Photonics Technologies towards Next Generation Broadband Networks

Hideo Kuwahara
Fujitsu Laboratories Ltd., 4-1-1, Kamikodanaka, Nakahara, Kawasaki, 211-8588, Japan

ABSTRACT

This paper describes the photonics technologies that make it possible to support exploding traffic demand in next generation broadband networks combining telecom and broadcast arena. Technology trends of high capacity transmission and network node are summarized including some Japanese government funded projects, together with access technologies and some emerging device technologies that support the system requirements.

Keywords: optical communication, optical fiber, transport, photonics

1. INTRODUCTION

Recent rapid penetration of broadband network and service is actually changing the landscape of our life in worldwide. Telecommunication and broadcast are rapidly merging. In Japan, TV broadcast to cell phone using one segment of frequency domain is already in service, and in US, IP-TV and iPhone is becoming hot and really competitive environment. Wired and wireless world are also merging and some buzz words are generated there, like Triple-Play is emerging to Quad-play obtaining mobility, and the merge of computers, TV and cellular phone is progressing.

These trends are actually changing our life style in business and residential environment, but these are all originated from the penetration of broadband networks. But the traffic of all the upper layer applications are, needless to say, supported by IP and/or Ethernet, and even SONET layers, hence transported by photonic physical layer. Even in the wireless network, the signal after reaching a base station is transported by photonic transport networks. Broadcast signal carried in the air is now changing to be carried in fiber as IP-TV. Optical transport technologies are thus calmly and steadily supporting our new life.

In this paper, I will describe briefly enabling technologies of high capacity transport systems for core networks, and its supporting new devices/components and next some introduction to new attempts funded by Japanese government.

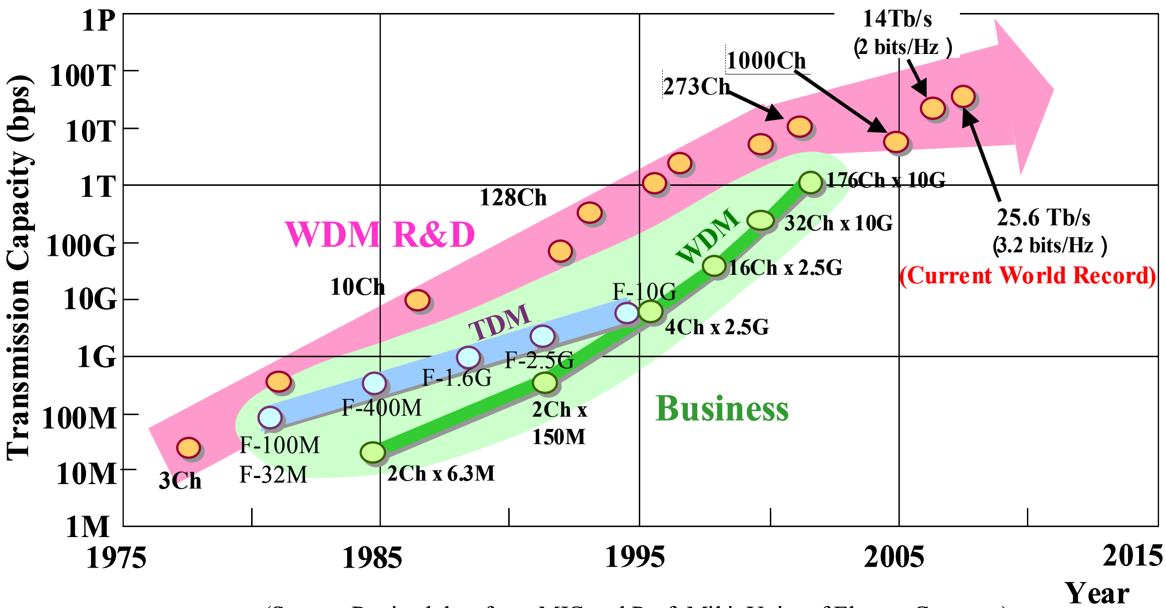
2. HIGH CAPACITY TRNAMISSION TECHNOLOGIES

Recently the record for high capacity transmission is reviving again after somewhat low profile of these 4-5 years during telecom bubble burst years. Figure 1 summarizes the recent report of experiment and commercial realization of high capacity systems. Using advanced technologies such as 40Gb/s and high efficiency modulation schemes, high wave count WDM, and polarization multiplexing, the high capacity of 25Tb/s was reported.

