

# Multi-Vendor Interoperability Demonstration of Wavelength Switched Optical Network (WSON) with GMPLS Lambda-Label Extension

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**Abstract** Interoperable wavelength path control was successfully demonstrated on a multi-vendor WSON testbed by utilizing GMPLS signaling extension with lambda-label. Data-plane connections over GMPLS wavelength paths were also confirmed in the testbed with an 880km-in-total network.

## Introduction

Optical transport technology has been continuously evolving and current WDM systems have realized high-capacity and long-distance transmission. In addition, advanced wavelength-switching equipment such as the optical add/drop multiplexer (OADM), reconfigurable OADM (ROADM) and wavelength cross connect (WXC) enables effective utilization of the wavelength resources and lower power consumption in the wavelength switched optical networks (WSON)[1, 2]. In operating such advanced high-capacity networks, operational cost can be reduced if the integrated control of multiple vendors' equipment would be achieved. However, in the multi-vendor WSON environment, interoperable integrated control is difficult because there are many differences in wavelength path control method and definition of wavelength information among vendors and equipment, which results in serious problems such as unexpected operational cost increase, human error and so forth. In order to solve these problems, common protocol with standard definition of wavelength information is required in the WSON control plane. In spite of active discussions on Internet Engineering Task Force (IETF) to develop the common Generalized Multi-Protocol Label Switching (GMPLS) protocols for WSON [3, 4, 5], no multi-vendor interoperability trial has been reported because of the difficulties not only in the interpretation and implementation of the GMPLS protocols with standard definition of wavelength information, but also in the interoperable connectivity of optical data plane between different types of wavelength-switching equipment from multiple vendors. From these viewpoints, this paper describes the architecture of GMPLS-controlled multi-vendor WSON, signaling protocol extension for the multi-vendor WSON control and the interoperable integrated control demonstration on a multi-vendor WSON environment for not only the GMPLS control plane, but also the data plane consisting of the 880 km transmission lines.

## Architecture of GMPLS-controlled multi-vendor WSON

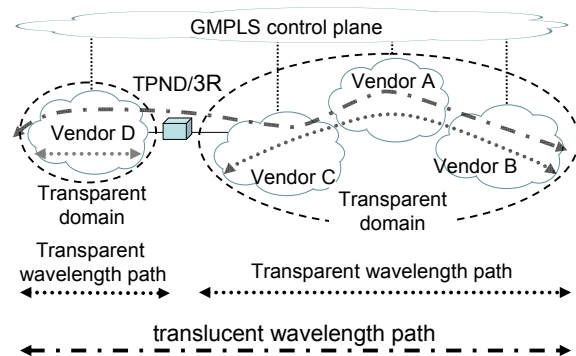


Fig. 1: Architecture of multi-vendor WSON.

Fig.1 shows the basic architecture of GMPLS-controlled multi-vendor WSON. This network consists of multiple transparent optical domains connected by 3R (or OEO regeneration) or transponders (TPNDs). Each transparent domain allows transparent wavelength paths satisfying the wavelength continuity constraint by using the lambda-label extension. In addition, such multi-vendor WSON can be controlled by a unified GMPLS control plane. In this architecture, two types of end-to-end wavelength paths can be envisioned. One is a fully transparent wavelength path within a single transparent domain and the other is a translucent wavelength path created between two or more transparent domains connected by transponders or 3Rs. This WSON architecture has two important issues to be solved. The first issue is the lambda path calculation with consideration of the wavelength continuity constraint and the optical impairment such as the OSNR, chromatic dispersion and so on[6, 7, 8, 9]. This issue is called impairment-aware routing and wavelength assignment (IA-RWA) and has been continuously discussed in both the International Telecommunication Union Telecommunication standardization sector (ITU-T) and IETF. In order to solve this issue, an additional scheme is required such as the Path Computation Element (PCE) with the WSON extension [10]. The other issue is the integrated provisioning scheme of wavelength paths through multiple vendors' equipment. This paper focuses on the interoperable integrated provisioning of wavelength paths between multiple vendors.

