Energy Consumption Targets for Network Systems

Tohru Asami(1), Shu Namiki(2)
1 :The University of Tokyo, 7-3-1 Hongo Bunkyo-ku, Tokyo 113-8656, Japan, asami@akg.t.u-tokyo.ac.jp
2 : National Institute of Advanced Industrial Science and Technology, shu.namiki@aist.go.jp

Abstract

Followed by related development activities in Japan, a comprehensive investigation on energy consumption in ITC industry is presented. Photonic network will have more important roles in mobile networks than in fixed networks.

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Introduction

Engineering is a kind of optimization under some boundary conditions. It is obvious that the most important optimization measure in telecom industry has been changed from speed to energy or power consumption. Figure 1 shows the energy consumption by various industry segments compared to 1990, redrawn according to the data provided from Agency for Natural Resources and Energy, Japan [1]. The energy consumption of the telecom and broadcasting segment became 2.7 times larger in 2006 than in 1990. It also shows that the increase ratio in consumption tends to be particularly high when new services such as ISP service, i-mode, etc. had been introduced. There are two other segments with high increase ratios, i.e. homes and offices, which is obviously due to the rapid penetration of office automation and information appliances such as PCs for the previous decade. Thus, a preemptive reduction of power consumption prior to the introduction of a new service will be one of the most critical issues in order to get rid of a potential gas guzzler in next decade. It is also important to realize the so-called "ICT-controlled" energy consumption in all the segments of our society.

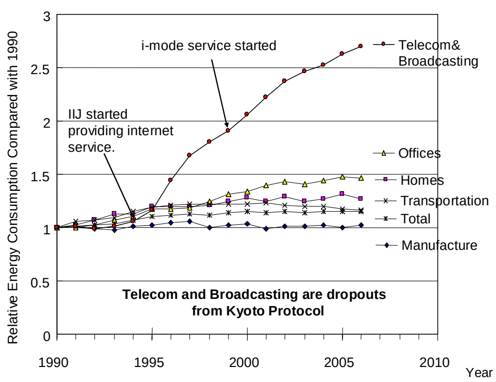

Figure 1: Warning by Agency for Natural Resources and Energy, Japan[1]

T. Aoyama listed eight measures under the project called 'AKARI' or 'New Generation Network (NWGN)' conducted by NiCT (National Institute of Information and Communications Technology) [2]. The eight measures are: Switching and Transmission Capacity, Power Consumption, Ubiquity, Mobility Support, Connectivity for Versatile Appliances, Security, Reliability and Social Safety. On the other hand, the project "Development of Next-generation High-efficiency Network Device Technology" launched last year by NEDO (New Energy and Industrial Technology Development Organization, Japan) is the first one in this organization, targeting the power consumption issue in the network-related technology area [3]. This paper presents the targets of energy consumptions in the ICT segment for 2030s and the areas of photonic technologies to be applied, part of which were comprehensively discussed by a panel of SAINT 2008 as we shall reference in due course. We also review the NEDO project mentioned above.

Possible targets and technologies of ICT industry in 2030s

NTT Corp. announces their annual electrical power consumption and their target in 2010. According to their data, the power consumption has been increasing annually by 5% since 1999 and is expected to reach 30 TWh in 2030 [4]. The consumption 8.7 TWh in 2006 is 2.6 times larger than that in 1990, 3.4 TWh [5]. To suppress the consumption in 2010 comparable to that in 1990, NTT focuses upon 2 approaches: DC power supply in their network centres to reduce conversion loss, and independent power generation to reduce large transmission loss on power lines. The former contributes to a 20% reduction of the overall consumption, and there is still room to improve within the range of 10%. They consider the further power reduction since Internet traffic is still increasing, and they think that optical technology is effective for metro/core networks and also that advanced CMOS technology is effective for metro/core edge routers.

Many reports say that the data centres consume a large portion of power used in the internet or other fixed network services. Among them, 50% is for cooling, 25% for servers and storages, 10% for conversion losses and 12% for networks [6]. The energy efficiency of a data centre is measured by

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PUE (Power Usage Effectiveness), which is defined as *PUE=Total Consumption/ICT Consumption*. PUE in this case is 2.7, whereas PUE of the NTT data centres is 1.7 and announced to be reduced to 1.4 [7].

Compared with the other service equipment 'servers and storages,' the contribution of networks is about half. But it is noted that the power reduction of network proportionally contributes to that of cooling since one third of the total power consumption for cooling is consumed by networks.

