

IP Photonic Node

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This paper describes an IP photonic node architecture and its migration based on a single virtual-router view network. The IP photonic node features node cut-through at a various levels such as the wavelength, SONET frame, and/or packet path. Its coordination capability for optical and packet paths enables efficient usage of network resources, for example, for the transportation and restoration of very large volumes of IP traffic. This paper also presents some recent photonic technology to make the IP photonic node configurable and expandable.

1. Introduction

The volume of IP traffic is growing exponentially because of the widespread use of applications such as the Internet; virtual private networks (VPNs); and communications between data centers, between collocation facilities, and within storage area networks. Photonic networking is regarded as an essential and core technology to cope with this trend. Vigorous efforts to accommodate a huge capacity have been made, and multi-vendor environment construction has been promoted by organizations such as the ITU-T, Internet Engineering Task Force (IETF), and Optical Internetworking Forum (OIF).

Against this background, we have proposed a virtual network paradigm for the next-generation network.¹⁾ This paper focuses on an IP photonic node architecture based on this concept, its ability to coordinate between optical paths and packet flows, and a migration scenario for the IP photonic node. This paper also describes some of the latest wavelength routing equipment and device technologies to realize the IP photonic node, for example, terabit wavelength division multiplex-

ing (WDM) transport, an optical amplifier for a large number of wavelengths, and tunable laser diodes and filters.

2. IP photonic node architecture based on a single virtual-router view

2.1 Virtual-router view network

To cope with the ever-increasing IP traffic, solve the processing bottleneck problem, and meet the demands for Class of Service (CoS) and Quality of Service (QoS), we proposed an IP core transport network and transport node architecture based on a single virtual-router view.²⁾ **Figure 1** shows our concept. Users are offered a variety of services through a virtual router core transport from application servers. Users do not need to know the network structure itself, but require networks to work as one huge virtual server which provides requested services at the requested network quality.

IP photonic networks based on a single virtual-router view can configure virtual private networks (VPNs) in a variety of ways to meet us-

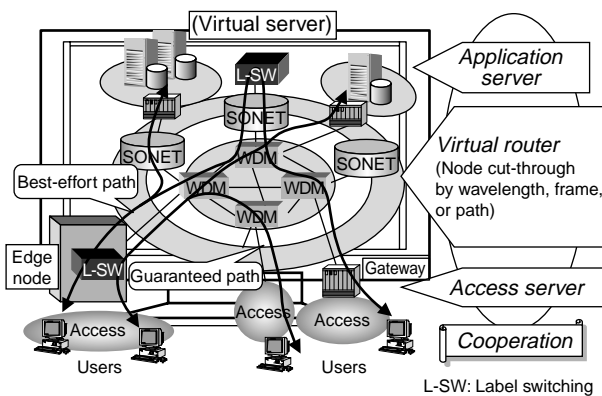


Figure 1
Virtual-router view network.

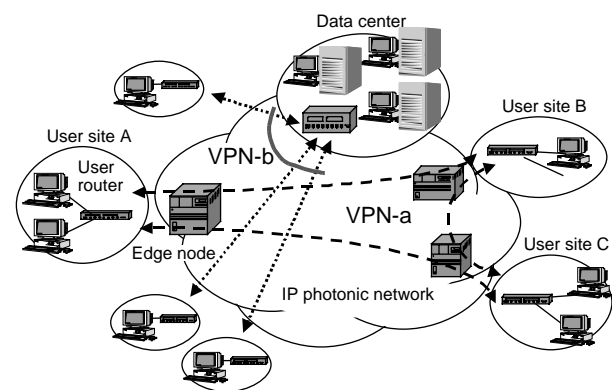


Figure 2
Example of main services provided by a virtual router: VPN.

ers' demands. An example is shown in **Figure 2**. IP-based virtual leased lines in VPNs are set-up between user sites in the point-to-point path or multi-point-to-point paths with a variety of QoS grades in terms of bandwidth, packet loss rate, priority, delay, delay variation, and so on. Because path isolation is required between VPNs, rigid paths such as wavelengths and SONET frames or a flexible granularity such as groomed IP packet labels are used as shown in **Figure 3**.