**GMPLS signaling protocol extension for the multi-vendor WSON control**

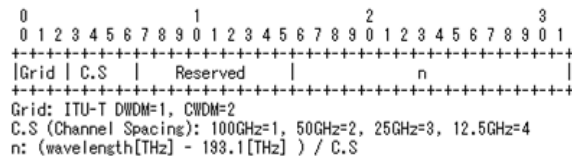


Fig. 2: Overview of GMPLS lambda-label extension.

In order to realize the integrated control of wavelength path provisioning between multiple vendors, a common definition of wavelength information is required. Fig.2 shows a brief overview of the IETF draft of the extended lambda-label definition for GMPLS protocols [4]. This definition is compliant with the ITU-T G.694.1 and G.694.2 standards of WDM spectral grids [11, 12]. The use of the global lambda-labels can release us from the use of vendor-specific channel numbers. For example, if it is required to establish the DWDM wavelength path at 188.9 THz (1587.04 nm) with 100 GHz spacing, each value is set as follows:

- ITU-T Grid = 1 (DWDM)
- Channel Spacing = 1 (100 GHz)
- $n = (188.9 - 193.1) / 0.1 = -42$

As a result, the lambda-label is calculated as "570490838" in decimal value. In the RSVP-TE signaling, the value of the lambda-label is assigned at each hop subobject in the Explicit Route Object (ERO). Generally, the GMPLS-controlled wavelength path is bi-directional, so two lambda-labels are assigned into each hop subobject in the ERO so as to represent the uplink wavelength and the downlink wavelength, respectively. In addition, if a fully transparent wavelength path is required, an identical wavelength should be assigned from the ingress node to the egress node. On the other hand, if the wavelength conversion is necessary at the intermediate node, different lambda-labels can be assigned before and after the wavelength conversion node.

**Experimental configuration**

In order to evaluate WSON interoperability in the control plane and data plane, a multi-vendor WSON testbed was set up consisting of two colorless ROADMs (A1, A2), two OADM (C1, C2) and two WXC (B1, B2) as shown in Fig.3. Nodes A, B and C represent the different vendor. These nodes were connected by 880km transmission lines consisting of single-mode fibers (SMF), non-zero dispersion shift fibers (NZDSF), the optical amplifiers with dispersion compensating fibers, and the gain equalizers. In order to confirm the data plane transmission, Ethernet testers with 10GbE interfaces were connected to the client ports of ROADMs and OADMs. To measure the established wavelength path, two optical spectrum analyzers (OSAs) were inserted between B1 and B2, and B2 and C2. The control plane was constructed onto an out-of-band Ethernet network, and GMPLS lambda-label extension was implemented into all the equipment.

In this evaluation, explicit creation and deletion of three wavelength paths were tried. The first one was a fully transparent wavelength path from C1 to C2 through B1, A1, A2 and B2 so as to confirm not only the interoperability of control plane, but also the data plane connectivity through all equipment. The second was a translucent path between A2 and C2 through A1, C1, B1 and B2 in order to assign the transponders and different wavelengths before and after the transponders. The third one was a fully transparent wavelength path from A1 to A2 through B1 and B2 to achieve the flexible utilization of available wavelengths by using colorless ROADM functionality with a tunable transponder. In the evaluation of the first path, wavelength at 1587.88 nm was inserted between A1 and A2 to be simulated as already used wavelength. Similarly, in the provisioning of second and third paths, four dummy wavelengths at 1585.36 nm, 1587.04 nm, 1588.73 nm and 1590.41 nm were inserted between B1 and B2.

