

A Study on Energy Savings Potential of Data Network Equipment for a Green Internet

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Abstract— A 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 on aspect of energy consumption. Secondly, we estimate energy consumption 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 QoS. Lastly, we propose the future works for green networking from the perspective of QoS.

Keywords— energy efficiency, green networking, QoS, wired network equipment

I. INTRODUCTION

Today, the Internet has been expended quickly but growing greenhouse gas emissions and electrical requirements from it has become key factors of limiting its expansion. To overcome these problems, greening of the Internet has begun to be studied with the goal of improving energy efficiency of the current Internet, and that is now a real challenge for the world's industries and governments for the future internet.

The number of current used electronics is enormous and most of them provide network connectivity. As home network grows, appliances also tend embed computing and networking functionalities. Besides, mobile devices are fastest-growing and network connectivity has become nearly ubiquitous, thus total energy consumption of network is forecasted to increase significantly. Even though there have existed various approaches to edge devices like end-user computers and data-centers, which found on energy-saving mechanisms and power management criteria, the current trend is moving a focus to greatly increased energy consumption associated with network functionality due to increasing IP traffic from excess network-connectivity. A common opinion among networking researchers is that for boosting the network energy efficiency, wired data network must add energy managing mechanisms by exploiting network-specific features like ad-hoc network

that explicitly manages energy saving. These issues usually referred to as **green networking**.

Network connectivity has become a part of daily life, but a volume of energy that is used to provide it is largely unknown. In particular, the aggregate energy consumption of wired data network equipment that offers primarily such functionality is more so. There are few reliable and practical figures of energy consumption and energy savings potential of wired data network equipment. Researchers' interest in them is less than wireless network, so researchers often even overlook their importance.

The Internet relies very strongly on electronics. As the Internet has extended, the future Internet might eventually be constrained by energy density limitations rather than by the bandwidth of the physical components. But, a subtle trade-off between energy saving and performance exists. Therefore, energy efficiency must be treated together with increasingly diversified demands of services and sophisticated 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 from top-down studying. 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 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.

II. BACKGROUND & MOTIVATION

Today, the reduction of energy consumption is the world's major concern. This concern has a strong influence on electronics designers and the ICT (Information and Communication) sector, and more specifically the networking field is also concerned. Residential and commercial buildings account for approximately 32% of global energy use and almost 10% of total direct energy-related CO₂ emissions. Energy demands from the buildings sector will be more than

double by 2050 [1]. Much of this growth is fuelled by the rising number of residential and commercial buildings in response to the expanding global population.

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 [2]), as shown in Figure 1, buildings accounts for over 70% of the total electricity consumption in 2006, and electronics account for about 11% of building electricity use. Electricity consumption of network-connected equipment forms about 52% of electronics and about 0.6~0.7% of the total buildings'.

[2] 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 Figure 2. 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 Figure 2 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).

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 hasn't. In this paper, we therefore discuss relatively unknown energy consumption and savings potential by wired data network equipment.

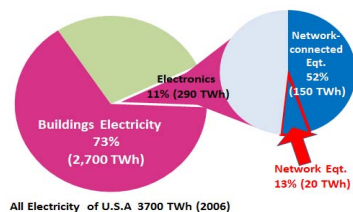


Figure 1. Electricity consumption of the USA (2006), source : [3]

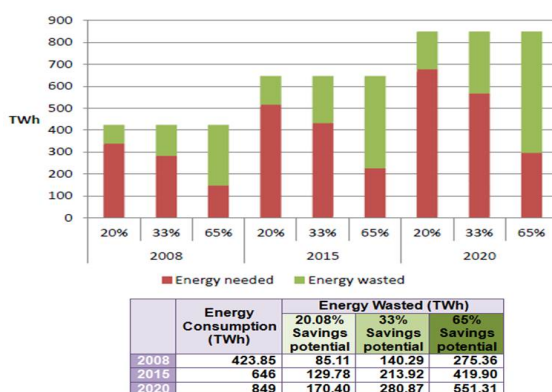


Figure 2. Projected energy consumption and wasted by network-connected equipment worldwide, source : [2]

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.

Figure 3 shows the typical access, metro and core device density and energy requirements in today's typical networks.