2.2 IP photonic node architecture

The key technology in a single virtual-router view is the node cut-through technology with multiple granularity achieved at 1) the wavelength level by wavelength routing, 2) the frame level (e.g., SONET/SDH) by electrical ADM and cross connection, and 3) the packet level by layer 2 label switching. We use the term "IP photonic node" to mean a conceptual node that coordinates optical paths and packet flows and then configures a single virtual network. Optical add/drop multiplexer (OADM), optical cross-connect (OXC), SONET/SDH equipment, and/or layer 2 packet switches can implement the node cut-through functionality in an IP photonic node. Therefore, an IP photonic node is a single or composite module that provides node cut-through for IP traffic transportation. Especially, node cut-through at the wavelength level will make transport net-

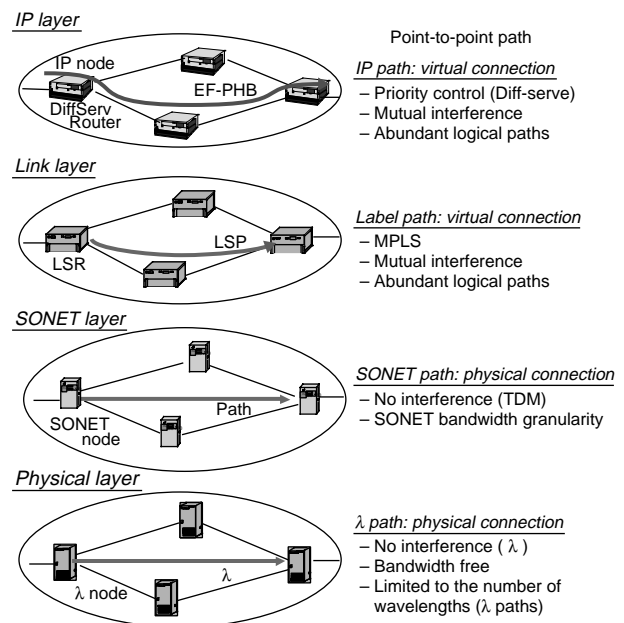


Figure 3
VPN implementation schemes.

works simpler and enable economic configuration just by handling the wavelength level.

An example IP photonic node configuration is shown in **Figure 4**. The node cut through at the wavelength level can be done such that only the required wavelengths are added or dropped at the designated node and other wavelengths are passed through. Similarly, node cut-through will be done at the layer 2 packet level. IP packets can be encapsulated with a fixed length label,

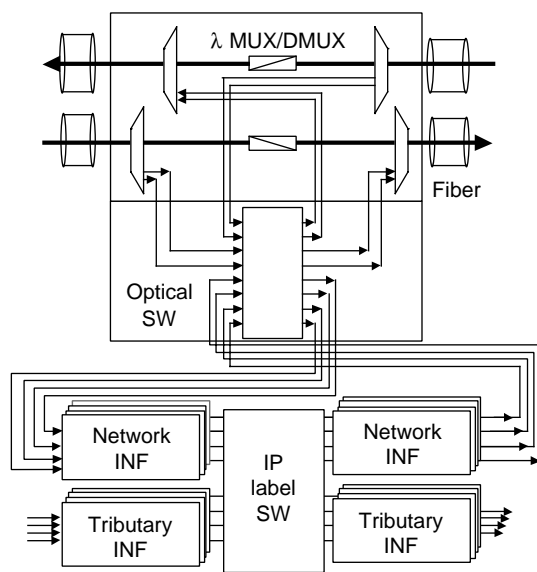


Figure 4
Example configuration of IP photonic node.

which is used as a switching label between ingress and egress edge nodes/routers. This type of labeled packet can be dropped or added at the designated node and passed through the intermediate nodes. In some cases, cut-through at the frame level can be applied such that payload information in only designated frames is added or dropped at the designated node and others are passed through.