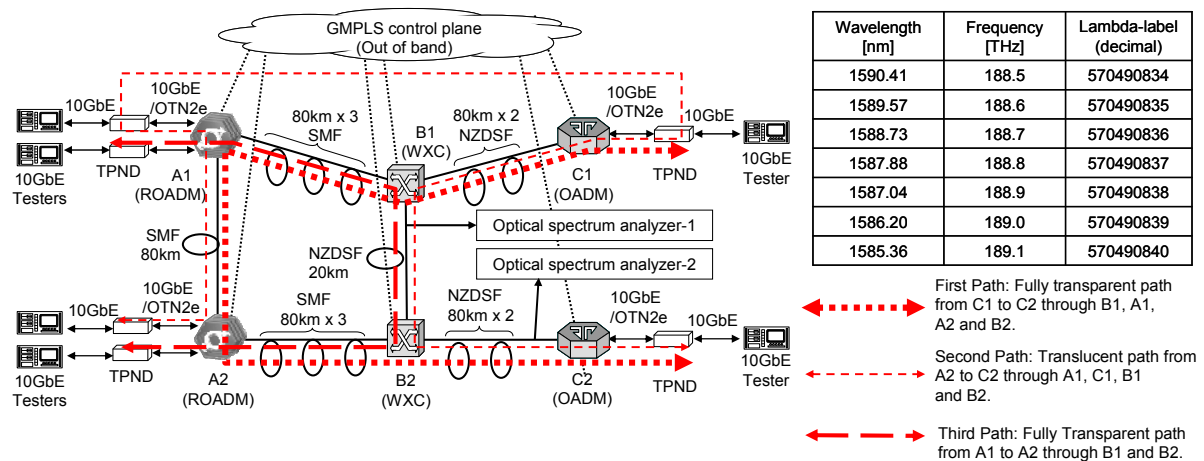


Fig. 3: WSON testbed configuration and utilized wavelength information.

Experimental results and discussion

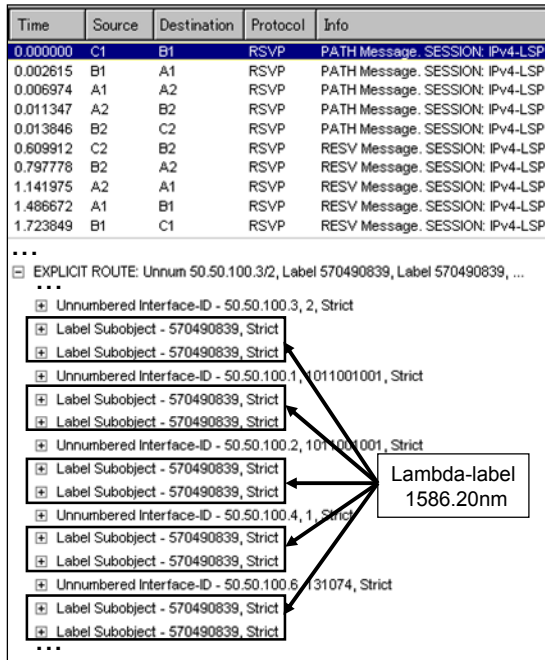


Fig. 4: An RSVP-TE signaling sequence of first (fully transparent) path between multiple vendors with lambda-label extension in ERO

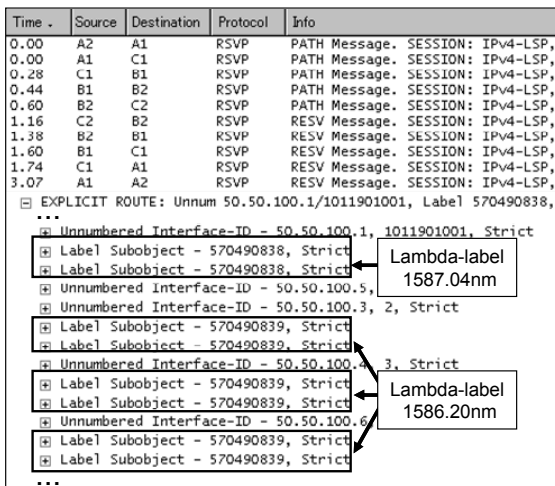


Fig. 5: An RSVP-TE signaling sequence of second (translucent) path creation.

