it is important to consider energy efficiency related to networking functionality in electronics. Moreover, it is useful to distinguish between edge devices and network equipment (where the main function is to maintain network links) because their function and energy-saving potential are quite different. So far, edge devices have become an object of attention in terms of energy efficiency and many related researches have carried out, but network equipment has not. In this paper, we therefore discuss relatively unknown energy consumption and savings potential by wired data network equipment.

III. ENERGY CONSUMPTION AND SAVINGS POTENTIAL FOR DATA NETWORK EQUIPMENT

In this paper, we specifically deal with the energy consumption and the implication of wired data network equipment whose primary purpose is to transport, route, switch, or process network traffic, excluding edge devices such as PCs, servers, other sources and sinks of IP traffic.

The reasons that we should note to energy conservation of the wired network equipment are the followings. Firstly, there is inefficiency of the current networking system. Networking infrastructure involves high-performance and high-availability machines. They therefore relay on powerful devices, which are organized in an over-provisioned and redundant architecture [1]. Traditionally, networking system are designed to endure peak load and degraded conditions, they are dimensioned with extra capacity to allow for unexpected events. As a result, during low traffic periods, over-provisioned networks are also over-energy-consuming. For resiliency and fault-tolerance, networks are also designed in a redundant manner. Devices are added to the infrastructure with the sole purpose of taking over the duty when another device fails, which further add to the overall energy consumption however these objectives are under-utilized in normal operation [1]. Moreover, network equipment expends a great deal of energy even when it's at idle (they are powered on 24/7). Unlike monitors or other computing equipment that satisfy Energy Star recommendations by going into various energy saving states when it's at idle, network equipment typically does not (there are no Energy Star recommendations for them). This is because maximizing network throughput and minimizing latency are the primary driving factors in network design [8], so network areas leave a large room for energy savings.

Secondly, to support new generation network infrastructures and related services for a rapidly growing customer population, telcos and ISPs need an ever larger number of devices, with sophisticated architectures able to perform increasingly complex operations in a scalable way. According to [8], high-end IP routers, which provide more and more network functionalities, continue to increase their capacities, with an increase factor of 2.5 every 18 months. At the same time, silicon technologies The sole introduction of novel low consumption silicon technologies cannot clearly cope with such trends, and be enough to draw current network equipment towards a greener future Internet. Thus, there is much likely as in other areas where energy efficiency is a concern, it is required more approaches to networking area for greening the Internet. Today's network relies very strongly on electronics, despite the great progresses of optics are in transmission and switching. Therefore, how energy consumption of the network equipment is a key factor of growing importance and it will become more and more significant to consider energy efficiency in terms of networking.

Thirdly, in many parts of the world, electricity is a scarce resource and poses one of the barriers to widespread Internet deployment. In addition, frequent power outages reduce the uptime of the deployed Internet. If energy consumption of the Internet devices is reduced, we can deploy more devices for the same energy cost and, given the same UPS capacity, have more of them up and running during periods of power outage thus improving overall network reliability [9].

Currently, the major solution of the paradigms for green networking is proportional computing. Many green network approaches follow this solution. It depicts different energy consumption profiles by its utilization level as shown in Fig 6. Energy-agnostic devices, whose energy consumption is constant, independently of their utilization, represent the worst case: such devices are either on and consume the maximum amount of energy, or off and inoperative. In contrast, fully energy-aware devices exhibit energy consumption figures proportional to their utilization level. Between these two extreme situations, there exist an infinite number of possible intermediate profiles. Today's many green networking techniques have been committed to make energy consumption figures proportional against their utilization level. This strategy can be introduced into individual devices or components, a networked system and protocols.