2.3 Coordination function in the IP photonic nodes

A wavelength or an optical path basically works as a point-to-point path, so the wavelength count increases with the number of connected points or nodes. An increase in the wavelength count requires an increase in the number of related optical transmitters/receivers and WDM filters. The cost of a node will depend on how many wavelengths need to be handled. Therefore, to make it possible to provide an economical service to users, a highly-efficient bandwidth utilization per wavelength should be considered. An aggregation and grooming function for converting IP packets into an appropriate wavelength or optical path is essential for the IP photonic node at

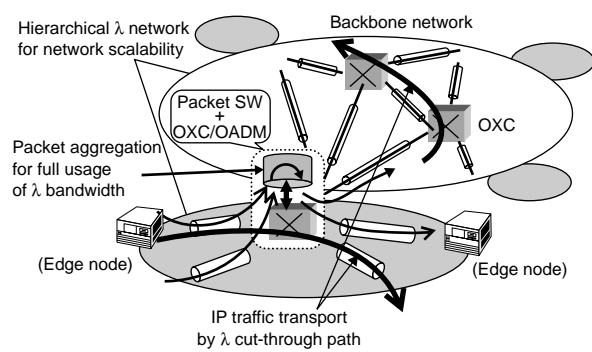


Figure 5
Collaborated work in λ and electrical levels.

network edges, as shown in **Figure 5**. The IP photonic node aggregates and grooms IP packets sent by connected nodes into the same destination or QoS and then accommodates them into the same optical path by a packet switch. The CoS/QoS during packet aggregation/grooming should be considered. In the future, if the economically available wavelength count increases, a more flexible usage of wavelengths would be applicable, for example, different QoS packets could be assigned to different wavelengths.

Some of the advantages of coordinating optical paths and packet flows from the viewpoint of optical path restoration or protection are described below.³⁾

A simple IP photonic node is composed of a separate optical path switch and packet switch. In this case, if the utilization of each optical path is low, the number of restored wavelengths becomes large. As a result, the optical path switch will need to be large. On the other hand, some integrated IP photonic nodes can be configured by using an integrated optical-path and packet switch, which replaces a part of the optical path switch with packet switches, thereby reducing the hardware size. If we coordinate the operation of the optical path and packet layer, the number of restored wavelengths can be reduced. **Figure 6** shows a simple optical path protection scheme and a coordinated optical path and packet layer pro-

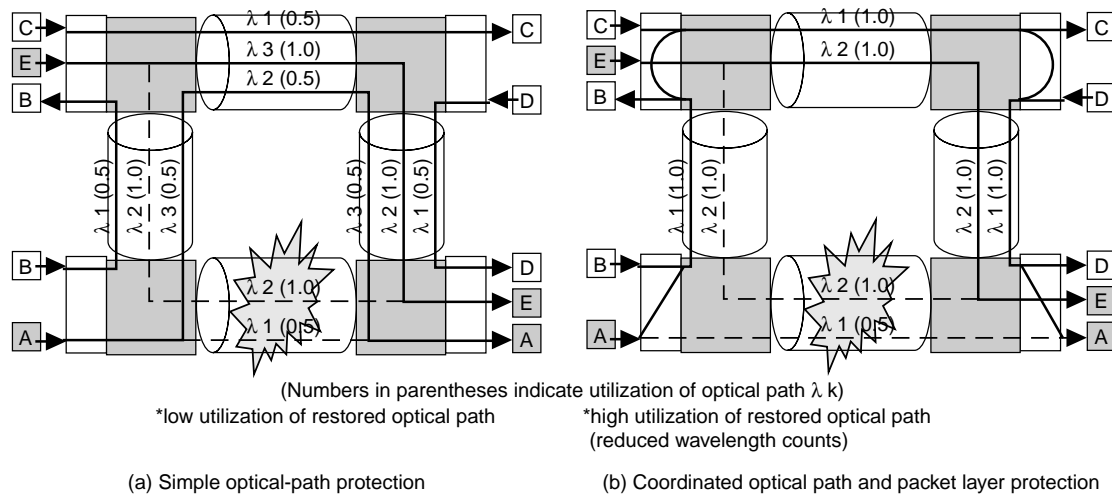


Figure 6 Protection schemes in IP photonic nodes.

