# 4-2 Compact Photonic Gateway with AOTF for Remotely Controlling λ-Paths

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Metro access networks require dynamic provisioning of high-capacity links to achieve bandwidth-on-demand because of frequent changes in data services and capacity to the users. We proposed a photonic gateway using Acousto-Optic Tunable Filters for Metro access that provides flexible and rapid any node-to-node connections via the wavelength path with a simple configuration, low cost, and compactness. We developed a prototype and confirmed that using the gateway flexibly establishes connections between any nodes at wavelength path switching speeds of 0.25 ms.

***Keywords***
Metro-Access network, WDM, OADM, Optical tunable filter, Wavelength path

## 1 Introduction

In recent years, broadband leased-line services using Gigabit Ethernet and 10-Gigabit Ethernet have become available for business networks. High-speed Internet environments such as those based on ADSL or FTTH are also becoming widely established in homes, and so the stage is being set for a variety of businesses to provide a wide range of services. These developments have resulted in a drastic increase in the volume of data transmission over the Metro-Access network, which operates closer to the user side. Wavelength division multiplexing (WDM) systems, which can expand transmission capacity in proportion to the number of wavelengths in use, have to date mainly been introduced into inter-city backbone networks, but this technology is now gradually being incorporated into Metro-Access networks as well.

Since the variations in demand for data transmission capacity due to changes in service type, or due to relocation and addition of communication stations, are significantly larger in Metro-Access networks compared to backbone networks, connection paths must be able to be changed more flexibly. Another important development is utility computing, which provides on-demand IT resources present on dispersed servers and storage locations. To meet associated requirements, the Metro-Access networks must not only provide a broadband path but must also flexibly respond to the addition and removal of and changes to paths. However, conventional WDM systems for Metro-Access networks require manual settings when the wavelength path changes, and thus these systems are incapable of responding flexibly to short-term data transmission demands.

In this paper, we propose a simple-configuration, compact, low-cost photonic gateway that enables remote wavelength path connection for Metro-Access and enterprise networks. This gateway uses an acousto-optic tunable filter (AOTF)[1]-[3] to realize swift and flexible change of connections between each point according to user demands for individual wavelength paths. Furthermore, new wavelength-based services may be provided using this gateway, such as wavelength multicasting and broadcasting used to transmit broadband content, leased wavelength service, and λ-VPN.

This paper also reports on the results of validation experiments on a prototype of the photonic gateway operated with high-speed wavelength path switching.

## 2 Photonic gateway system using AOTF

### 2.1 Network configuration and example of application

Figure 1 shows an example of the network configuration for the present system. The photonic gateway node has an optical drop/add function, and the connections between the nodes are established through WDM signals. The connection between the nodes may be made on a per-wavelength basis, and the wavelength may be assigned depending on the bandwidth demand. Furthermore, it is possible to perform multicasting and broadcasting linking multiple nodes at the same wavelength. All of these wavelength path settings are remote-controlled and may be changed freely. The present system offers broadband path connections that can be switched with a compact architecture, with low capital expenditure and operational expenses, and should be effective in constructing data-center connections, business networks, campus networks, and more. For example, in a data-center connection, the broadband path may be specially used by allotting a wavelength on demand only for the time required to transfer broadband content, simultaneously, both to the Cache Center and/or to a back-up center from a front data center. For a business network, the present gateway should allow for the establishment of a system that can connect branches in distant locations and also respond flexibly to relocations and new additions, and should also be effective in utility computing, in which the user may access or share resources on dispersed servers and storage locations, all on demand, for the required duration.

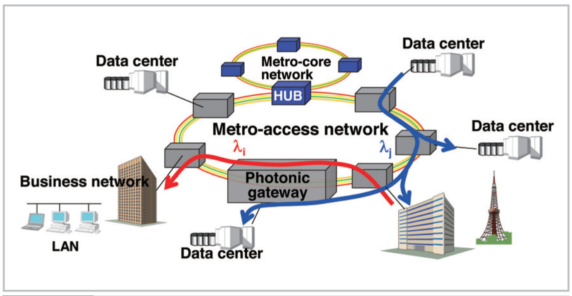


**Fig.1** Example of network configuration using the present system

### 2.2 Basic configuration of the photonic gateway node

Figure 2 shows the configuration of the photonic gateway. In order to reduce the cost of the present gateway, the number of processed wavelengths was restricted to a practical four wavelengths per node. The drop unit consists of an optical coupler and an acousto-optical tunable filter, and the add unit consists of a transponder with a fixed-wavelength laser and a group-reject-and-add filter.