Energy harvesting or power scavenging technologies are very important as sustainable battery resources for sensor networks [8]. In [8], low-cost paper-based inkjet-printed RF modules with 3D "cubic" antenna scavengers are introduced. This technology has another importance which will contribute to the total energy reduction. That is, they can be also considered as novel cooling methods, which absorb a part of thermal energy, acoustic energy and also electromagnetic energy that are radiating into the environments wastefully. Thus it increases the energy efficiency to a significant extent.

The segment of mobile network service shows a different profile of power consumption, where the consumption of all the mobile terminals is 1/150 of that of the network [9]. The main consumers in this case are not data centres, which consume only 3% of the total consumption, but Radio Access Networks (RAN), which consume 70-80% of the total electricity. Another report from China Mobile says that their data centres consume only 6% of the total 7,890 GWh in 2007 [10]. The efficiency of data transmission is described with Byte/Power Efficiency Measure, which is 20 Kbyte/Wh for the current technology [9]. The higher volume or speed of communications requires more energy. According to Huawei Technologies, low power consumption base stations can reduce 50% of their current consumption with two approaches: (1) high efficiency transmission scheduling algorithm to reduce more than 60% of the static power consumption, and (2) enhanced Doherty based power amplifier whose efficiency has changed from 33% in 2007 to 50% in 2008 [11]. The further reduction comes from Radio on Fiber and smaller cell size. Thus enhanced photonic technologies can contribute greatly to the energy reduction of RAN. After getting less-than 750W base stations, they can run with green energy (e.g. solar, wind).

The reduction of home appliances, where dynamic power management is commonly used, is considered from two different aspects, operation and stand-by. Panasonic (Matsushita Electric Industrial Co., Ltd.) tries to reduce the consumption of BD recorder below 60W. In their products, system LSI consumes 20% of power in operation and 50% in stand-by [12]. The reduction of the latter case is more significant since appliances connected to home network are almost always in this mode. Their project Lifinity ECO system with ultra-thin and small sized current sensor (20-30mm) can measure the electric current and power consumption of each electric branch (by room, or by each appliance). To get a good energy saving result, the family members should be involved in the energy reduction activity through (1) Visualization of electricity of each appliance, (2) Easy and enjoyable Eco-life by animation (By penguin animation, displaying the result of eco-life and advises in control panel and/or TV) and (3) Easy check and control functions.

As for the energy efficiency in router or switching systems, the normalized system energy consumption, E_{CR} , is defined as a function of installed components or units to the actual full-duplex throughput [13].

$$E_{CR} = \frac{\sum_{i \in I} C(i)}{T}$$

where $C(i)$, *I* and *T* are the power rating of a router's component *i*, the set of all components in configuration and the system's capacity (full-duplex) respectively. The unit of E_{CR} is typically watts/Gbps. E_{ER}, the inverse of E_{CR}, shows energy efficiency or available packet processing speed at a fixed power budget, and is expressed in Gbps/Watt. According to the routers of Juniper Networks, Inc., the inverse E_{ER} has been improved from 13 Gbps/KW in 1998 to 96 Gbps/KW in 2007.

Despite of dynamic power management, the general-purpose CPU-based implementation requires $E_{CR} = 400 - 800$ Watts/10Gbps, whereas a custom LSI-base implementation shows higher energy efficiency. They say E_{CR} in IP/MPLS routing by T1600 fulfils 94 Watts/Gbps, which is an order of magnitude better than the former implementation. The simpler and the faster a packet forwarding silicon is, the better energy efficiency comes on. This means the deduction of unnecessary protocols and capabilities from(?) routers/switches is important for the energy reduction.

The topological analysis on networks and the functionalities of routers/switches will contribute to find these redundancies. A physical network is similar to a tree or at least an augmented tree. (1)Circuits are spanning from a TELCO office to offices or homes. This topology is a star. (2) Communication traffic is proportional to economic activity. This makes a star topology from a central city to leaf towns or villages in the target area. These central cities or prefectural capitals are also connected to the capital Tokyo as a star topology. (3) The construction cost of fibre cable does not depend on the number of fibres in it since other costs are far more expensive. Using existing fibre lines via Tokyo may be more inexpensive than the construction of the new direct cables to neighbour cities. (4) Any cable must be constructed along roads or rail ways which reflect the economic relations among cities. Thus the construction is physically restricted.

There is another tree in the Internet business, i.e. one consisting of tier 1, 2, 3, etc. internet service providers (ISPs). Communication among users in remote tier 3 ISPs must be done via intermediate tier 1 and 2 ISPs. According to this physical topology of network, the current router routing may provide us excess functions.

They add emphasis to that prefix tree-based lookup is more efficient than TCAM which is a huge power-eater but predominant in this market.