tection scheme. In the figure, when there are no link failures, optical paths A and E are set as shown by the dotted lines. The line rate conversion is assumed to be 0.5, 0.5, 0.5, and 1.0 for paths A, B, C, and E, respectively. In a coordinated protection scheme, the number of required wavelengths can be reduced as compared to the simple optical path protection scheme. This is because, in the coordinated protection scheme, paths A and B can be accommodated on a single optical path.

To confirm the effects of coordination on protection schemes, the number of wavelengths required for a photonic network was evaluated in a 6×6 -grid network. **Figure 7** shows the evaluation results. Firstly, 630 routes, which connect all nodes in a full-mesh configuration, were defined as demand 1 and then additional routes were assigned up to demand 4. Here, demand k ($k=1, 2, 3, \text{ or } 4$) means the number of connection paths between nodes. The traffic load of each optical path in the normal state was assumed to be 0.25. The evaluation results show that, regardless of demand, the required maximum number of wavelengths in the coordinated protection scheme can be reduced by about 30% compared with the simple optical path protection scheme.

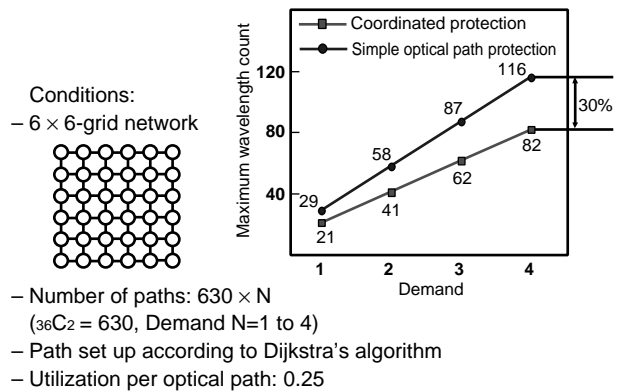


Figure 7 Evaluation of number of required wavelengths.

3. IP photonic node migration

The IP photonic node architecture based on a single virtual-router view will migrate as photonic technology advances. It is expected that networking in the virtual route core transport will be simpler in the future because there will be an abundance of wavelengths that can be flexibly assigned. Generally, we can categorize the development into the three stages shown in **Figure 8**.

- 1st stage: Wavelength paths are used as point-to-point paths or as virtual fibers between nodes.
- 2nd stage: Wavelengths are flexibly assigned among nodes on demand.

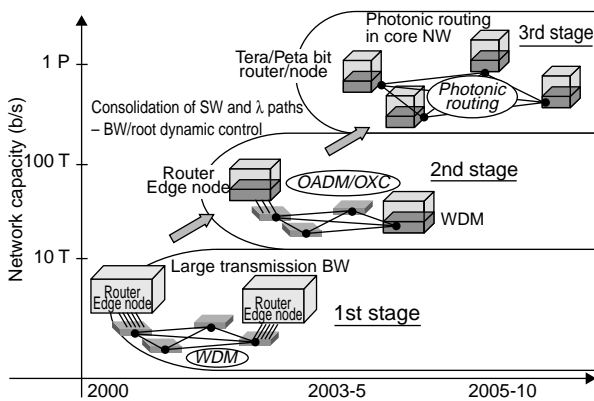


Figure 8 IP photonic network development.

- 3rd stage: Optical packets can be transported in the network, for example, using wavelength or optical coding information.

These stages will be completed in sequence or they may overlap in certain areas.

In the 1st stage, optical paths are used as semi-permanent paths between nodes. For IP traffic transportation, wavelength transparency or independency is used for different transmission protocols.