2.1 40 Gb/s Technologies

About 15 years ago first 10Gb/s optical system was developed in Japan. At that time, there still was a discussion, “10Gb/s is too big. Where can we find suitable application?” Now 10Gb/s system is becoming the majority of optical communication systems and next 40Gb/s is also becoming commercially available. In the deployment of 40Gb/s system, there still is a discussion which modulation is the most suitable from the viewpoint of performance, size, power consumption and cost. There are several modulation schemes discussed, from simple on-off keying, duo-binary, DPSK, DQPSK with variation of combining RZ (Returned to Zero) or NRZ (Non-RZ), and carrier suppress schemes. In the case of 40Gb/s system, polarization mode dispersion is surely an origin of big deterioration, which will fluctuate with temperature and mechanical vibration. So it is proposed to optically and electronically compensate PMDs. But optical PMD compensation is still expensive because of channel by channel compensation, while electronic compensation is still under development. DQPSK [1] modulation scheme has a compact modulation spectrum and is a promising candidate. We investigated and compared the various effects and influences and developed DQPSK transceivers [2].

Optical Transmission Systems and Equipment for Networking VI, edited by Werner Weiershausen,
Benjamin B. Dingel, Achyut Kumar Dutta, Ken-ichi Sato, Proc. of SPIE Vol. 6774, 677402, (2007)
0277-786X/07/$18 · doi: 10.1117/12.725111



(Source: Revised data from MIC and Prof. Miki, Univ. of Electro-Comms.)

Fig.1 Challenges for higher transmission capacity

Fig.2 40Gb/s DQPSK module

2.2 Coherent transmission

In these several years the research on optical coherent transmission is becoming active again. Coherent transmission technologies are very intensively investigated in the late 80s [3]. However the emerging of EDFA (Erbium doped fiber amplifier) covers large part of the advantages of coherent transmission, it was not commercialized at that time. With the advent of electronic dispersion compensation and digital signal processing technologies supported by ultra fast CMOS technologies operating faster than 10Gb/s, coherent transmission technologies are recently intensively studied again with new capabilities and expectations. Comparing with the status of ’80s, the laser phase noise, or oscillating linewidth, is greatly improved, and also the requirement is also largely relaxed because of the increase of bit rate. The electronics speed is also greatly increased, and twin pin photodiode configuration, polarization diversity, phase diversity configuration have been discussed, and becoming popular. The remaining big issue for realizing coherent transmission utilizing electronic signal processing would be the operation speed of A/D converter and DSPs. Measuring equipment, such as sampling scope, are currently used for ADC, and personal computers are used for off-line processing. In near future the CMOS technology will be capable to handle 10GSample/s, 20GS/s and even 40GS/s, and optical communication will follow several technologies developed in wireless communications.

2.3 100Gb/s Transmission

The discussion on 100Gb/s is also becoming active, especially in the standardization arena [4]. Though it is still early stages, several schemes are discussed, like 10 parallel, 4 parallel, WDM approach using 10 x 10Gb/s, 4 x 25 Gb/s, 2 x 50Gb/s, and ultra high speed serial approach. If we try to transmit 100G Ether signal in existing WDM networks of 100GHz spacing, where band narrowing by concatenated multiple ROADMs is limiting 50-60 GHz bandwidth, several technologies like higher order modulation and/or polarization multiplexing may be incorporated. Figure 3 summarizes the various transceiver technology options in future high capacity optical communications.