Development of Next-generation High-efficiency Network Device Technology

"Development of Next-generation High-efficiency Network Device Technology" is a project from 2007 to 2011, launched by The New Energy and Industrial Technology Development Organization (NEDO) of Japan [14]. The previous discussion says that the photonic network technology is important to metro/core network including RANs and that advanced CMOS technology is effective for metro/core edge routers. Consequently the main purpose is to develop optical/electronics device technology and related integration technology, packaging technology, and systemization technology required by next generation high-efficient networks.

The driving force of the increase of internet traffic has been video content transfers such as P2P and YouTube for the last decade. These are CGM (Consumer Generated Media) with the state-of-the-art technology and their available technology is now moving toward more high-definition. NHK is conducting the development of Super Hi-Vision, SHV [15], which will be commercially introduced in 2020s as a successor of the currently newest HDTV. SHV has a resolution of 7,680 × 4,320 pixels which has 16 times more information than HDTV (1920 × 1080 pixels). Because of its large bandwidth, it will be very unlikely to broadcast all the TV channels via only wireless media, and the photonic network is more promising as the transfer media for these contents. For the energy consumption, a photonic router plays an important role [16]. But in this case, guaranteeing the bandwidth is crucial, and it is obvious that circuit-switching is more suitable, which is the background assumption for the development of 'Dynamic Optical Path-Switching (DOPS)'[17]. DOPS optical paths are dynamically provisioned by end users. They show that a 256x256 MEMS switch consumes less than 100 Watts, which is four orders of magnitude better than that of an router with equivalent 82Tbps throughput.

The fundamental technologies enabling DOPS are categorized into (1) High capacity optical network interface card (NIC) for end users and (2) Optical path processing and (3) conditioning. The NEDO project focuses on the development of power efficient 172Gbps integrated OTDM (Optical Time Division Multiplexing) NICs as shown in Figure 2. Also, a new class of optical tunable dispersion compensation (OTDC) as a key enabling technology for (3) optical path conditioning is studied by one of the authors, in which optical parametric processes are exploited with dispersive media to attain wider and seamless operating bandwidths and faster response time [18].

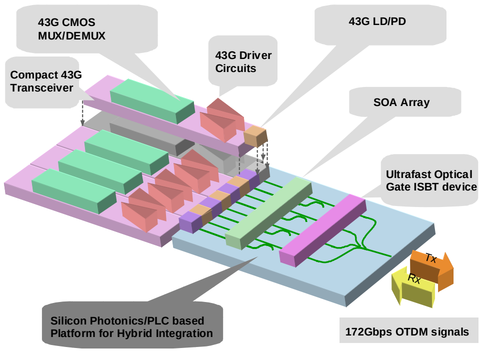

Figure 2: 172Gbps OTDM NIC[17]

The other main target of NEDO project is to realize low power consumption edge routers for next-generation networks, with particular emphases on traffic monitoring, analysis and management for 40Gbps/ch throughput of services. Considering the number of edge routers are 2 or 3 orders of magnitude larger than that of core routers, and that they are used to provide value-added services, they are more important than core routers to carriers and Internet Service Providers (ISPs). To construct scalable router architecture adaptable up to 10Tbps throughput, the speedup of internal communication links is required to connect functional modules or devices. They propose optical backplane to connect the electronic devices, which enables a high-speed and power efficient data transmission in backplane of routers and switches [19]. They estimate around 20% improvement of power efficiency. Furthermore traffic management is important for energy saving as well as for traditional QoS control, traffic monitoring and analysis technology are also investigated in this project.

There are two approaches to improve the power efficiency of electronic circuits, which are important to design the next generation Ethernet or equivalents. The first one is the advanced CMOS process technology. Circuit design technique is also investigated to support 40Gbps/ch operations [20]. Another possible solution is superconductive single flux quantum (SFQ) circuit. It is shown to operate at a more than 100-GHz clock frequency with less than 1µW power consumption per gate. The current targeted application of the SFQ circuit is a real-time oscilloscope, since it is indispensable for future network monitoring. A new SFQ ADC (Analog to Digital Converter) was confirmed, through computer simulations, to have a sampling clock rate higher than 150 GS/s without any interleaves [21]. Including cryo-cooler, the power dissipation of SFQ fabric card for 100 Tbps router is reported as 10 kW, which is significantly smaller than 1.27 MW of CISCO CRS-1 with 92 Tbps throughput connecting 72 line card chassis (LCC) and 8 fabric card chassis (FCC).

Conclusions

This paper introduced possibilities of the photonic network technology in fixed and mobile network services and a brief summary of the related NEDO project. As for the contribution to the energy reduction, the photonic network technology contributes more to wireless networks or RANs than to fixed networks or data centres. A part of this work belongs to “Next-generation High efficiency Network Device Project,“ which OITDA contracted with NEDO.

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