In the 2nd stage, the IP transport core networks become simpler as the number of available wavelengths increases. Wavelengths are flexibly used for protection or network restoration when faults occur in the transmission. Also, to secure traffic load balancing and/or Cos/Qos, optical paths are flexibly re-assigned or re-routed on demand. In this stage, some optical paths are pre-assigned to provide logically direct paths conveying huge amounts of traffic between nodes. Other optical paths are utilized on-demand by traffic engineering, restoration, and so on. To use optical paths flexibly on-demand, nodes should have the potential to change transmitter wavelengths and/or receive dynamically changed wavelengths. Tunable laser diodes which can change transmitter wavelengths on demand and tunable filters which can receive wavelengths that are dynamically and selectively designated are therefore considered to be key functional devices. OXC/OADMs, which

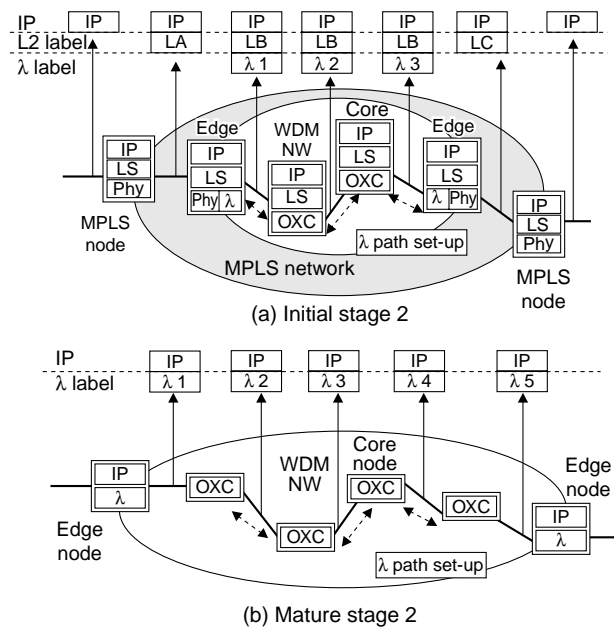


Figure 9 IP photonic node processing in the stage 2.

can flexibly handle wavelengths for re-routing, dropping and/or adding, will play an important role in wavelength networking. Because of the situation in stage 2, the IP packet handling process and optical path handling in IP photonic nodes will be migrated as shown in **Figure 9**. IP photonic nodes at the edge will handle more IP-related functionality, and IP photonic nodes at the core will focus on flexible wavelength switching to configure simpler transport networks. As a result, OXC/OADMs will work mainly in the transport core networks.

In the 3rd stage, IP packets may be handled in the form of optical packets, which have their destinations as wavelengths or optical coding information. Currently, the key technologies for optical recognition, optical memory, and so on are in the infant phase and there is an extremely high barrier in front of us that needs to be overcome. An example IP photonic node for handling optical packets is outlined below. **Figure 10** shows its schematic diagram.

Some areas, for example, metropolitan areas, are considered to be candidates for the optical