The fixed-wavelength laser of the add unit will allocate a preset wavelength group to each node. These added signals are multiplexed to the transmission line at low-loss

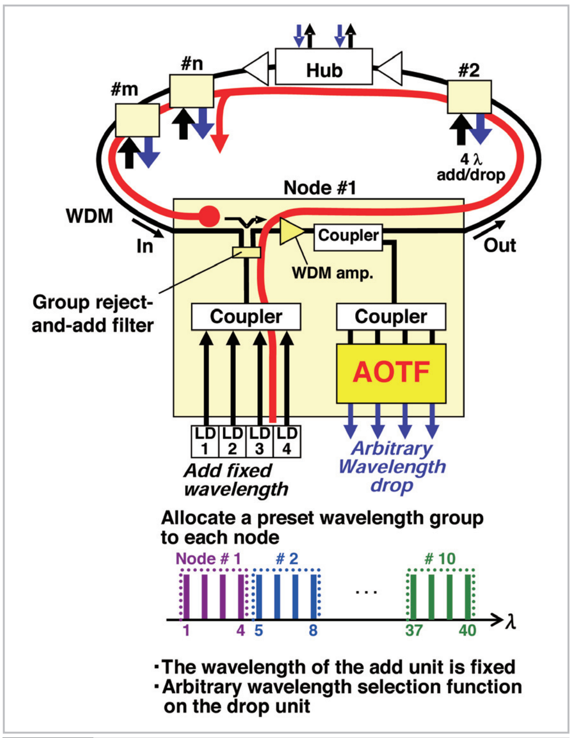


**Fig.2** Configuration of the photonic gateway node

from the add port of the group-reject-and-add filter. Here, a 4-skip-0 filter is used that does not need guard bands between wavelength groups. The added signal travels the transmission line of ring network and is terminated at the group-reject-and-add filter at their own node, so it does not make multiple travels and thus does not interfere with the added signals.

The AOTF of the drop unit filters light signals by making use of the acousto-optic effect created by the surface acoustic wave excited on a substrate such as $LiNbO_3$ by RF control signals. This device selectively transmits a given wavelength by controlling the frequency of the RF signal that corresponds to the central wavelength. This device is capable of high-speed wavelength selection, requiring only several tens of nanoseconds over a wide wavelength range (less than 100 nm). Furthermore, since this is an optical waveguide device, integration leads to a more compact size and lower cost. The present gateway controls the AOTF via software and will select and drop only the wavelength from the node of interest within the transmitted WDM signal. Although the wavelength of the add unit is fixed, the arbitrary wavelength selection function of the AOTF on the add unit allows the network system to establish flexible connections between any given nodes on a per-wavelength-path. Also, selecting the same wavelength at multiple nodes with the AOTF will enable wavelength multicasting and broadcasting.

## 2.3 Configuration of the prototype node

A prototype node was manufactured for the node configuration described above.

The present system enables batch amplification of the WDM signal, add signals, and drop signals using a single WDM amplifier, thereby reducing cost by eliminating the need for a individual optical amplifier dedicated to add signals; additionally, the transmission distance is also extended. The system allows for a maximum of 10 nodes within a single ring, a transmission distance of 200 km, and a maximum of 40 transmission wavelengths (at 100-GHz spacing).

Figure 3 shows an external view of the node. A single rack is 19 inches wide and 2U (88 mm) high, to allow installation in a standard office environment. Remote control of transmission—including path setting and full-time remote monitoring of transmission-line conditions (such as disconnections)—may be carried out on the monitoring and control terminal using SNMP (Simple Network Management Protocol). Furthermore, the present system features an OUPSR (Optical Unidirectional Path Switched Ring) in a redundant configuration (switching time: 3 sec.), and two photonic gateway systems—work and backup—are included within a single node[4].