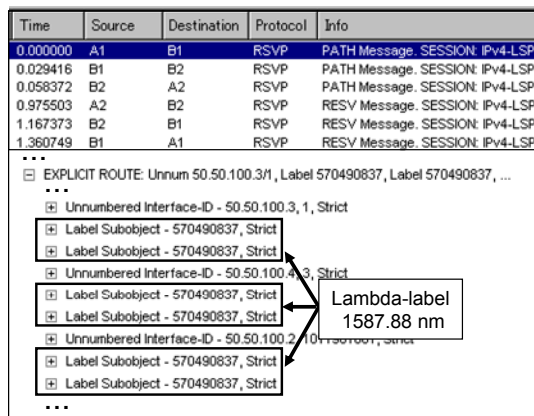


Fig. 6: An RSVP-TE signaling sequence of third (fully transparent) path creation assigning unused wavelength.

These three wavelength paths were successfully created and deleted by using RSVP-TE signaling with lambda-label extension along the routes as shown in Fig.3. Fig.4 shows an RSVP-TE signaling message sequence and each hop subobject in ERO when the first (fully transparent) path was created. Two lambda-labels were inserted into each hop subobject of ERO to assign the appropriate wavelength in both directions of uplink and downlink. Fig.5 shows an RSVP-TE signaling message sequence and each hop subobject in ERO when the second (translucent) path was created. The value of the lambda-label representing 1587.04 nm was swapped for another value of 1586.20 nm between A1 and C1 in order to perform a wavelength conversion. Fig.6 shows an RSVP-TE signaling message sequence and each hop subobject in ERO when the third (fully transparent) path was created at unused wavelength of 1587.88 nm. The creation time of these wavelength paths measured by a protocol analyzer was about 1.7 seconds for the first path, 3.0 seconds for the second path and 1.3 seconds for the third path, respectively. The main reasons for these differences were the number of hops and the control of different devices in the equipment.

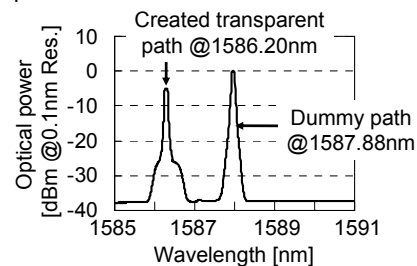
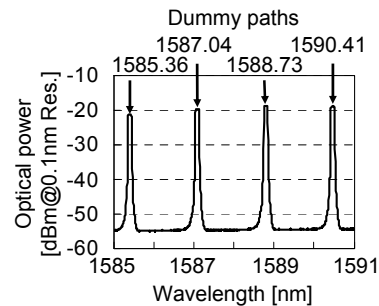
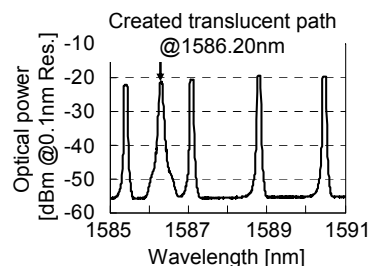


Fig. 7: Wavelength form of created first (fully transparent) path measured between B2 and C2.



(1) Before the path creation

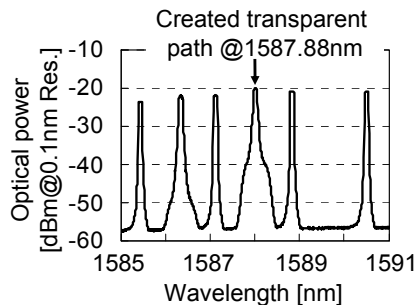


(2) After the path creation

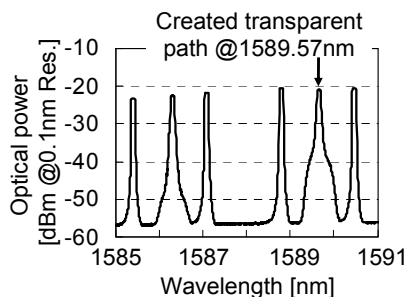
Fig. 8: Wavelength form of created second (translucent) path measured between B1 and B2.

