A Proposal for Software-Defined Circuit-Switched Networking on Optical Packet and Circuit Integrated Networks

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Abstract— **We present how software-defined circuit-switched networking (SDCN) should be realized on an autonomous-distributed controlled optical packet and circuit integrated (OPCI) network. We introduce a basic architecture suited for SDCN on the OPCI network. For OCS network virtualization, we propose to establish multi-wavelength logical paths as a C-plane slice. After creating a C-plane slice, unique control protocols/configurations (including signaling, routing for OCS, path computation, resource control, and so on) can be flexibly implemented for the C-plane slice on programmable platforms.**

Keywords-component; optical networks, optical packet switching, optical circuit switching, lightpath, software-defined networkings

I. INTRODUCTION

We have been developing an optical packet and circuit integrated (OPCI) network as a core network, in which both optical packet-switching (OPS) and optical circuit-switching (OCS) can be provided on the same fiber infrastructure [1]-[3]. The given optical bandwidth is separated into two resources (i.e. OPS-resource and OCS-resource) by means of wavelength division multiplexing (WDM) technologies, and the number of wavelengths in each resource can be dynamically allocated. The OCS occupies an end-to-end wavelength often called optical path or lightpath to provide high-quality services, while the OPS provides best-effort services. Our OPCI network achieves autonomous-distributed controls for signaling, routing for OCS and dynamic resource-allocation (DRA). In addition, OCS control messages (i.e. signaling, routing for OCS, etc) are transferred on OPS links in order to unify the control interfaces of both OCS and OPS.

In [1], we developed an OPCI node prototype equipped with both OPS and OCS devices, and demonstrated an 80 Gbps (10 Gbps × 8 wavelengths) multi-wavelength OPS with a packet-error rate of less than 10^{-4} and transfer of OCS control signals on the same optical packet links. A multi-wavelength optical packet is a packet consisting of multiple wavelengths in the resource allocated for packets. In [2], we developed an OPCI ring network node in which the OPS device has much higher stability than the one in [1] and can handle variable lengths and densities of packets. In [3], we developed an autonomous-distributed OCS control system for the OPCI network. The control system mainly consists of signaling, routing for OCS and DRA. The DRA automatically changes the amount of each of OPS- and OCS-resource depending on demands for optical paths.

On the other hand, network virtualization techniques [4] and software-defined networking (SDN) such as OpenFlow [5] will be key technologies for new-generation networks. By means of such technologies, diversified protocols and services can be effectively implemented and provided on a common physical infrastructure. However, currently, our conventional controllers in [3] can establish only one OCS control-plane (C-plane) with fixed configurations/protocols, and thus cannot meet distinct requirements (e.g. route of path, quality of services (QoS), and so on) to each logical network when the network will be virtualized. Therefore, we need to upgrade our controllers so that they can establish multiple C-plane slices with diversified/programmable configurations and protocols.

On the other hand, the OpenFlow protocol adopts a centralized control method. In [6], the OpenFlow protocol is used to unify the packet- and circuit-switching control. It would be useful for data centers (DCs) or local-area networks (LANs), but is not always suitable for large-scale core network. This is because the centralized control lacks scalability and it is unrealistic to manually set up paths by a centralized control every time a flow comes in the core network. In [7], optical FlowVisor is proposed to achieve optical network virtualization, but it is based on the OpenFlow protocol. Our OPCI network technologies adopt autonomous-distributed OCS controls for core networks, and thus, it is required to realize network virtualization and SDN suited for such controls on the OPCI network.

In this work, we present how software-defined circuit-switched networking (SDCN) should be realized on the OPCI network providing autonomous-distributed OCS controls. Here, SDCN includes not only SDN but also virtualization on OCS network resource. This is the first work to discuss SDN and virtualization on autonomous-distributed controlled and unified network environments simultaneously providing both OPS/OCS. We mainly focus on OCS in this work though it is possible to virtualize the OPS-resource as well as the OCS-resource. We introduce a basic architecture suited for SDCN on the OPCI network. Our architecture does not adhere to use the OpenFlow protocol. For OCS network virtualization, we propose to establish “multi-wavelength logical paths” as a C-plane slice. After creating a C-plane slice, unique control protocols/configurations (including signaling, routing for OCS, path computation, resource control, and so on) can be flexibly implemented for the C-plane slice on programmable platforms.