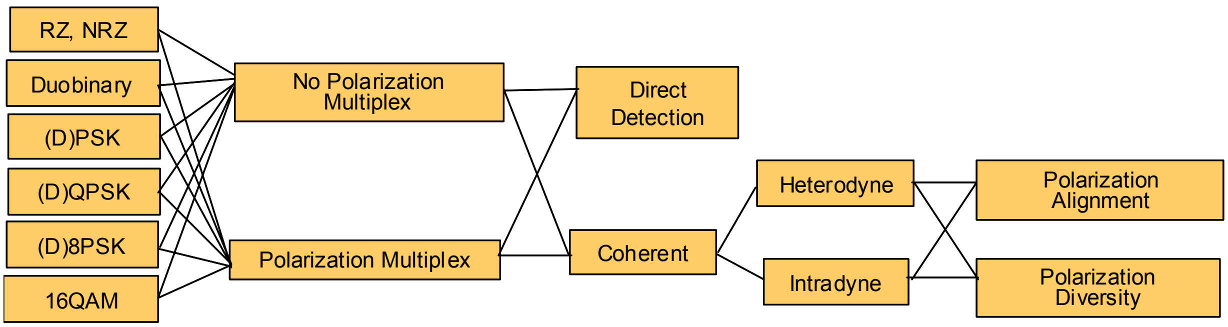


Fig. 3 Transceiver technology options

3. NODE TECHNOLOGIES

3.1 ROADM based ring and mesh WDM networks

The node technologies of the traditional telephone based metro network, where the majority of traffic is local call, is basically configured in ring networks, which is extensively developed with rings and spurs, and then scaling to mesh networks as internet based long distance traffic increases. Key enabling technology of ring network is a reconfigurable optical add drop multiplexer (ROADM), which is realized by wavelength selective switch (WSS). WSS is inherently a switch that can select the specific multiple wavelength signals from WDM signals, and change the output port of designated wavelength signals. With the scaling of the network, various factors such as available fiber, topology and flexibility are relating to performance limitation and tradeoffs in the network [5,6]. By adopting a modular structure in the node using WSS, the network can be configured effectively and economically, and scalable from ring to mesh networks. Currently operation speed of WSS is relatively slow because it uses slow switching mechanisms such as thermal effect, liquid crystal and MEMS (micro electrical mechanical systems), but in the future similar operation will be done by more fast switches to handle burst traffics.

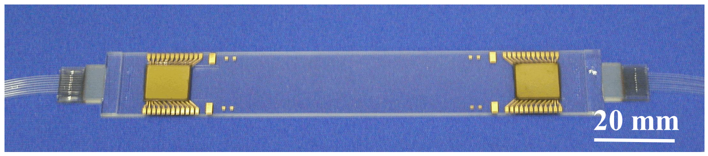
Recently the requirement of combining packet signals with TDM and even WDM technologies is becoming strong [7]. Conventional TDM transport system is carrying packets signals like Ethernet or IP data. Transport efficiency will be highly improved due to statistical nature of packet signals.

3.2 Control plane of photonic networks

For the control of node, or control plane technology, GMPLS is a promising technology. Several investigations are reported for multi-layered GMPLS control. A new concept of “Photonic Virtual Router” was proposed as robust and efficient control method for multilayered GMPLS network in 2004 [8]. A shared segment recovery mechanism for fast recovery is also proposed [9]. In Japan a GMPLS field trial was performed using JGN II (Japan Gigabit Network) demonstrating inter-carrier path provisioning using RSVP-TE signaling, and disaster recovering. JGN II is operated by the National Institute of Information and Communications Technology (NICT). Optical path switching of 272 ms was achieved [10]. NGN (next, or new, generation network) is quite actively discussed recently, and will be installed in commercial systems soon. Further study on the connections between physical properties/monitoring and control plane will be needed to implement wide and flexible photonic networks.

3.3 High speed optical burst switch

An integrated 8x8 electro-optic high-speed switch was developed for future optical burst transport networks [11]. A beam-deflecting optical switch utilizing electro-optic effect of PLZT realizes one microsecond switching speed. Packaging technologies with PLC is also developed. This work was partly supported by the New Energy and Industrial Technology Development Organization (NEDO) of Japan.



(a)

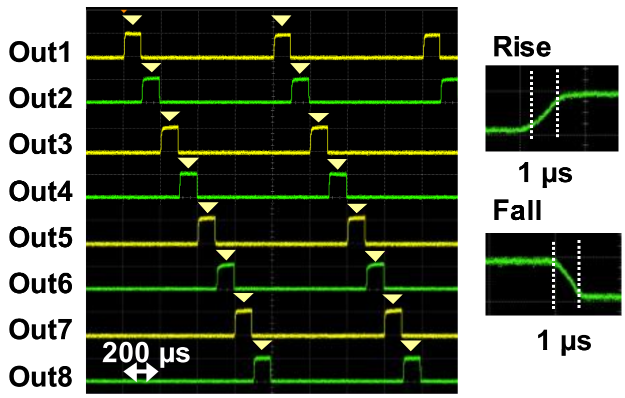


Fig.4 High-speed switch; (a) outer view, and (b) its optical switching response [11]

3.4 Photonics technologies for Peta-flops ultra-high performance computer system

Optical packet node technologies are investigated for future high performance computing systems. WDM optical packet interconnection using multi-gate SOA switch architecture for Peta-flops ultra-high performance computer systems [12]. Optical interconnection technology is becoming another big concern in realizing higher performance computers, and 10Gb/s base multiple parallel array link is an attractive approach [13].