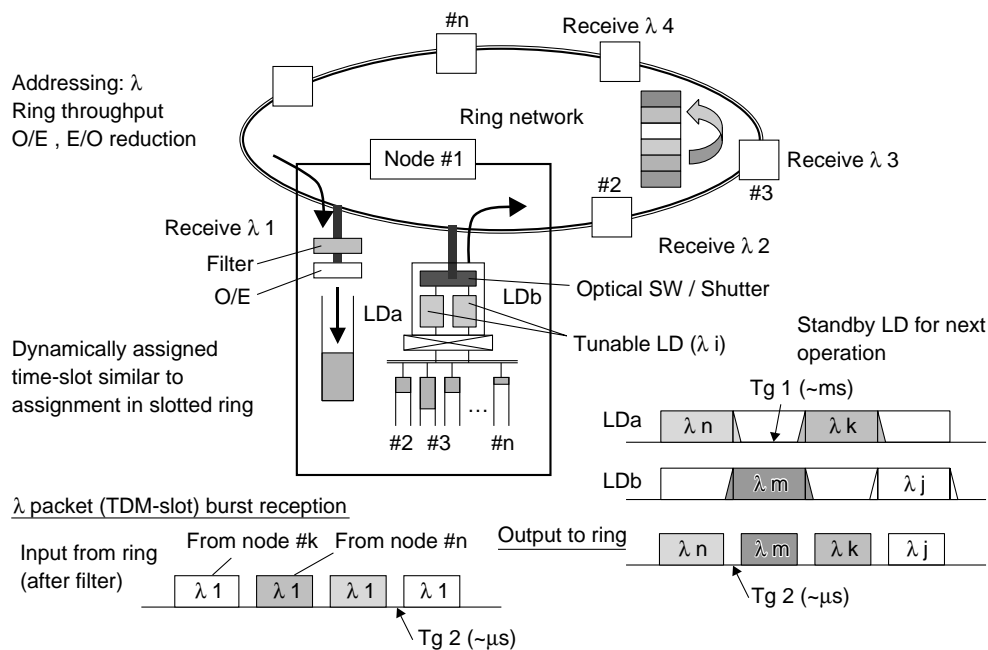


Figure 10
Example scheme of wavelength packet handling.

packet transportation scheme. In a conventional two-fiber ring network with N nodes, each node shares its line traffic capacity with the other nodes. If each node can use multiple wavelengths, then the communication traffic can be increased at the cost of providing each node with multiple optical transmitter/receivers that can send different wavelengths. The optical packet transportation scheme, however, has the potential to reduce the number of optical transmitter/receivers and achieve a high traffic capacity.

A certain wavelength for each node is assigned as a destination flag, and then the node assigned by its wavelength extracts its designated wavelength. Each node prepares the packets to be sent to other nodes, and at an appropriate time, these packets are issued on designated wavelengths by using a tunable laser diode (TLD). To avoid a collision of the same wavelength packet on the ring, as in a token ring network, a time domain multiplexing access scheme or time-slot assignment scheduling method can be applied for each wavelength that a node uses to send its packets. Currently, the switching time from one

wavelength to another in a tunable LD is relatively long, so standby tunable LDs are required to compensate for the transition time-gap. In this example, a ring network with N nodes requires N wavelengths and the available bandwidth between two nodes is limited to the transmission line rate per wavelength. Also, a burst packet optical receiver operating at, for example, 10 Gb/s, is required. However, a highly efficient utilization of the wavelength bandwidth, for example, a utilization equal to the number of nodes N times the transmission line rate, can be attained with a single pair of optical tunable transmitter/receivers. A similar scheme can also be applied if a fixed wavelength is assigned to each node for sending packets and tunable filters are used to detect packets from a designated node.

4. Wavelength routing equipment and device technology

The salient features of the photonic network technology are fully utilized to configure the proposed IP photonic node architecture and its migration described above. The rest of this

section describes various advanced photonic networking systems and devices: the recently developed terabit WDM equipment (FLASHWAVE-OADX); a wide-band optical amplifier for combined C-band and L-band operation; and an acousto-optic tunable filter (AOTF), tunable laser diode, and other key devices for wavelength routing.

4.1 Terabit WDM transport systems

We have developed and reported two types of WDM systems:⁴⁾ the FLASHWAVE 320 G for long-haul networks and the FLASHWAVE Metro for metro networks. We developed FLASHWAVE-OADX to meet the demand for further capacity and long-distance transmission.⁵⁾ This system provides a transmission capacity of 176 wavelengths \times 10 Gb/s = 1.76 Tb/s per fiber. We applied leading edge device technologies such as Raman optical amplifiers and tunable laser diodes. To compensate for degradation due to optical noise accumulation and non-linearity and to secure the required system gain, we implemented forward error correction (FEC) based on ITU-T Recommendation G.975. The system specifications are shown in **Table 1**.