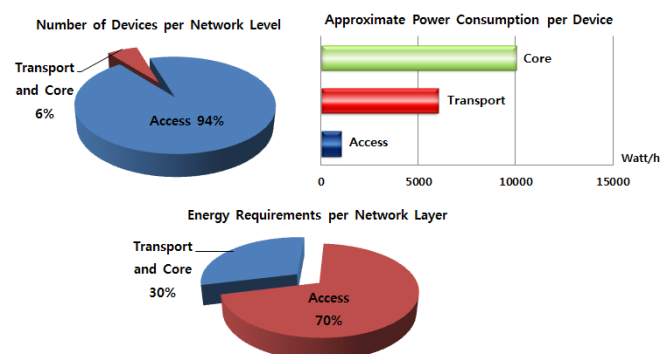


Figure 3. Typical access, metro and core device density and energy requirements in today's typical networks deployed by telcos, source : [4]

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 [1], B_i is the share of buildings in the total electricity of a country [6], 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.

$$E_{g_ne} = \sum_{i=1}^n E_{ne_i} \quad (1)$$

$$E_{ne_i} = E_i \times B_i \times N \times w_i \quad (2)$$

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

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 [7]. 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, which accounts for the largest amount of the world's electricity use.

Therefore the energy consumption of network equipment is :

$$E_{ne} = \sum_{i=1}^n (E_i \times B_i \times N \times I_{sb_i} \times \frac{1}{I_{sb_{us}}}) \quad (4)$$

The results are shown in Figure 4. 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 [19]) 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 [8] (an average life of a nuclear reactor is 40~60 years [20]). As shown in Figure 4, 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 Figure 2. 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 have 20% and 65% energy savings potential (as the lower and upper limit) over BAU.

As shown in Figure 4, 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 [1]) 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) [5] 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 [5]) of energy use in the global access network. As a typical case, According to the energy use distribution in

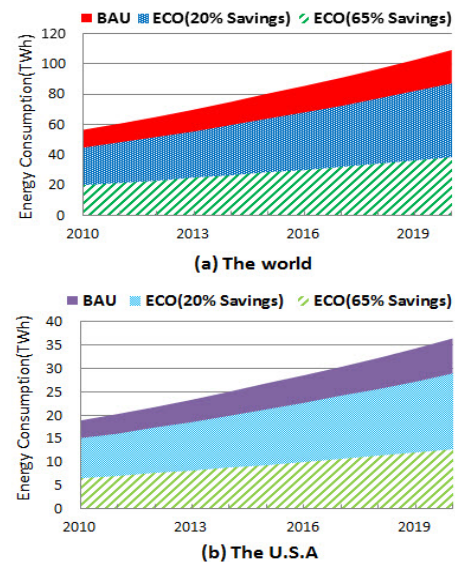


Figure 4. The energy consumption and costs by access network equipment

Berkeley campus LAN reported by LBNL [5], 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 [9], typically, 60 % of power consumption in networking equipment is associated with packet-processing part and packet-processing support part such as memories (DRAM (Dynamic Random Access Memory) and TCAM (Ternary Content Access Memory). Figure 5 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 doesn't 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 doesn't 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, EEE (Energy Efficiency Ethernet [21]) of ALR (Adaptive Link Rate) 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. But green approaches of resource consolidation and selective connectedness are required more sophisticated mechanisms in terms of QoS. The current green networking techniques have hardly taken into account QoS.

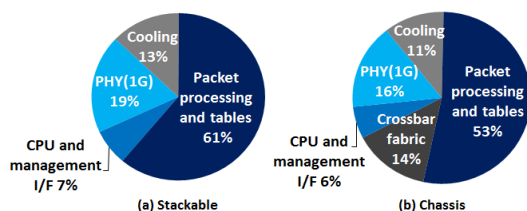


Figure 5. Typical switch power allocation , source : [9]

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.

For this approach, we made an effort to look specifically impacts on network equipment based on Traffic types. According to [10], annual global IP traffic is forecasted to surpass the zettabyte threshold by the end of 2016. In 2016, global IP traffic will reach 1.3 zettabytes per year or 110.3 exabytes per month. As a result, in 2016, global IP networks will deliver 12.5 petabytes every 5 minutes and IP traffic per capita will reach 15 gigabytes per capita, up from 4 gigabytes per capita in 2011.

Figure 6 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 and they 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.

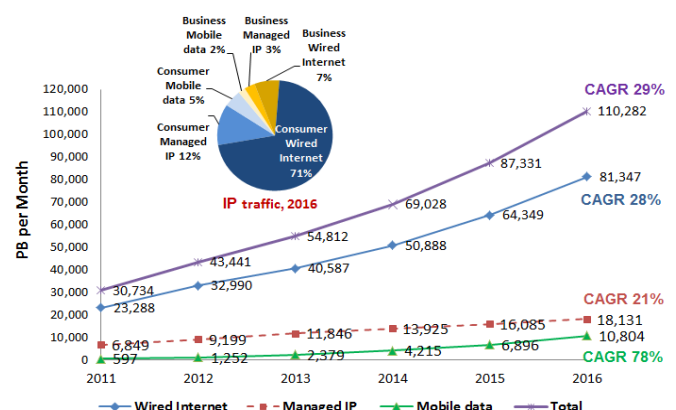


Figure 6. Global IP traffic, 2011-2016, source : [10]

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 [10]. Also, with reference to a power benchmarking for network devices in [11][12][13], 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 (1), E_{en} is the total enterprise switching equipment's energy consumption and S_e is the share of it in the total access network equipment, therefore $1 - S_e - r$ 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 [5]). 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 MB. p is the energy proportionality formed by Figure 7.