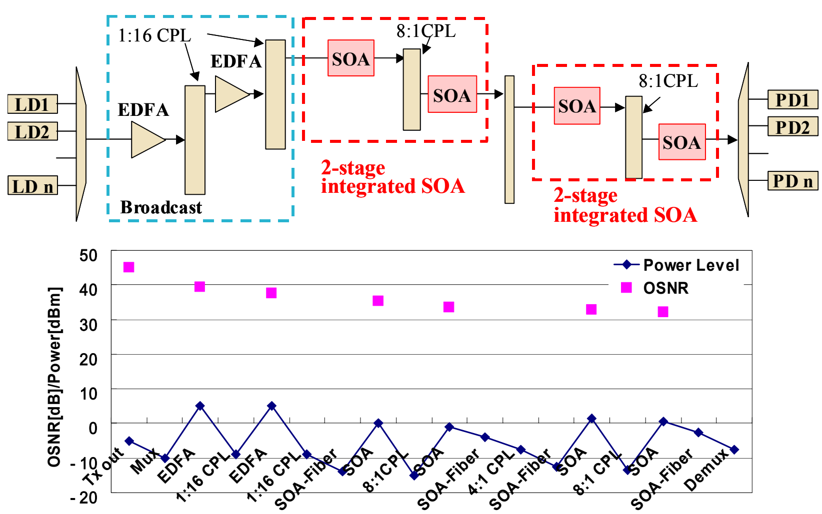
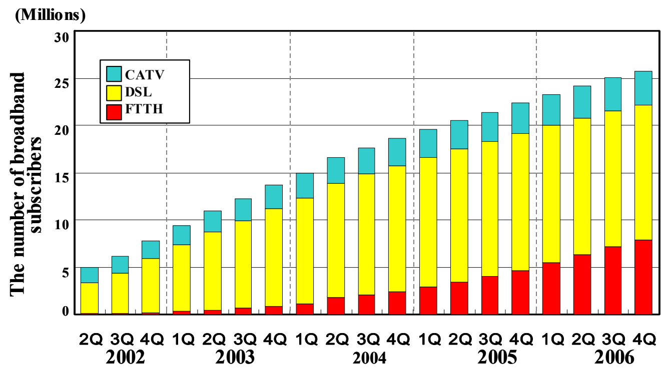


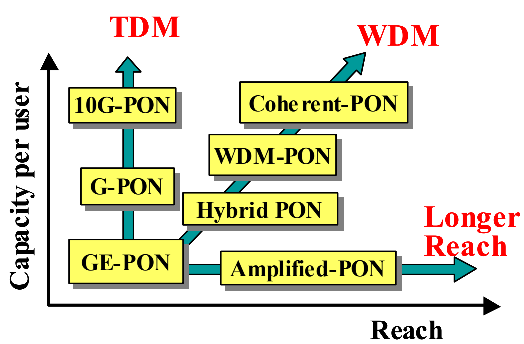
Fig.5 Multi-gate SOA switch architecture for Peta-flops ultra-high performance computer system [12].

4. ACCESS TECHNOLOGIES

The deployment of residential fiber access is becoming active worldwide. Especially NTT in Japan is promoting the fiber to the home (FTTH) systems, aiming to deploy 30 million subscribers by 2010. At the end of 2006, about 8 million are already subscribing. Recently Japanese newspaper announced about 95 households are connected in broadband connection, via DSLs, fiber, cable, and so on. Previously deployed B-PON is now changing to GE-PON in Japan, and G-PON has started to be deployed in US. Cost, size and power consumption are always big concerns in access systems, and one of effective approaches will be PON module with wide operating temperature range without thermal controller. Next generation access technologies are also discussed in standardization bodies, such as FSAN (Full Service Access Network), in which 10G-PON [13], WDM PON and cost-effective wavelength shared hybrid PON [14] architecture are also discussed. New business models for carriers or service providers are requested which support the construction cost of broadband access and exploding traffics due to increasing video-based services.