II. OPCI NETWORK

A. Concept

Figure 1 shows the concept of our OPCI network. Our network can provide diversified services on a common fiber infrastructure. The network separates the given wavelength bandwidth into OPS-resource and OCS-resource, and dynamically moves the boundary between those resources according to service usage conditions. We explain the DRA in the chapter II-B. *All* OCS control messages are transferred on OPS links. In other words, the network multiplexes and transfers both OCS control signals and packet data on the same OPS links in order to unify the control interfaces of both switching methods within a specific bandwidth for OPS. If OCS control packets are not delivered due to discarding of packets, the network cannot establish lightpaths. Thus, the network gives higher priority to OCS control packets.

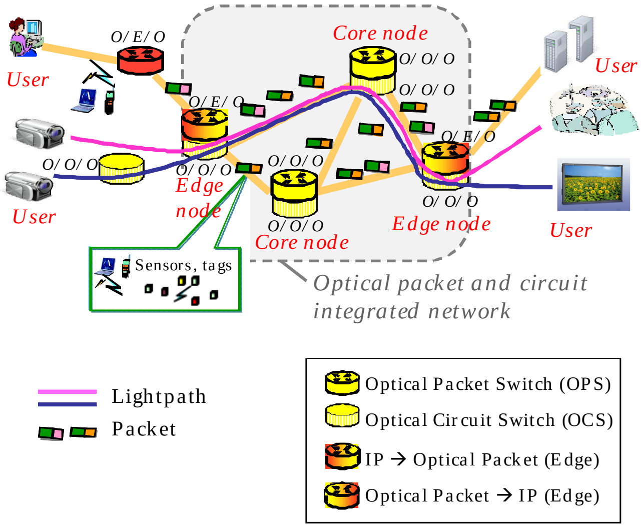

Fig. 1. Concept of our OPCI network.

B. *Control Mechanism*

Figure 2 shows the three autonomous-distributed control protocols in our OPCI network [3]: signaling and routing both for OCS, and DRA. As for the OPS control, each optical packet is transferred to the destination output port by packet-by-packet label processing and scheduling in each node [1][2]. The OPS control has not yet been interlocked with the other controls, but we plan to interlock them in future works.

One of the main characteristics of OPCI network is DRA. Each node can autonomously increase or decrease the OCS-resource for each link depending on the number of in-use lightpaths [3]. Figure 3 shows an image of DRA to OPS/OCS at each link interface. The wavelength bandwidth consists of three kinds of wavebands corresponding to the fixed OPS-waveband dedicated to OPS, the fixed OCS-waveband dedicated to OCS, and the shared-wavebands. Each of shared-wavebands is used for either OPS or OCS at one time depending on users' demand for optical paths. In this way, the amount of resources can be dynamically changed between OPS and OCS. At present, we assume that each of the fixed OPS-waveband and fixed OCS-waveband contains 10 wavelengths (hereafter 10-λs), and all other wavelengths are included in the shared-wavebands. Inside each node, every time signaling messages are transferred for lightpath setup or release, the wavelength usage status is autonomously checked at each input and output interface in each relevant node. Then, each node autonomously adjusts the OCS-resource if the status meets a predefined condition: For example, when a lightpath is established, the OCS-resource increases from 10-λs to 20-λs if the number of in-use lightpaths reaches 9 within the fixed OCS-waveband. Similarly, when a lightpath is released, the OCS-resource decreases from 20-λs to 10-λs if the number of in-use lightpaths is less than 9 and equals to zero within the fixed OCS-waveband and its adjacent shared-waveband, respectively. We can flexibly change the condition if necessary. Note that the conditions need to be the same at coadjacent interfaces on a link connecting two nodes. The OCS-resource at each link interface is adjusted independently of the status of OCS-resources of other interfaces. The process of DRA also changes the structure of

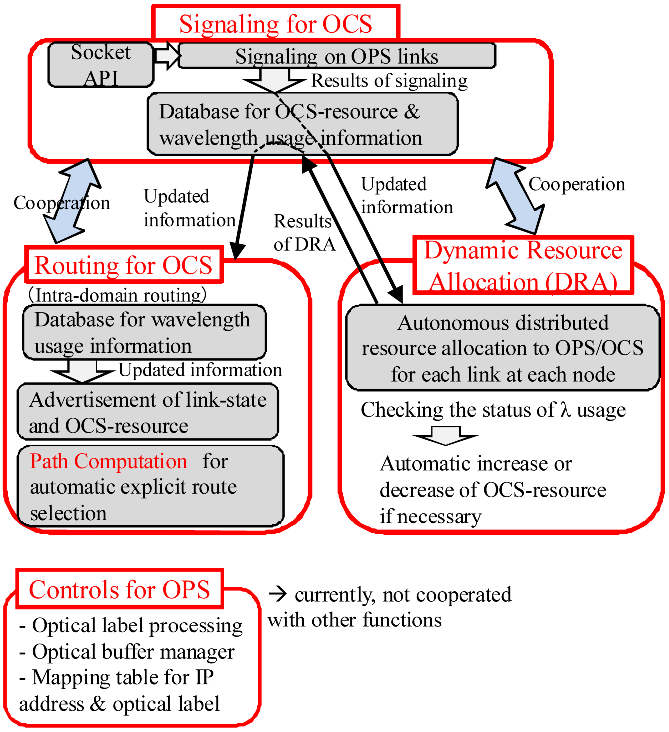

Fig. 2. Control mechanism at each core node in our OPCI network.

