2 R&D Activities of Photonic Networks in the World

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With full-scale deployment of broadband services, a future-proof 21st-century network, which is based upon innovative photonic network technologies, has to be built to cope with the rapid growth of IP traffic. In this paper, R&D programs supported by national institutes in Japan, United States, and European Union are introduced.

Keywords
Photonic network, R&D, Japan, US, EU

1 Introduction

Today, Japan has more than 5 million FTTH users, with the number expected to reach 30 million in 2010. Recently, a type of broadband services offering IP phone service, Internet access, and delivery of television content, known as "triple play" service, has been spreading rapidly. Delivery of television content, which requires far more bandwidth than IP phone and Internet services, is likely to lead to an explosive increase in traffic volume in the future as streaming and peer-to-peer applications come into wide use. With the non-utilization rate of optical fiber transmission capacity for long-hauls decreasing from the previous 65 % in Japan, concerns are being voiced over a possible shortage of router processing capability[1]. If the question were asked whether we are fully prepared for a sharp rise in traffic, the answer might be no.

There is no room for doubt that the photonic network is now the core technology that serves as a platform of the communications infrastructure in the 21st century. While some even went so far as to say that R&D on optical fiber communications was complete in the late 90 s, the widespread use of the Internet in the past few years has led to explosively expanding traffic at a pace exceeding Moore's law (approx. 10-fold/5 years), completely changing priorities in R&D. Advances in WDM technology have enabled an approximately four-fold increase per year in transmission capacity per optical fiber (also referred to as Gilder's Law)[2]. Although there thus seem to be few issues as far as transmission capacity is concerned, routers which transfer IP packets to their destinations at each node are problematic. Since the electronic router processing capability follows Moore's law (doubling every 18 months) rather than Gilder's Law (quadrupling every 12 months), there is a fear that routers may soon become a bottleneck for the entire network in real-world applications with limited installation space and power consumption. As it may be impossible to solve this bottleneck with network layers alone, incorporation of so-called revolutionary optical layer technology therewith appears necessary to reaching a solution. Turning our attention to the US and EU, we see that broadband services are not as widespread as in Japan. As such, though there is a shared perception that R&D on photonic networks is a critical issue, there are some differences in the level of commitment. This paper focuses on mid- and long-term R&D programs related to photonic networks currently being conducted with government funding, presenting projects selected from among those currently underway in Japan, the US, and the EU.

As an aside, it was in the mid-90 s when the CRL, as NICT was formerly known, initiated research on photonic networks, and there is no denying that we were a late starter at that time. Nevertheless, our efforts are now coming to fruition in the current NICT after 10 years of working to differentiate our research from that of others and pursuing challenging research topics which could not be pursued by the private sector but only tackled by a national institute. Above all, the optical CDM and optical packet switching covered in this special issue should be regarded as proof of our leadership, as these are themes that we have addressed since they first appeared on the development horizon. In this sense, it is safe to say that NICT's research on photonic networks is an exemplar of national institutes serving as role models.

2 R&D trends in Japan

In Japan, the Ministry of Internal Affairs and Communications announced in the e-Japan Priority Plan 2003 that it will establish the following three fundamental technologies for photonic networks by 2005 and commercialize these technologies around 2010.

- Advanced WDM capable of multiplexing 1,000 wavelengths per optical fiber
- Optical node technology making possible a 10 Tbps optical router
- Control/management technology required to create a terabit/s optical network

To achieve these objectives, the National Institute of Information and Communications Technology (NICT) (founded as the Telecommunications Advancement Organization of Japan (TAO)) pushed ahead with the following four commissioned research projects with the participation of leading communications carriers, vendors, and universities, all of which ended in March 2005.

- R&D for "Total optical communication technology" (1996–2005)
- R&D for "Optical access network high-speed wideband communication technology related to photonic networks" (2000–2005)
- R&D for "Photonic network technologies using optical burst switching" (2001–2005)
- R&D for "Terabit supernetworks" (2002–2005)

In the same vein, the Ministry of Economy, Trade and Industry forged ahead with the following two commissioned researches through the New Energy and Industrial Technology Development Organization (NEDO):

- Devices for photonic networks (2002–2006)
- Femtosecond technology (1995–2004)

These national projects have nearly achieved their objectives in relation to link transmission technology and cross-connect switch technology—constituent technologies of the photonic network. To ensure that photonic networks can be used in practical application, however, the final challenge has yet to be addressed, that of how to shift the R&D paradigm and integrate the results obtained so far from the viewpoint of networking. In future R&D, it will be essential to have a viewpoint aimed at providing utilization technologies for widespread use in a variety of network applications including e-commerce, e-science, network storage, e-education, e-medicine/nursing and network entertainment, and providing a "Photonic platform" that is capable of serving as a development environment. In the meantime, the issues listed below have been singled out for their importance in relation to the IP infrastructure in Japan in the recently announced primary report from the Next-Generation IP Infrastructure Research Society[1]; we must focus on providing photonic technology solutions to these issues as well.