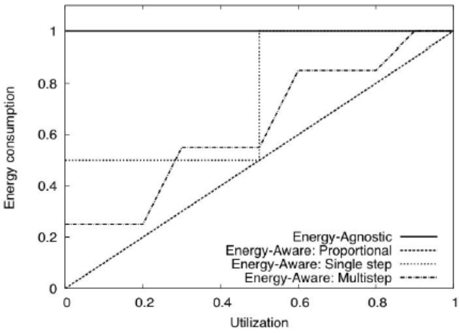


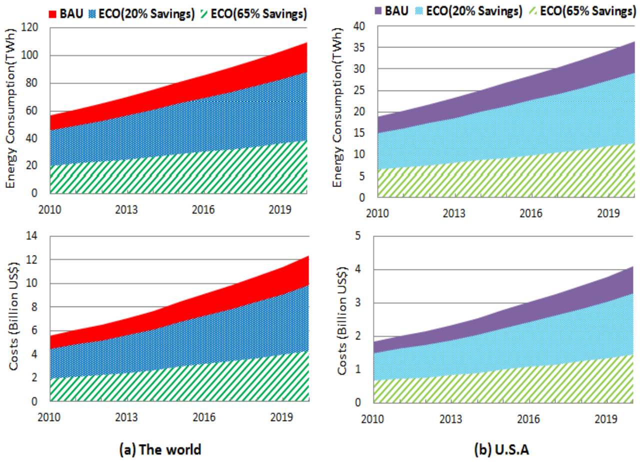
Fig. 6. Energy consumption as a function of the utilization [10]

According to [8], the typical access, metro and core device density and energy requirements in today's typical networks. The power consumption of transport and core network represents about 30% of the overall network requirement, and access devices weigh for 70%. Even if power consumption of an access device is approximately one-sixth of a core device, the number of access devices is much more than core devices. Thus power consumption of the today's overall network is driven by access networks.

To look at a scale of local and global energy consumption of access network equipment, we estimated it by (1).). **E_{g_ne}** is the global energy consumption of network equipment in BAU (assuming that continuity is maintained considering the current situation and trends) and ECO scenarios (assuming that there is a push for ICT-based energy efficient solutions) and it is sum of **E_{ne_i}** which is each country's total energy consumption of network equipment **E_{ne_i}** can be calculated with (2). **E_i** is a country's total consumption of electricity [11], **B_i** is the share of buildings in the total electricity of a country [12], **N** is the share of network equipment in the buildings electricity, which is assumed 0.7% based on the USA [3]. **n** in (1) is the number of countries included and its value is 136.

$$E_{g\_ne} = \sum_{i=1}^{n} E_{ne_i} \tag{1}$$

$$E_{ne_i} = E_i \times B_i \times N \times w_i \tag{2}$$



(a) The world (b) U.S.A

Fig. 7. The energy consumption and costs by access network equipment

$$w_i = I_{sb_i} \times \frac{1}{I_{sb_{us}}} \qquad (3)$$

w_i is weight, which the value is used for taking into account levels of IT development varied by country. This weight is determined by the IDI access sub-index in 2010. IDI (The ICT Development Index) is one benchmark measure that serves to monitor and compare developments in information and communication technology (ICT) across countries. It was developed by the International Telecommunication Union (ITU) and aims to capture the evolution of the information society as it goes through its different stages of development, taking into consideration technology convergence and the emergence of new technologies [13]. I_{sb} access sub-index of the IDI captures ICT readiness, and includes infrastructure and access indicators. We use I_{sb_i} the IDI access sub-index of a country adjusted by $I_{sb_{us}}$, the IDI access sub-index of the USA, 5.75 in 2010, which the USA accounts for the largest amount of the world's electricity use.

Therefore the energy consumption of network equipment is :

$$E_{g\_ne} = \sum_{i=1}^{n}\left(E_i \times B_i \times N \times I_{sb_i} \times \frac{1}{I_{sb_{us}}} \right) \qquad (4)$$

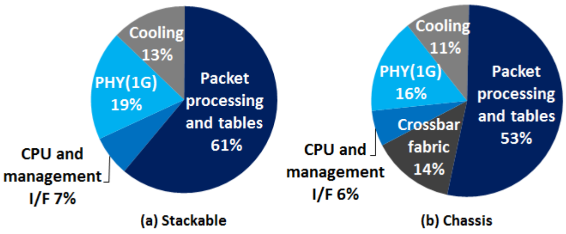
The results are shown in Fig. 7. According to that, the global energy consumption by access network equipment is around 57TWh in 2010. Approximately 9TWh costs in the order of 0.9 billion dollars per year (at 9.8 cents per kWh from all sector average in 2010 [23]) and requires one nuclear reactor unit. A typical average nuclear power plant have two reactors, each of which generates an average of 9TWh electricity per year [9] (an average life of a nuclear reactor is 40~60 years [24]). As shown in Fig. 7, in 2010, the USA access network equipment's energy consumption per year is an enormous amount that required more than two nuclear reactors. Moreover, to look at a scale of savings by energy efficient technologies just at a glance, we estimated local and global energy consumption of it in BAU and ECO scenarios between 2010 and 2020. In this work, as the growth of network equipment is correlated with that of the network-connected equipment, similar growth rates can reasonably be applied to network equipment in general. So, the yearly growth rate of the energy consumption of it is assumed to be the same those in Fig. 4. In here, we supposed that the energy consumption of access network equipment grows annually at 7.3% from 2008 to 2015 and at 6.3% from 2016 to 2020 and ECO scenarios are assumed to has 20% and 65% energy savings potential (as the lower and upper limit) over BAU.