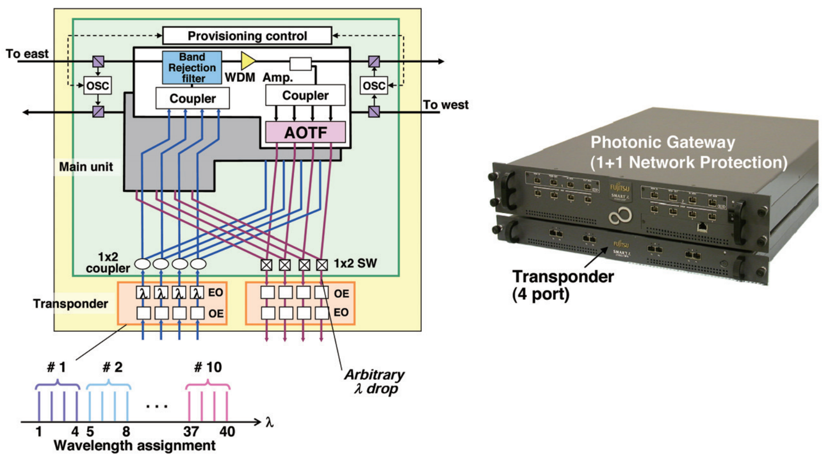


**Fig.3** External view of the prototype node

## 2.4 Validation of photonic gateway node system performance

A network testbed was constructed using the prototype photonic gateway (Fig. 4). The system consisted of three nodes with two fiber rings of 180-km.

Figure 5 shows a selected state of an arbitrary wavelength (Ch. 23) from the 40 WDM input signal (top of Fig. 5) by controlling the settings on the network monitoring and control terminal. Here we can see that a crosstalk ratio of ≥27 dB is obtained for a selected wavelength at a transmission distance of 200 km (bottom of figure).

Figure 6 shows the switching speed of a wavelength path with the present gateway node. High-speed wavelength switching may be completed with this device in a total of 0.25 ms, in a process of searching for and selecting a requested wavelength and then switching from the original to the newly selected wavelength[5]. Detection of the requested wavelength using the wavelength search function was confirmed even in the presence of wavelength fluctuations, and the tracking function for constant following of the selected wavelength operates well even in the event of such fluctuation occurring after selection. Furthermore, the speed of four-port simultaneous tracking control was nearly the same as that for single-port selection.

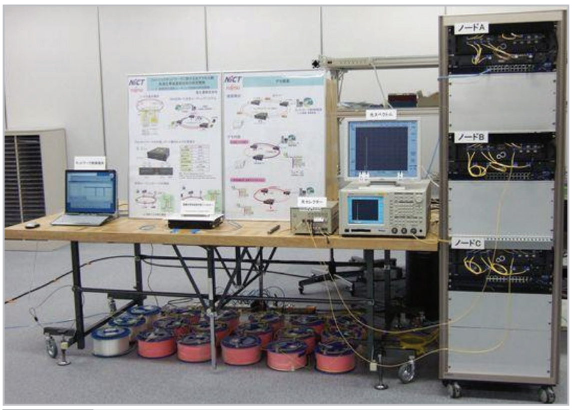

Fig.4 Network testbed using the photonic gateway

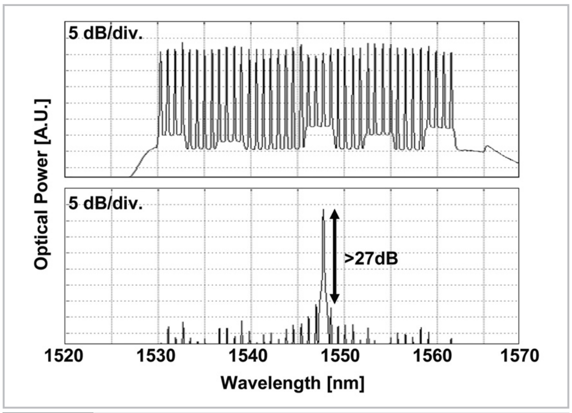


Fig.5 WDM input signal (top) and selected dropped signal (bottom)

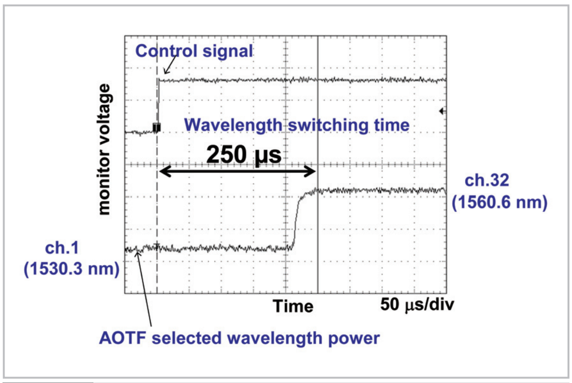


Fig.6 Wavelength path switching speed

## 2.5 AOTF subsystem

Finally, we would like briefly to describe the AOTF and the AOTF subsystem, which form the core technologies of the present gateway node.