4.2 Optical amplifier for large number of wavelengths

To increase the number of wavelengths, a

Table 1
Main features of FLASHWAVE-OADX.

Item	Parameters
Multiplexed wavelength	1 to 176
Wavelength range	1528.77 to 1607.04 nm (0.4 nm spacing)
Fiber	SMF/NZDSF
Signal rate	9.95382 Gb/s
Signal format	Scrambled NRZ
Maximum distance	SMF: 500 km (100 km \times 5) NZDSF: 600 km (100 km \times 6)
System gain	SMF: 25 dB \times 5 NZDSF: 25 dB \times 6
Dispersion compensation	Dispersion compensator
BER	< 1E-15
Supervisory	Optical supervisory channel

combined C + L-band optical amplifier was developed (the C band is from 1530 to 1570 nm, and the L band is from 1570 to 1610 nm). The block diagram of the combined C + L-band optical amplifier is shown in **Figure 11**. By using this type of optical amplifier in the FLASHWAVE-OADX, 88 wavelengths in each band are available with a wavelength spacing of 0.4 nm (50 GHz).

R&D is continuing towards the target of 1000 wavelengths by further narrowing the wavelength spacing to 0.2 nm and also by developing an optical amplifier which can cover the shorter and longer wavelength regions. **Figure 12** shows the WDM spectrum of this amplifier after a 7221 km transmission of 211 wavelengths separated by 0.3 nm.

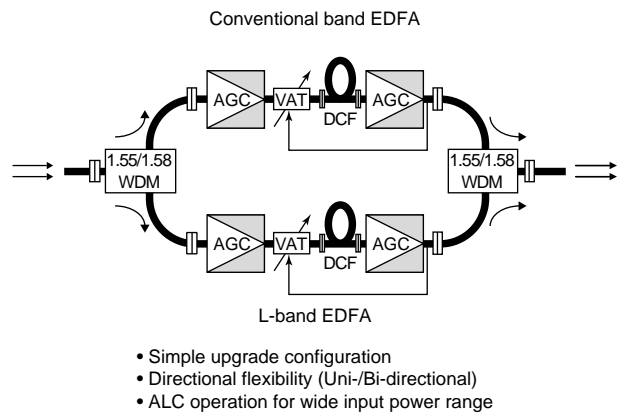


Figure 11
Configuration of C+L-band optical amplifier.

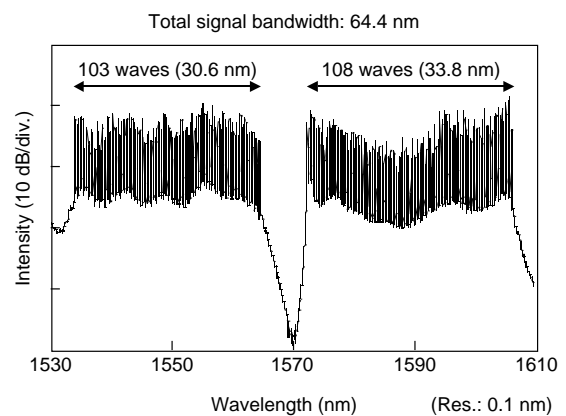


Figure 12
Spectrum after 7221 km transmission using C + L-band optical amplifier.

4.3 Tunable filter

We have developed advanced tunable filter devices based on the acousto-optic tunable filter (AOTF) design.⁶⁾ The AOTF is the ideal component for OADM systems because its inherent flexibility, bit rate/format transparency, and single device structure enable single or multi-wavelength add, through, and drop functions to be realized in a single integrated device. **Figure 13** shows the structure and the key parameters of our AOTF. By adding a high-frequency control signal of around 170 MHz to the AOTF, the wavelength corresponding to the control signal is dropped out at the drop port and the remaining wavelengths travel to the through port. Multiple wavelengths can be selected by simultaneously adding multiple control signals. This AOTF has a good performance and is suitable for use in practical systems.