(a)



(b)

Fig.6 Broadband access penetration. (a). Broadband subscribers in Japan (b) Future trends in FTTX

5. DEVICE TECHNOLOGIES

5.1. Quantum Dot devices

Quantum dot devices are very attractive because the electron and hole energy states are so confined; hence with good features such as temperature stability, lower operation current. Our quantum dot laser operates in wide temperature range from -40 degC to 90degC, and it will be extremely attractive features. Quantum dot structure is also effective to realize high power semiconductor optical amplifiers (SOAs) with low polarization dependent gain.

5.2 Mode-hop-free monolithic tunable distributed amplifier (TDA) laser

Wide tunable, yet stable, mode-hop-free lasers have long been desired. Tunability and stability are, however, inherently contradicting features, and the realization of stable, compact and fast tunable laser was a big concern. Tunable distributed amplifier (TDA) laser, in which active waveguide and tuning waveguide are arranged alternatively, shows stable mode-hop-free operation because of DFB laser like structure. One TDA laser can vary its wavelengths up to about 5nm, and 8 array having different Bragg wavelengths shows 39.5 nm tuning range covering full band of C band [16]. TDA tunable laser is also attractive for fast tuning time of 300 ns [17].

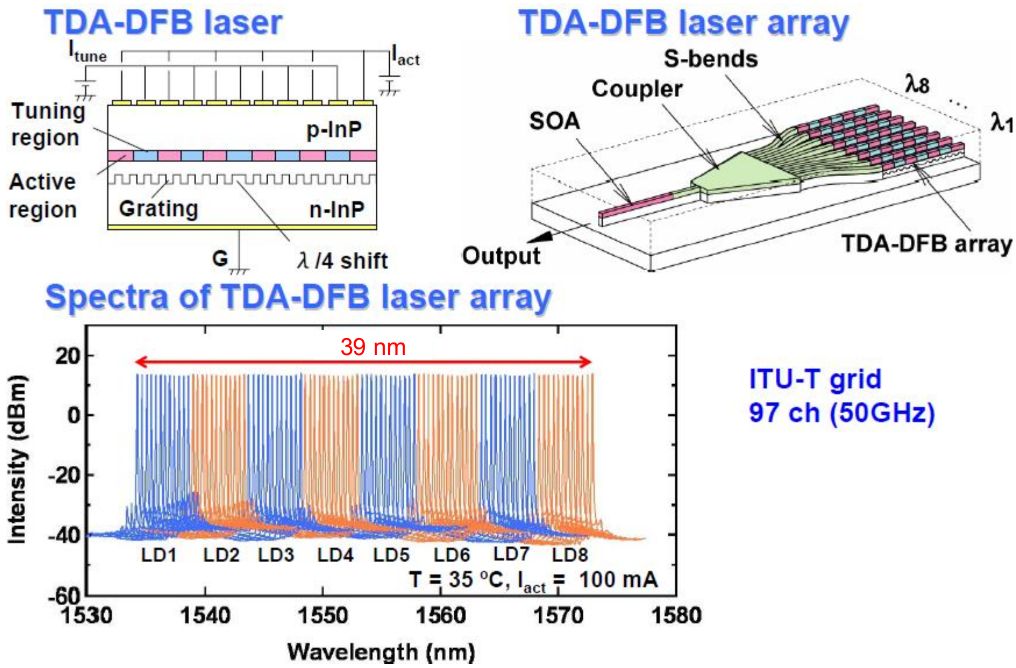


Fig.7 Tunable Distributed Amplifier (TDA) Laser [16]

5.3 $LiNbO_3$ modulator

The high electro-optic coefficient of $LiNbO_3$ is attractive to realize the high speed advance modulation schemes. For 40Gb/s system RZ-DQPSK modulation format is a promising one. Relatively complex two stage configuration connecting RZ signal carving and two parallel Mach-Zehnder interferometer configuration for I and Q branch is realized by utilizing newly developed U-turn waveguide and integrating multiple devices in one chip [18]. The $LiNbO_3$ modulator will be still attractive in multi-value modulation such as 8-, 16-, 32-, 64-QAM in future.