In the AOTF, a given RF control signal frequency corresponds to a specific selected wavelength, and so an arbitrary wavelength may be selected simply by changing the RF frequency. However, it is possible that a selected wavelength may fall out of the AOTF transmission band due to factors such as temperature changes, environmental changes, wavelength drift in the transmission laser, etc. Furthermore, high-speed frequency switching of the RF drive circuit must be achieved in order to take full advantage of the high-speed wavelength switching performance of the AOTF. To maximize the effectiveness of the AOTF and to realize stable operation in actual application, the system requires high-speed RF frequency switching at the start of wavelength switching, a requested wavelength search function, and RF frequency tracking controls after switching.

An AOTF subsystem with a temperature control circuit, a monitoring circuit, an arithmetic and control circuit, and an RF drive circuit integrated in the immediate vicinity of the four-channel integrated AOTF module were developed and installed in the present gateway. The configuration is shown in Fig. 7.

Each of the selected signals from the AOTF are split with the optical coupler and monitored on the PD. The arithmetic and control circuit calculates the optimal RF frequency based on the PD-monitored values, and the AOTF is controlled through the RF drive circuit. The Direct Digital Synthesizer (DDS), which is capable of high-speed frequency switching, was applied in the development of the RF drive circuit. The present drive circuit has achieved an RF signal switching speed of less than 400 ns through optimization of the circuit configuration and packaging[6]. A high-speed arithmetic and control circuit was developed and equipped with DSP and FPGA. By combining these circuits with firmware, we were able to generate the required high-speed RF frequency switching at the start of wavelength switching, as well as tracking controls that match the signal wavelength with the AOTF transmission peak after switching. Furthermore, the subsystem also offers functions for external monitoring of the optical power level at the I/O unit to provide control and monitoring information, internal temperature data, and emergency notifications. The present subsystem allows for simultaneous, independent selection of any four wavelengths from the WDM signal through external command input via RS-232C.

## 3 Conclusions

The application of AOTF has enabled us to devise and create a prototype of a compact, low-cost photonic gateway node for Metro-Access networks with transmission distance of 200 km that can perform on-demand flexible wavelength path switching between any given wavelength path and is equipped with OUPSR redundancy. The basic performance of the remote-controlled wavelength path switching function was experimentally validated using a monitoring and control terminal. Furthermore, the validation experiment confirmed that high-speed wavelength switching of 0.25 ms was possible with a prototype gateway.

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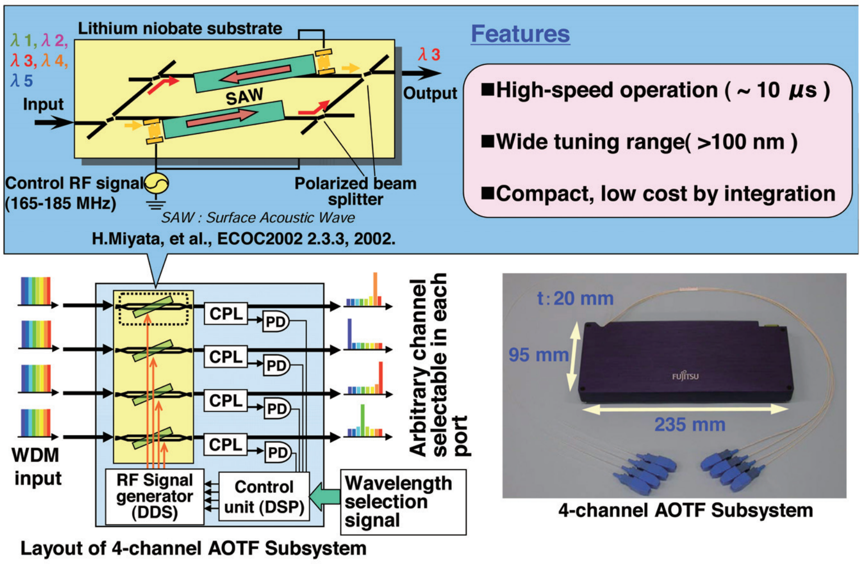


**Fig.7** *AOTF subsystem configuration*

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