As shown in Fig. 7, the 2010 energy consumption of the world's access network equipment accounted for 0.3% (56.6TWh) of the total world's electricity consumption (17,839TWh [11]) and it is forecasted to show growing trend continually. In 2020, it is forecasted to increase by about 109.7TWh and this doubles in 2010. If the energy consumption of the world's access network equipment was possible to save by 20% over BAU, it could save 11~22TWh per year from 2010 to 2020. In the USA, it is possible to save by 4~7TWh per year, then this is an amount needed almost one nuclear reactor.

Access network equipment mainly consists of office network switches and residential equipment. They account of approximately 0.7% (2006) [3] and 1% (2008) [14] of power use in buildings in the USA. In particular, the enterprise network equipment is largely responsible for about 60% (42% at switches, 6% at routers, 10% at security appliances and 2% at WLAN [14]) of energy use in the global access network. As a typical case, According to the energy use distribution in Berkeley campus LAN reported by LBNL [14], switches and routers are account for 87% of total energy use of campus LAN. So, switches would account for most of energy use in general enterprise network. This clearly implies why switches are targeted leadingly for energy efficiency.

IV. AN IMPACT OF DATA NETWORK EQUIPMENT BASED ON TRAFFIC TYPES

We devoted to analyze energy consuming factors in the switching equipment which is the major cause (over 80%) of energy consumption in a general enterprise network. According to [15], typically, 60 % of power consumption in networking equipment is associated with packet-processing part and packet-processing support part such as memories



(a) Stackable (b) Chassis

Fig. 8. Typical switch power allocation [15]

(dynamic random access memory (DRAM) and ternary content access memory (TCAM)). Fig. 8 presents the maximum switch power consumption happens at the packet processing subsystem. This subsystem processes vast traffic with functionality such as buffering, lookup, forwarding, switching fabric and I/O. To increase power savings, the best place to start is to reduce the power consumption associated with packet processing.

The traditional network equipment does not consume energy proportional to traffic loads, because they consume constant energy even during idle period. Total energy consumption of the current typical switches (non-green network switches) depends on the number of active ports, capacity of each port, but does not on port utilization. Current Ethernet switches require both transmitters and receivers to operate continuously on a link, thus consume energy all the time, regardless of the amount of data exchanged. That is to say, they consume large energy even at low loads, which means very low energy efficiency. As solution to this problem, green technologies are devoted to make its energy consumption nearly proportional to its traffic load by approaches such as resource consolidation and selective connectedness. Representatively, energy efficiency Ethernet (EEE) [25] of adaptive link rate (ALR) solutions is already well advanced and addressed by IEEE Std. 802.3az and has shown important energy savings at low loads. Network equipment in today’s Internet is being rapidly replaced to high-end ones and EEE shows better energy efficiency over high speed link. With such the trend, energy consumption of switches would become proportional to its traffic load. However, green approaches of resource consolidation and selective connectedness are required more sophisticated mechanisms in terms of the quality-of-service (QoS). The current green networking techniques have hardly taken QoS into account.

In this context, that switches comprehend a volume and characteristic of traffic on them and manipulate appropriately could improve energy efficiency. Moreover, at the line consuming second-largest energy, it is important that switches consider a volume and characteristic of traffic to decide sensitive factors like states (sleeping or idle), timers in green techniques such as ALR. Further, the green networking techniques need to focus on the quality of the user experience. The current green networking techniques have hardly taken into account QoS but should consider energy efficiency with view of QoS in the future. Processing traffic by green levels classified on the basis of characteristic of traffic could further improve energy efficiency. For this, switches need to understand and manage information about traffic characteristic in an aspect of energy efficiency. This enables to consider further QoS, and thereby could provide more sophisticated energy efficiency. Also this information can be utilized for smart decisions and exact predictions in the resource consolidation and dynamic adaptation for green networking, either.