5.4 Optical signal processing

Ultra high speed optical signal processing using, e.g., high nonlinear fiber (HNLF) has a potential of attractive direct optical signal processing in near future. One example is ultra high capacity single channel 1.28/2.56 Tb/s DQPSK

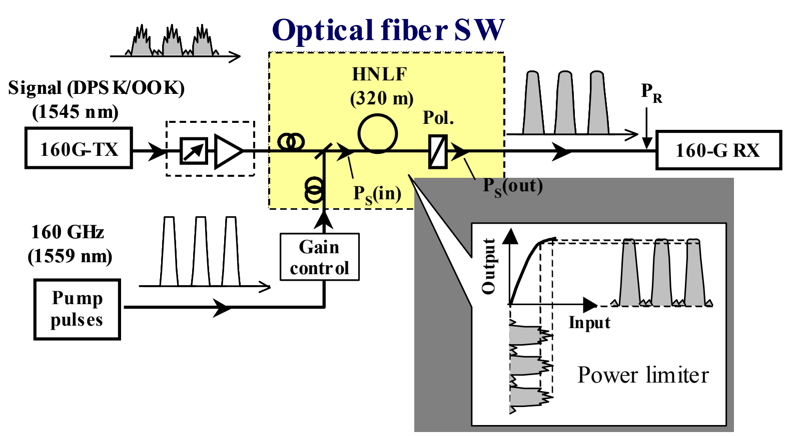
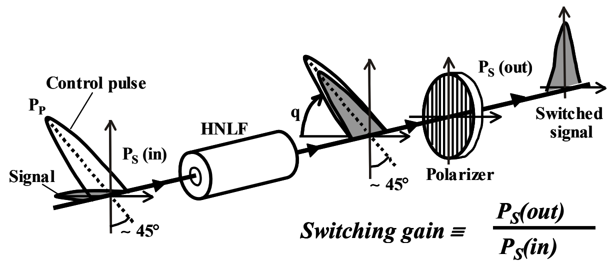


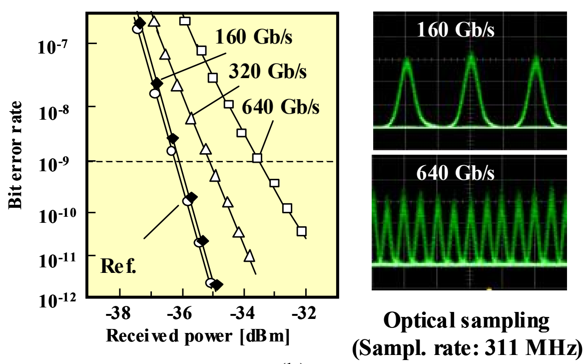
Fig. 8 Amplitude noise suppression using nonlinear fiber [21]

transmission which was achieved by combining multi-level modulation, optical TDM and polarization multiplexing technologies, and optical demultiplexing using HNLF [19]. Optical 3R-regeneration (re-amplifying, reshaping and re-timing) at 160 Gb/s was also achieved by combining optical pulse shaper, optical decision gate and wavelength shifter using HNLF [20]. Though it takes some more time before optical 3R technologies are practically feasible, optical 2R may be a good candidate to process in network nodes in power efficiently manner for large granularity signals. Recently Noise suppression by optical fiber limiter was achieved using gain saturation of optical parametric amplification (OPA) and suppression of system deterioration due to AM-PM conversion for PSK transmission [21].

Ultra fast optical switching is effectively feasible using nonlinear Kerr effect in the HNLF shown in Fig.9, and this configuration is applied to optical demultiplexing, and optical sampling [22].



(a)



(b)

Fig. 9 Optically parametric amplified fiber switch. (a) Switching configuration, (b) BER and sampling waveform

6. CONCLUSIONS

Photonic network technologies are still evolving rapidly with new optical transport technologies, such as new modulation schemes, coherent technologies, and advanced electronics processing, beyond 40Gb/s and towards 100Gb/s and more. Photonic node technologies are also emerging beginning from wavelength selective capabilities and new control schemes. New photonic devices are emerging with new characteristics hence with novel capabilities. Optical access technologies deploying now in the world is actually changing the scenes of our business and life, and even creating new ones. These technologies will serve to implement next generation photonic network where total traffic will increase to one hundred times of current one accommodating public and private video stream traffics. Though discussions on regulatory issues and business model of telecom networks seem to be still somewhat lagging to technological ones, the discussions are becoming quite active recently, and they will eventually be prepared to pave the way to really broadband networks and resulting network oriented society.