Figure 7 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 behavior 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 Figure 7 and we defined as $p = \frac{\tan \theta}{\tan \phi}$. 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.

We estimated impacts on the total switches in enterprise network based on traffic types by (5) and the results are

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

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

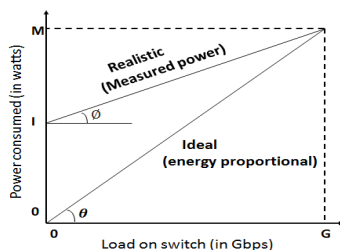


Figure 7. Ideal and realistic power characteristic of network equipment

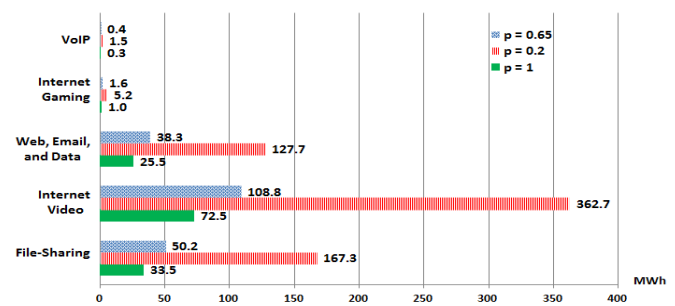


Figure 8. Impacts of Traffic Types on Switching Equipment

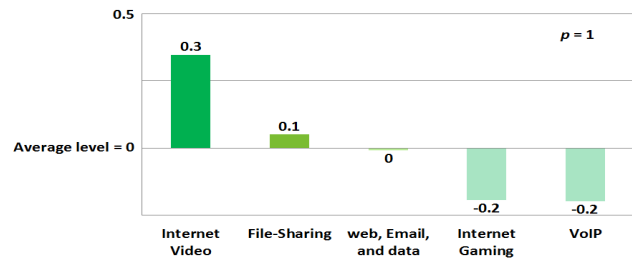


Figure 9. The greening impacts based on traffic type

presented in Figure 8. Also, we normalized as shown in Figure 9 on a basis of Figure 8. In Figure 9, 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 Figure 8 and Figure 9. This view is possible to classify with more sophisticated green QoS levels based on traffic type. The current green approaches by the dynamic adaptation involve only local decisions. The classified green information based on energy efficiency could help them make precisional decisions and predictions about network state and idle/sleep modes, as aware of information about patterns and loads of traffic. Thus, it could support sophisticated energy management by using knowledge in an aspect of QoS. Moreover this could be used to build an energy efficient virtual network by inserting in L2 or L3 header of PDU. This approach could also introduce to building virtual networks at global level because Ethernet 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 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.

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REFERENCES

- [1] IEA, "Energy Technology Perspectives 2012", 2012.
- [2] BIO Intelligence, "Estimate of energy wasted by network-connected equipment Final Report", Jun., 2011.
- [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] 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.
- [5] 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.
- [6] The United States in consultation with MEF Partners, "Technology Action Plan Buildings Sector Energy Efficiency", Dec., 2009.
- [7] ITU "Measuring the Information Society 2012", 2012.
- [8] 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.
- [9] Hewlett-Packard Development Company, "Energy Efficient Networking Business white paper", May, 2011.
- [10] Cisco, "Cisco Visual Networking Index: Forecast and Methodology, 2011-2016", May., 2012.
- [11] 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 2009) pp.795-808, 2009.

- [12] GeSI, "Fixed Network Operators Energy Efficiency Benchmark", Mar., 2012.
- [13] Cisco White Paper, "Cisco Ethernet Power Study of Cisco and Competitive Products", 2008.
- [14] EC DG INFSO, "Impacts of Information and Communication Technologies on Energy Efficiency", final report, Sept., 2008.
- [15] 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.
- [16] 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.
- [17] 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.
- [18] 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.
- [19] U.S. EIA website : <http://www.eia.gov/oiaf/aeo/tablebrowser/#release=AEO2013&subject=0-AEO2013&table=8-AEO2013®ion=0-0&cases=ref2013-d102312a>, Electricity Supply, Disposition, Prices and Emissions, AEO 2012 Reference case
- [20] Website: http://www.world-nuclear-news.org/RS_Is_there_life_after_sixty_0302121.html
- [21] IEEE P802.3az Energy Efficient Ethernet Task Force <http://www.ieee802.org/3/az/index.html>



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