Fig. 9 shows global IP traffic growth from 2011 to 2016. In 2016, about 93% of the global IP traffic will be comprised of the consumer traffic which includes IP traffic generated by households, university population, and Internet cafes and the consumer wired Internet traffic of them will account for the majority (over 70%) of the IP traffic. Thus switching equipment will require tremendous energy for processing these huge amounts of IP traffic. Internet video, file sharing, and web/email data account for 99% of total. Especially, Internet video streaming and downloads of them are beginning to take a larger share of bandwidth and will grow to over 54% of all consumer Internet traffic in 2016 [16].

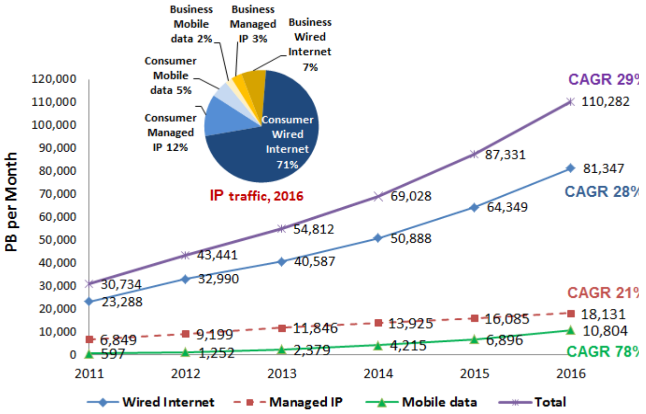


Fig. 9 Global IP traffic, 2011-2016, source : [16]

Depending on the traffic types, volumes of traffic have very big difference. Their characteristics and needs are different in terms of energy efficiency as well. Thus, we put effort to figure out impacts on network equipment by traffic types in an aspect of greening network. We focused on consumer the wired Internet traffic which is the majority of the Internet traffic. We classified based on traffic types and estimated their impacts from the viewpoint of greening.

In this work, we limited network equipment to enterprise switching equipment which account for the majority of energy consumption of access networks and used the forecast in 2016 in [16]. Also, with reference to a power benchmarking for network devices in [15][17][18], we supposed that a switch has a line card with 48 full-duplex 1Gbps ports and it consumes average 3.3mWatts/1Mbps when it transmits at fully load with the aggregate bandwidth of 48000Mbps.

In (5), $\boldsymbol{E_{en}}$ is the total enterprise switching equipment’s energy consumption and Se is the share of it in the total access

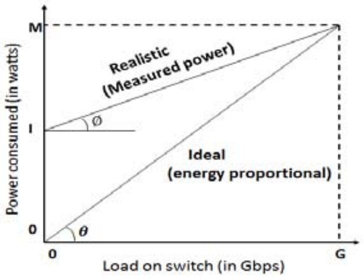


Fig. 10. Ideal and realistic power characteristic of network equipment

network equipment, therefore $1 - Se - r$ is a share of the residential customer premises equipment (r is a share of routers, security appliances, WLAN and etc. of the enterprise network devices and it is about 15% in 2008 [14]). We assumed that S_e is assumed about 40% by section III. T is the amount of the traffic generated per hour and E_{MB} is the energy consumption per megabyte. p is the energy proportionality formed by Fig. 10.

$$E_{en} = T \times E_{MB} \times S_e \times \frac{1}{p} \qquad (5)$$

$$= \left(\frac{MB\ per\ Month}{30\ days \times 24\ hours}\right) \times 0.003Wh \times 0.4 \times \frac{\tan\theta}{\tan\phi}$$

$$G_{en} = E_{en} \times g_{kwh} \qquad (6)$$

Fig. 10 shows the power consumed by network equipment against the load on it with a maximum load of **G** bps. Ideally, the power consumed should be proportional to the load, with the maximum power, M watts, being as low as possible. In practice however, the behaviour of network equipment follow the line marked realistic, with the equipment consuming ***I*** watts even under idle (no load) conditions. Thus, p is the difference between the ideal and measured lines in Fig. 10 and we defined as $p = \frac{\tan\phi}{\tan\theta}$. In here, θ and ϕ are angles at the origin for the ideal and measured power. $p = 1$ implies that the equipment has perfect energy proportionality, and $p = 0$ implies that the energy consumed by the equipment is completely agnostic to offered load.