In each established wavelength path, end-to-end error free data transmission was confirmed by the 10GbE Ethernet testers with 100% transmission rate of 1500 bytes per frame.

Fig.7 shows the optical spectrum measured by the OSA inserted between B2 and C2 after the first (fully transparent) path creation. Fig.8 (1), (2) show the optical spectrums measured by the OSA inserted between B1 and B2 before and after the second (translucent) path creation, respectively. In Fig.8 (2), the wavelength of 1586.20 nm for the second (translucent) path was measured between B1 and B2.



(1) Wavelength form of created path at 1587.88 nm between B1 and B2.



(2) Wavelength form of created path at 1589.57 nm between B1 and B2.

**Fig. 9:** Flexible available wavelength assignment in the third (fully transparent) path creation.

Fig.9 shows the result of flexible wavelength assignment evaluation with a single tunable transponder by using colorless ROADM functionality through the creation of the third path. In this evaluation, the second (translucent) path and four dummy wavelengths were kept established. Thus, the wavelengths of 1586.20 nm, 1585.36 nm, 1587.04 nm, 1588.73 nm and 1590.41 nm were occupied along the route of the third path. Firstly, an unused wavelength of 1587.88 nm was utilized to create the third path. Fig.9 (1) shows the measured optical spectrum and the successful creation can be seen at that wavelength. Then this path was deleted and a new wavelength path was created at 1589.57 nm by using the same transponder. Fig.9 (2) shows the optical spectrum of the successfully created third path at 1589.57 nm.

**Conclusions**

The basic architecture of GMPLS-controlled multi-vendor WSON and signaling protocol extension for the multi-vendor WSON control were described. Interoperable demonstration of integrated control of both fully transparent wavelength paths and translucent wavelength path was successfully evaluated on the multi-vendor WSON testbed by introducing the common GMPLS lambda-label extension. Through this evaluation, we are confident that GMPLS protocols with lambda-label extension could effectively operate future all-optical networks, even consisting of multi-vendor equipment.

**Acknowledgment**

The authors thank all members of the Keihanna Interoperability Project who gave us insightful comments and suggestions for this evaluation.

**References**

- 1 G. Bernstein et al., "draft-ietf-ccamp-rwa-wson-framework-02.txt" (2009).
- 2 T. Tsuritani et al., "GMPLS-controlled All-optical Mesh Networking Demonstration using Path Computation-capable NMS" ECOC2008. We.1.B.1 (2008).
- 3 G. Bernstein et al., "draft-bernstein-ccamp-wson-signal-00.txt" (2009).
- 4 T. Otani et al., "draft-ietf-ccamp-gmpls-g-694-lambda-labels-04.txt" (2009).
- 5 G. Bernstein et al., "draft-ietf-ccamp-rwa-wson-encode-01.txt" (2009).
- 6 A. Giorgetti et al., "Routing and Wavelength Assignment in PCE-based Wavelength Switched Optical Networks" ECOC2008. Th.1.E.3 (2008).
- 7 G. Bernstein et al., "draft-bernstein-ccamp-wson-impairments-05.txt" (2009).
- 8 S. Seno et al., "Design of a Chromatic Dispersion Measurement Control Protocol Based upon the GMPLS Architecture" OFC/NFOEC2009. NMB4 (2009).
- 9 S. Seno et al., "draft-seno-ccamp-wson-impairment-compensate-ctrl-00.txt" (2009).
- 10 R. Casellas et al., "Design, implementation and validation within ADRENALINE® testbed of a Path Computation Element for Wavelength Switched Optical Networks" iPOP2008. T5-1 (2008).
- 11 ITU-T G.694.1, "Spectral grids for WDM applications: DWDM frequency grid" (2002).
- 12 ITU-T G.694.2, "Spectral grids for WDM applications: CWDM wavelength grid" (2003).