- Insufficient traffic control in consideration of utilization efficiency of the network as a whole
- Lack of quality of service (QOS) assurance across networks of multiple carriers

- Insufficient route information authenticity
- Concentration of traffic in Tokyo

Under these circumstances, the Photonic Internet Forum spent about half a year from August 2003 compiling proposals on R&D challenges likely to be posed by next-generation photonic networks from 2006 in the report Photonic Phase II[3]. These proposals were later incorporated in the report[4] of the "Promotion Council on Research of Fundamental Technology for the 21st Century Networks," organized by the Ministry of Internal Affairs and Communications, and reflected in the policy as a budget request for fiscal 2006. Figure 1 shows the four major R&D challenges incorporated in the report; these challenges are listed below as well.

- λ-utility
- λ-access
- Photonic node capable of switching multi-granularity data
- Quest for Ultimate photonic network technology

3 R&D trends in the US and EU

3.1 US

In the US, high-risk, high-return research subjects are being tackled, including "Data in Optical Domain Networks (DOD-N)" under the sponsorship of the MTO (Microsystems Technology Office) of DARPA (Defense Advanced Research Projects Agency). In this area, two programs are competing with each other; LASER (Label Switched Optical Router), led by the University of California, Santa Barbara, and IRIS (Integrated Router Interconnected Spectrally), led by Bell Laboratories at Lucent Technologies[5]. These 4-year programs, initiated in 2004, are geared toward developing packet routers equipped with interfaces offering 100 Tb/s and 40 Gb/s in throughput. They are not new in terms of architecture or transfer protocol, as both employ a transfer protocol which avoids packet collision using wavelength conversion and wavelength spatial separation devices. Rather, they are more focused on realizing a processor chip densely integrated with a high-agility

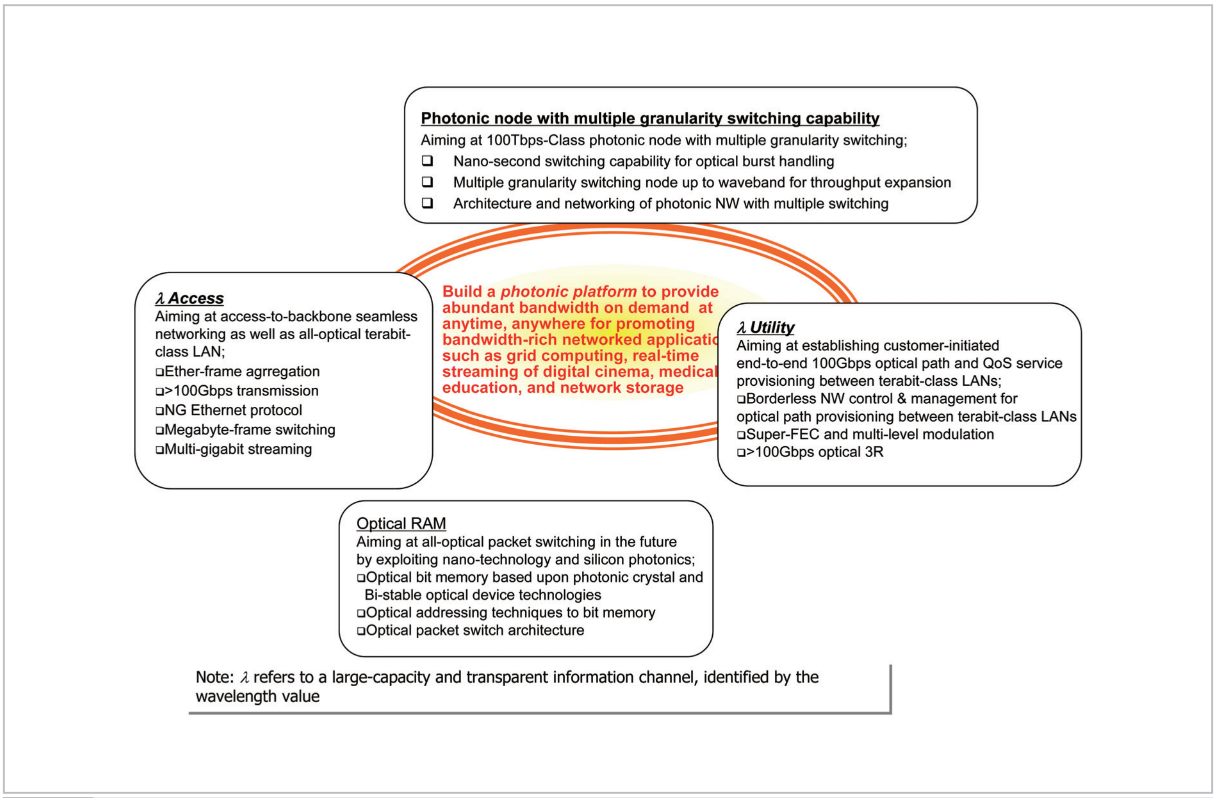

Fig. 1 *Major R&D subjects*

wavelength variable laser, wavelength converter, and drive circuitry. While the number of I/O ports is only 2×2 at present, it seems that this number is steadily expanding.