In (6), G_{en} is the amount of CO_2 emission for processing the traffic and g_{kWh} is the CO_2 emission per kWh and 0.524lb [19].

We estimated the global energy consumption on switches against the energy proportionality (p) by (5), as shown in Fig. 11. The more p approaches to 1, the more the energy consumption decreases and it drops sharply by $p = 0.2$. Although energy efficiency improves lightly, it can achieve much energy saving. Based on traffic types, we also estimated impacts on the total switches in enterprise network by (5) and (6) (Fig. 12 and Fig. 13). As shown Fig.12 and Fig 13, the Internet video traffic is critical for greening network. When the energy proportionality drops below 0.2, energy consumption and GHG emission of it have strong impacts on network.

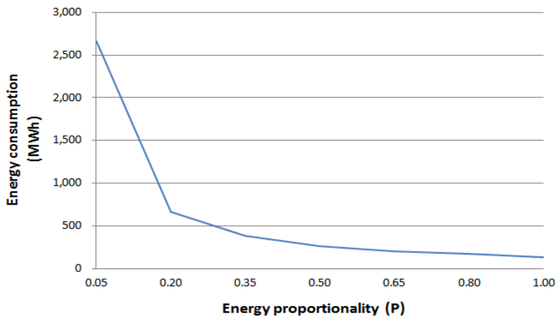


Fig. 11. Energy Consumption against Energy Proportionality on Switching Equipment

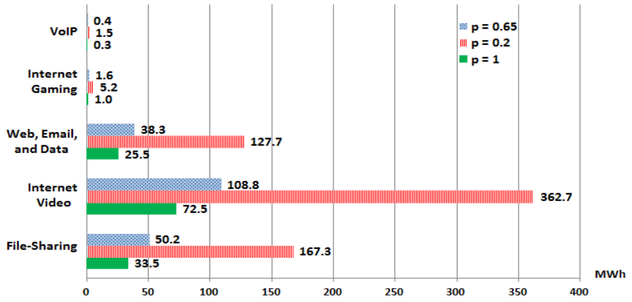


Fig. 12. Energy Impacts of Traffic Types on Switching Equipment

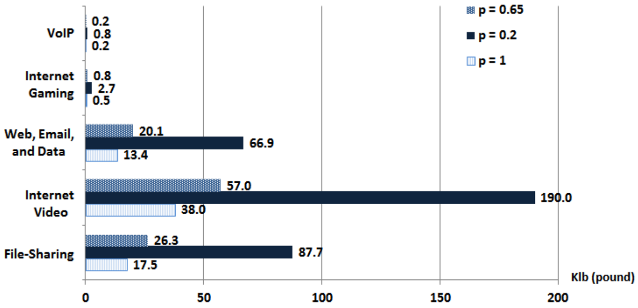


Fig. 13. GHG Impacts of Traffic Types on Switching Equipment

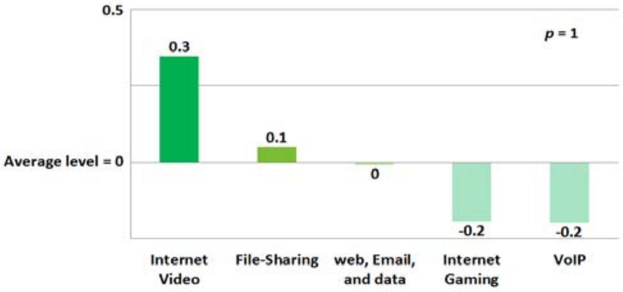


Fig. 14. The greening impacts based on traffic type

We normalized the greening impacts in Fig 14 on a basis of Fig. 12 and Fig 13. In Fig. 14, we set the average level is 0 at average traffic volume and each figures are the relative values of it. Internet traffic is possible to be more specifically distinguished to application-level classification by IP address, port number, connection duration, packet size, packet arrival time, and others, and they can be classified by aspects of energy efficiency as Fig. 12, Fig. 13, and Fig 14. This view is possible to classify with more sophisticated green QoS levels based on traffic type.