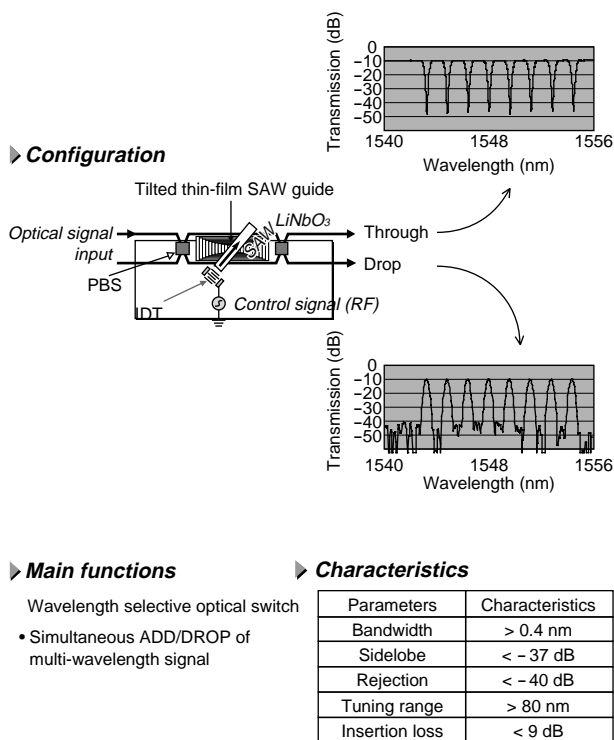


Figure 13 Acousto-optic tunable filter (AOTF).

4.4 Tunable laser modules

When the WDM network wavelength count reaches a certain level, it becomes essential to use tunable wavelength laser devices (TLDs). These devices can greatly reduce the cost of network ownership because it is not necessary to keep a large number of spare optical transmitters in stock and they simplify network maintenance. Additionally, TLDs provide enhanced wavelength allocation flexibility. Wavelength interchange can be readily achieved, remotely, without the need to change hardware. Wavelength stability is crucial within a WDM network, and wavelength-locking technology has been employed to guarantee that the wavelength variation of any source is maintained within the desired operating tolerance. **Figure 14** shows the structure of our tunable LD. In this example, eight LD arrays, an optical coupler, and a semiconductor optical amplifier are monolithically integrated on a chip. Each LD has a tunable range of more than 400 GHz, and the total module can cover 32 wavelengths with a 100 GHz spacing.

Recently, we have developed a TLD which can cover more than 20 wavelengths with a 50 GHz spacing. By using just eight of these devices in our FLASHWAVW-OADX, we can cover 176 wavelengths, which will lead to a reduction in the number of maintenance packages that must be kept in stock.

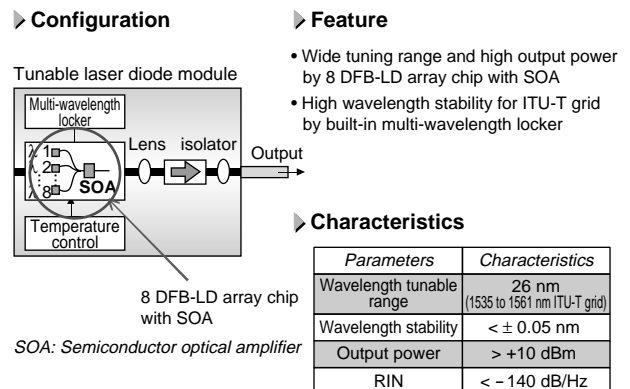


Figure 14 Tunable LD structure.

5. Conclusion

This paper introduced an IP photonic node architecture based on a virtual-router view network proposed for the next-generation IP transport network and discussed its future migration. An example of an IP photonic node with coordination for wavelength paths and packet paths was described and its effect on restoration was evaluated. Lastly, this paper described some advanced photonic network systems and devices that can form the foundation of the proposed node architecture and migration.

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