OptIPuter (Optical networking, Internet Protocol, computer storage, processing and visualization technologies) is a large-scale attempt to build an infrastructure capable of effectively utilizing globally dispersed computing power by using LambdaGrid. This attempt is currently underway, led by the University of California, San Diego and the University of Illinois at Chicago under the sponsorship of the US NSF (National Science Foundation)[6]. Its objective is to provide an environment that allows for the exchange and visualization of terabyte and petabyte data—global meteorological observation, computational physics, and other data—over optical networks and for checking against distributed databases. This project makes use of a novel computer architecture premised on unlimited use of network bandwidth. National LambdaRail has two darker fiber routes for research education that extend a total distance of 24,000 km in an east-west direction using a 32-wavelength DWDM—an optical network test bed on a nationwide scale owned and operated by the participating research organizations, connecting leading universities including Duke University and Pittsburgh Supercomputer Center and providing a 10 Gbps wavelength path and 10-gigabit Ethernet LAN PHY service between nodes[7].

In a similar vein, GENI (Global Environmental for Networking Investigations, http://www.geni.net/index.php) of the NSF (National Science Foundation), an initiative that seeks to explore possible future Internet paradigms, has been launched[8]. To resolve several major issues associated with the current iteration of the Internet, including fragile security, difficulty involved in assuring resource availability, difficult network management, and difficulties in addressing mobility, the initiative has declared that it will scrap the current Internet architecture and create a new architecture from the ground up. GENI states that it will aggressively tackle optical device integration technologies and breakthrough technologies for optical networks.

3.2 EU

Having “Broadband for All” as an objective in the e-Europe 2005 Action Plan, the EU (European Union) is devoting its energies to R&D focusing on the widespread use of broadband. Their R&D is characterized by its wide variety of access technologies—ranging from fixed wireless access and CATV to satellite, xDSL, and power lines in addition to optical fiber—as options because of differences in the technological situation from one country to another, thus seeking to provide inexpensive broadband services across the EU through standardization of equipment standards and unification of communication regulations. As for R&D related to photonic networks, a number of programs are being conducted on a wide variety of themes included in the Sixth Framework Program (FP6) of IST (Information Society Technologies). The major programs are shown in Table 1. NOBEL is a comprehensive program covering from core and metro network architectures to transmission, switching and parts/devices, in which 33 organizations participated and which lasted two years, from 2004 through 2005. In addition, there are wide-ranging programs including those on unique themes such as LASAGNE, covering all-optical label processing node technologies, and GANDALF, which is related to integrated wireless access technology.

The EU is also devoting its energy to improving its research education terabit/s network test bed. GEANT2 is a network test bed linking 30 national research education organizations through 34 nations on Continental Europe, and this 2.4–10 Gbps WDM network is being built primarily using dark fibers. Among the general features of R&D in the EU are a reliable portfolio of technological alternatives, a stress on fundamental research, continuation of themes, and adequate measures for the mobilization of human resources.

Table 1 Major programs

Name	Type	Period	Budget	Remarks
NOBEL	IP:Integrated project	04.1~05.12 (24months)	13.7M €	Next generation optical networks for broadband European leadership
e-Photon/ONe	Network of excellence project	04.2~06.1 (24months)	2.9M €	Optical Networks: Towards Bandwidth manageability and cost efficiency
GANDALF	STREP:Specific targeted research project	04.1~05.12 (24months)	1.9M €	Gigabit access network using remote delivery optical feeder for heterogeneous broadband wireless and wireline nodes
LASAGNE	STREP:Specific targeted research project	04.1~06.12	2.7M €	All-optical label swapping employing optical logic gates in network nodes
BREAD	Coordination project	04.1~06.06 (30months)	1.7M €	Broadband in Europe for all: A multi-disciplinary approach

4 Conclusions

This paper focused on the mid- and long-term R&D programs on photonic networks being conducted under government sponsorship and presented some select projects from among those underway in Japan, the US, and the EU. On the other hand, there are also new developments, as evidenced by initiatives such as GENI, which pursue future Internet paradigms. In light thereof, Japan's R&D must make appropriate preparations in advance of other nations, at the same time keeping an eye on these new trends.

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