As we have said above, the traditional Internet has large energy savings potential and this field remains to be challenged a lot. A major shift is truly needed in research and development to introduce energy-awareness in the network design, without compromising either the QoS or the network reliability. The ultimate goal of networking is to provide services to end-users, so the quality of the user experience is topics that span all branches of the green networking. So, the energy gain from energy efficiency techniques must not come at the price of a network performance loss.

However this delicate tradeoff arises from opposite principles: networked systems have traditionally been designed and dimensioned according to principles such as over-provisioning and redundancy, green networking approaches praise opposite practices such as resource consolidation and selective connectedness. The challenge lays in this case in applying the latter principles in a way that is as transparent as possible to the user. Most of the previous green studies focused more on the achievable energy gain, and QoS has at least partly been taken into account. Furthermore they have been studied in isolation and that could constitute serious threats to the QoS. Also, the studies and the developments related to green networking have been concentrated on controlling interface on Layer 2.

The techniques based on L2 such as EEE need more delicate synchronization mechanism for link termination and they have to take the trade-off between QoS and energy savings into consideration. Additionally, diverse transitional techniques will have been required until the current network equipment is completely replaced with the green network equipment.

In terms of these, the estimated data in Fig. 12, Fig. 13, and Fig 14 can be used as knowledge for building energy efficient virtual network. As an example, they can be available to build VLANs, which provide logical segmentation based on broadcast domains so reduce unnecessary traffic, improve network performance and offer independency of network. VLAN supports 8 levels as 802.1Q [26] tag user priority level for QoS. These priority levels are possible to be changed by management policy, so they could be classified under the green priority levels including information such as energy consumption, CO2 emissions and costs of network equipment based on traffic types. Traffic could be processed by the levels and the network resource could be allocated by them. If VLANs are mapped by sorts of applications, using mapping based on protocol types, it is possible to make policies by green levels such as Fig 12, Fig 13 and Fig 14, and dynamically build and manage networks by green factors.

Moreover, the above traffic classification based on energy efficiency can help the current green techniques with the dynamic adaptation approaches involving only local decisions make precisional decisions and predictions, as aware of information about patterns and loads of traffic and it can support sophisticated energy management by using knowledge in an aspect of QoS. This approach is possible to introduce to building virtual networks at global level because of Ethernet which has extended to backbone network. We remain to develop specifically advanced these in the long term.

V. CONCLUSION

In this paper, we analyzed impacts of data network equipment for the green Internet and presented future works for the green networking. For this work, we introduced motivation and background of the concern about greening the Internet in view points of energy resource and also presented importance and reasonability of study on energy efficiency of data network equipment. Moreover, we explored detailed energy consumption and savings potential of data network equipment by top-down approach. Then, we stated the current research trends for the green networking and presented limitations in aspects of the quality-of-service (QoS) and a lack of the global view point in them. In this context, we further estimates impacts of data network equipment depending on traffic types and proposed directions for future works related to our estimates. So far, the studies of energy efficiency in the green networking field have focused on dimensioning discreetly components in hardware or controlling network interface by local decision. Moreover few works exist from the global viewpoint which have based on network topology and traffic characteristic. Our traffic classification based on energy efficiency is possible to treat more sophisticatedly trade-off between energy efficiency and QoS. Also these could help precise decisions and predictions of existing green techniques as using the knowledge in an aspect of QoS. Further, this classification can be used in building L2/L3 virtual networks considering for both energy efficiency and QoS. For this work, we need to undertake more precise measurement and modeling, and they remain as our future works.

Greening the Internet is inevitable due to with the energy depletion and environmental threats. Therefore, the green networking solution should be transparent to users and be undertaken to do more elaborate works for QoS support. It should also be developed with a comprehensive view at both local and global - which opens a number of interesting questions that are so far all unexplored.

REFERENCES

[1] A.P. Bianzino, C. Chaudet, D. Rossi, J.-L. Rougier, “A Survey of Green Networking Research”, *IEEE Communications Surveys & Tutorials,* VOL. 14, NO. 1, pp.3-20, Jan., 2012.

[2] IEA, “Energy Technology Perspectives 2012”, 2012.