ACKNOWLEDGEMENT

These works are partly supported by National Institute of Information and Communications Technology (NICT), New Energy and Industrial Technology Development Organization (NEDO), and Ministry of Education, Culture, Sports, Science and Technology of Japan.

REFERENCES

1. T.Hoshida et al., "Optimal 40 Gb/s Modulation Formats for Spectrally Efficient Long-Haul DWDM Systems", IEEE J.LT, Vol.20, No.12, pp.1989-1996 (2002)
2. T.Hoshida et al, "Design Optimization of 40 Gb/s RZ-DQPSK Transceiver for High OSNR and PMD Tolerance under Fast Polarization Changes " ECOC2007
3. H.Kuwahara et al, "New Receiver Design for Practical Coherent Lightwave Trans. System", ECOC86, pp.407-409
4. IEEE HSSG web site; (http://grouper.ieee.org/groups/802/3/hssg/index.html)
5. Bert Basch et al, "DWDM System Architecture and Design Trade-Offs" OFC/NFOEC2006, NThC2
6. K.Tse, "Tradeoffs for Performance in Long-Haul Transmission Systems: A Carrier's Perspective" OFC2003, FE1
7. S.Gringeri et al, "Optimizing Transport Systems to Integrate TDM and Packet Services", OFC/NFOEC2007, NTuA4
8. T.Soumiya et al,. "Robust and Efficient Control Method for Multilayered GMPLS Networks", ICC/WTC 2004
9. S.Kano et al, "Shared segment recovery mechanism in optical networks", Asia-Pacific Symposium on Information and Telecommunication Technologies (APSITT) 2005, Nov 9th
10. Y.Sameshima et al, "JGN II Testbed Demonstration of GMPLS Inter-Carrier Network Control with Actual Operational Consolidation", ECOC2006, We 4.1.5
11. A.Sugama et al, "Integrated 8x8 Electro-Optic High-Speed Switch for Optical Burst Transport Networks", OFC/NFOEC2007, OWV2
12. H.Onaka et al, "WDM Optical Packet Interconnection using Multi-Gate SOA Switch Architecture for Peta-Flops Ultra-High-Performance Computing Systems", ECOC2006 Tu 4.6.6
13. K.Terada et al, "10Gbps x 4ch Arrayed Optical Modules for Petascale Computing Systems using a Novel Assembly Technique", ECOC2007
14. S.Ide et al, "Seamless and Cost-effective upgrade from G-PON to 10G-PON by Dual-rate Mixture PON system using Electrical Multiplexing", ECOC2007
15. M.Bouda et al, "Cost-Effective Optical Access Upgrade using Wavelength Shared Hybrid Passive Optical Network", OFC/NFOEC2007, NThD5
16. K.Takabayashi et al, "Mode-hop Free and Electrically Wavelength-Tunable Laser Array with 39.5nm Tuning Range Using Tunable Distributed Amplification DFB Structure", IEEE ISLC2006, TuB5
17. K.Nakamoto et al, "High-Speed Wavelength Tuning of Tunable Distributed Amplification DFB-LD in Long Haul Transmission", OFC2007, JWA31
18. M.Sugiyama et al, "Low-drive-voltage and compact RZ-DQPSK LiNbO3 Modulator", ECOC2007
19. H.G.Weber et al, "Single Channel 1.28 Tb/s and 2.56 Tb/s DQPSK Transmission", ECOC2005, Th 4.1.2
20. S.Watanabe, "Technologies for 160 Gb/s Optical 3R-Regeneration", ECOC2004 Symposium Tu 4.1.2
21. F.Futami et al, "All-optical Amplitude Noise Suppression of 160-GB/s OOK and DPSK Signals using a Parametric Fiber Switch", OFC/NFOEC2007, OThB3.
22. S.Watanabe et al, "Novel Fiber Kerr-Switch with Parametric Gain: Demonstration of Optical Demultiplexing and Sampling up to 640 Gb/s", ECOC2004 PD, Th4.1.6