Challenges for the future networks and enabling photonic technologies

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Abstract
This talk will provide a high-level overview to redress the value of photonic technologies in the context of the looming energy issues, suggesting the potential of dynamic optical path switching along with enabling technologies.

Introduction
A set of pertinent statistics from Japan shows that serious limitations of the energy consumption of IP routers will loom and prevent the current network technologies from scaling up their capacity to the constantly increasing network traffic. Figure 1 tells the whole story: the total electricity consumption of entire IP routers in Japan was investigated in 2006. It amounted to approximately 1 % of Japan's total electricity supply without taking into account the power for air-conditioning, and actually increased by 10 times since 2001 while the Internet traffic was also increased by more than 10 times. Likewise, a simple extrapolation of the energy consumption growth due to the traffic growth in future would exceed the total energy supply of Japan soon or later.

Looking back on the technological evolutions of electronic devices over the past decade, the single-device performance improvement was reaching its fundamental limit, and thus parallel processing has been adopted to sustain the Moore's law. For the next decade to come, the conventional parallelism may not be able to sustain the growth due to both the architecture and energy limitations.

Recently, we have pointed out the potential of the 'dynamic optical path-switching (DOPS)' as the most energy-efficient network scheme to handle huge data transfers [1]. DOPS is used here as a general term representing any possible technology to realize a fast circuit switching optical network that is suitable for providing high-bandwidth video-related services with ultra-low energy consumption. As discussed in detail in [1], DOPS is meant be deployed in an independent manner on top of the current IP networks, such that huge data transfers associated with the high-definition video services will not go through energy-consuming IP switches. Instead, the data is kept purely in optical domain as much as possible from one end-user to another. In so doing, we could save a huge amount of computation power of entire L2/L3 switches. However, of course, technologies breakthroughs for various optical devices and/or sub-systems will be necessary to make DOPS practical and attractive for market.

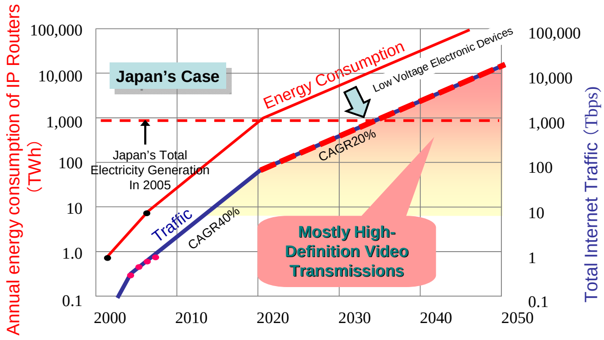

Fig. 1. Projected energy consumption of IP routers along with Internet traffic in Japan. Plots are based on the surveys by Japanese Government.

Challenges toward DOPS and VICTORIES project
Once given the optical devices / subsystems breakthroughs, upper-layer network technologies have to make use of them. In order for the upper-layers to better utilize optical technologies as possible, new network architecture has to be sought on a clean-slate basis, while optical technologies have to be developed vice versa so as to be suitably used in such a network. This process inevitably suffers from the chicken-egg dilemma, completely isolated from market needs. Particularly, the motivation for energy savings is on a different axis from business activities, while on the other hand, the looming energy issue will eventually force the telecom industry to turn the axis. In this regard, the innovation toward truly energy-saving DOPS will not occur until government and/or academia will take an initiative. And it is also true that a proactive approach, rather than market-driven, is essential to prevent the forthcoming bandwidth crunch due to such energy limitations. This talk briefly exmplifies a project called 'VICTORIES: Vertically Integrated Center for Optical Routing toward Ideal Energy Savings", recently launched by the authors' Institute in collaboration with key telecom companies under support from Special Coordination Funds for Promoting Science and Technology of Ministry of Education, Culture, Sports, Science and Technology, Japan [2].

Enabling photonic technologies

Having said that DOPS is promising, though, the enabling photonic technologies have yet to be identified and many breakthroughs at device levels are still being sought. In this context, it is highly critical that we redress the value of photonic technologies in such a way that we can increase the chance of network innovations as much as possible. We categorize the enabling technologies for DOPS into three areas; 1) Optical Path Interface: high capacity optical network interface card (NIC) that interfaces end users with the DOPS, 2) Optical Path Processing: that switches and provisions numerous optical paths, and 3) Optical Path Conditioning: that conditions the physical parameters such as SNR and dispersion of a provisioned optical path such that the optical data is successfully transmitted. These areas are not necessarily unique to DOPS, but the value of which has to be redressed to better achieve DOPS. In this talk, we will review the following four topics, by introducing the activities in authors' group.

OTDM-NIC

Exploiting the newly discovered ultrafast cross-phase modulation in the so-called 'inter-subband transition (ISBT)' InGaAs/AlAsSb waveguides [3], the authors and their colleagues have proposed ultrafast optical LAN in which a DOPS is configured to accommodate 172 Gbps integrated OTDM NICs. The use of the DOPS in LAN is inevitable for the sake of the energy, space, and cost reasons, while the effectiveness of such an extremely high-bandwidth circuit switching in conjunction with the conventional packet switching has also been pointed out from the view point of performance evaluation [4]. Such an effort is extensively made as a part of the Project "Development of Next-generation High-efficiency Network Device Technology", conducted by The New Energy and Industrial Technology Development Organization (NEDO) of Japan [5].

Parametric Tunable Dispersion Compensation

Recently, one of the authors proposed a completely new approach to realize an optical tunable dispersion compensator (OTDC) [6], in which optical parametric processes are exploited in conjunction with dispersive media such that much wider and seamless operating bandwidths and faster response speed are attainable. We will discuss the unique and essential features of the parametric tunable dispersion compensation in realizing DOPS.

Parametric Delay-Dispersion Tuner

If we look at the amount of group delay (GD) in the above mentioned parametric TDC discussed, it is also varied corresponding to the varied amount of group velocity dispersion (GVD) because GVD is the derivatives of GD with respect to angular frequencies. This implies that by cascading these processes, we can control the delay and dispersion over a very wideband in a simultaneous and independent manner [7]. We will discuss that this unique feature leads to a world record delay-bandwidth product of 20,000.

Silicon Photonics

This talk will also refer to the potential of silicon photonics as an enabling integrated platform for DOPS. Because of the large index, silicon photonics can be considerably compact. For example, if we could realize low-loss silicon waveguides, a 256 x 256 matrix switch could be as small as 50 x 50 mm2. The thermo-optic effect of Si is also much larger than silica, such that the power consumption of TO-switch based on Si could be a few orders of magnitude smaller than silica, while the response time is much shorter as well. A simple estimation reveals that only less than 10 W is necessary to drive this Si switch, the response time of which is only of microsecond order.

Not only linear optical properties, silicon photonics has attractive nonlinear optical properties. Because of the tight confinement of the optical field and a large n_2 value, silicon photonics could operate as an ultrafast nonlinear optical integrated device [8, 9]. This talk will also touch upon a possible way of avoiding adverse effects due to two photon absorption and free carrier absorption [10].

Conclusions

We have discussed that the emerging energy bottleneck will result in a critical need for new network technologies most likely based upon high-bandwidth optical circuit switching on top of the current packet-based networks. The global and cross-layer joint R&D efforts for the 'redressed' photonic technologies enabling DOPS under the governmental and/or academic initiative will be the key for such innovation. This talk reviewed the relevant seminal activities of authors' group.

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