[3] B. Nordman “What the Real World Tells Us about Saving Energy in Electronics”, presentation, at the 1st Berkeley Symposium on Energy Efficient Electronic Systems(E3S), Jun. 11, 2009.

[4] European Commission DG INFSO, “Impacts of Information and Communication Technologies on Energy Efficiency,” final report, Sep. 2008.

[5] GeSI(Global e-Sustainability Initiative), “SMARTer2020: The Role of ICT in Driving a Sustainable Future”, Dec. 2012.

[6] IPCC(the Intergovernmental Panel on Climate Change),.“2007: Climate Change 2007: Mitigation”.

[7] BIO Intelligence, “Estimate of energy wasted by network-connected equipment Final Report”, Jun., 2011.

[8] R. Bolla, R. Bruschi, F. Davoli, F. Cucchietti, “Energy Efficiency in the Future Internet: A Survey of Existing Approaches and Trends in Energy-Aware Fixed Network Infrastructures”, *IEEE Communications Surveys & Tutorials,* VOL. 13 , NO. 2, pp. 223 – 244, May., 2011.

[9] M. Gupta, S. Sigh, “Greening of the Internet”, in Proc. *The ACM conference on Applications, technologies, architectures, and protocols for computer communications (SIGCOMM '03),* Karsrhue, Germany, pp. 19-26, Aug., 2003.

[10] L. A. Barroso and U. H¨olzle, “The Case for Energy-Proportional Computing,” *IEEE Computer*, vol. 40, pp. 33 – 37, Dec. 2007.

[11] IEA, “ electricity Information 2012”, 2012.

[12] The United States in consultation with MEF Partners, “Technology Action Plan Buildings Sector Energy Efficiency”, Dec., 2009.

[13] ITU “Measuring the Information Society 2012”, 2012.

[14] Lawrence Berkeley National Laboratory, “Data Network Equipment Energy Use and Savings Potential in Buildings”, 2010 ACEEE Summer Study on Energy Efficiency in Buildings, Jun., 2010.

[15] Hewlett-Packard Development Company, “Energy Efficient Networking Business white paper”, May, 2011.

[16] Cisco, “Cisco Visual Networking Index: Forecast and Methodology, 2011-2016”, May,. 2012.

[17] P. Mahadevan, P. Sharma, S. Banerjee, P. Ranganathan, “A Power Benchmarking Framework for Network Devices”, *LNCS*, Vol.5550, *(in proc. IFIP International Federation for Information Processing 200*9) pp.795–808, 2009.

[18] GeSI, “Fixed Network Operators Energy Efficiency Benchmark”, Mar., 2012.

[19] Cisco White Paper, “Cisco Ethernet Power Study of Cisco and Competitive Products”, 2008.

[20] K. Hooghe, M. Guenach, “Towards energy-efficient packet processing in access nodes”, in Proc. *Global Telecommunications Conference (GLOBECOM 2011),* Houston, Texas, USA, pp. 1 – 6, Dec., 2011.

[21] P. Reviriego, J.A. Maestro, J.A. P. Hernández, D. Larrabeiti, “Burst Transmission for Energy-Efficient Ethernet”, *IEEE Internet Computing,* Vol 14, No. 4, pp.50-57, Jul.-Aug., 2010.

[22] K. He, Y. Wang, X. Wang, W. Meng, B. Liu, “GreenVLAN : An Energy-Efficient Approach for VLAN Design”, in proc. *Computing, Networking and Communications (ICNC 2012),* pp. 522-526, Jan. 30 - Feb. 2, 2012.

[23] US Energy Information Administration, Electricity Supply, Disposition, Prices and Emisssions, AEO 2012 Reference case. Available : http://www.eia.gov/oiaf/aeo/tablebrowser/#release=AEO2014ER&subject=0-AEO2014ER&table=3-AEO2014ER&region=1-0&cases=full2013-d102312a,ref1914er-d102413a

[24] World Nuclear News. Is there life after sixty? Available: http://www.world-nuclear-news.org/RS_Is_540there_life_after_sixty_0302121.html

[25] IEEE P802.3az Energy e_cient Ethernet task force. Available : http://www.ieee802.org/3/az/index.html.

[26] WG802.1 - Higher Layer LAN Protocols Working Group. Available : http://standards.ieee.org/findstds/standard/802.1Q-2011.html.

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