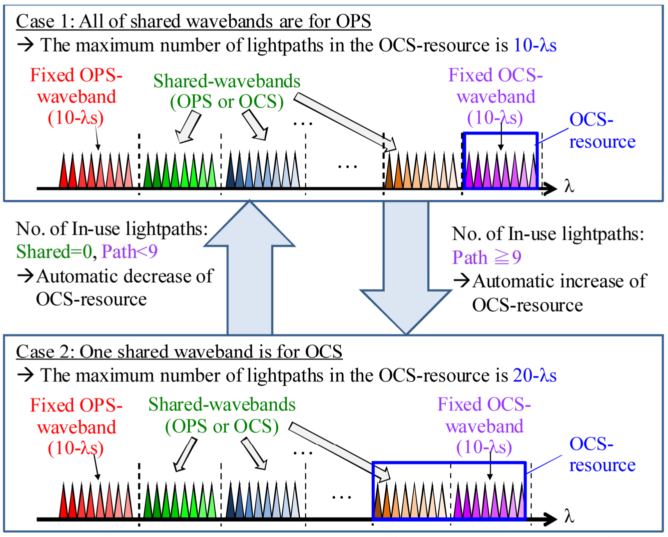

Fig. 3. An image of DRA at each link in our OPCI network.

optical switch on the D-plane because a shared-waveband is switched to OPS or OCS.

In our control system, the signaling and routing protocols each have a database for both the OCS-resource and wavelength usage information in each relevant link at each node. Every time lightpath establishment, lightpath release, or DRA is executed, each protocol updates the information in the database.

III. A BASIC ARCHITECTURE SUITED FOR SDCN ON THE OPCI NETWORK

Figure 4 illustrates an image of slicing by OCS network virtualization. Recently, the OpenFlow has been the most likely candidate for the control protocol in DCs or LANs. The major advantage of using the OpenFlow is that it is possible to easily control and manage the statuses of switches by only one centralized control system. It would be useful for data centers (DCs) or local-area networks (LANs), but is not always suitable for large-scale core network. This is because the centralized control lacks scalability and it is unrealistic to manually set up paths by a centralized control every time a flow comes in the core network. Currently, autonomous-distributed controls would be more suitable for controls of core networks than centralized controls such as OpenFlow. Thus, our OPCI network mainly adopts autonomous-distributed controls. However, regardless of the styles of control methods, end-to-end C-plane slices can be created over multiple networks including the OPCI network and DCs (or LANs) as described in Fig. 4. And, on each C-plane slice, end-to-end wavelength paths are dynamically established or released by use of the reserved wavelengths. Inside the OPCI network, each wavelength on C-plane slices corresponds to a unique substantial wavelength on OCS D-plane. This means that the OCS D-plane is logically separated by WDM technologies and the C-plane slices occupy distinct substantial wavelengths on the OCS D-plane each other. Note that the reserved wavelengths on each C-plane slice are variable. There are several functions between OCS C-/D-plane, which perform not only controls of optical switches including DRA [3] but also creation of C-plane slices.

Figure 5 shows a basic architecture for SDCN on the OPCI network. Each C-plane slice can be created by establishing multi-wavelength logical paths on all relevant fiber links/nodes. Note that those paths are logical ones, and not substantial/physical lightpaths. The number of wavelengths on the logical paths (i.e. a C-plane slice) depends on a QoS (bandwidth) requirement received from the creator of the C-plane slice. Each C-plane slice may consist of continuous multiple wavelengths and also it would be possible to create a C-plane slice by selecting discontinuous wavelengths. When a C-plane slice is created, some multicast signaling protocol may be required because it is possible that a node has more than two logical link interfaces on a C-plane slice. Upon request of the creator of a C-plane slice, the multicast signaling protocol automatically reserves multiple wavelengths for all relevant links/nodes on the C-plane slice in an autonomous-distributed control. After a C-plane slice is created, unique configurations and protocols are set for the C-plane slice depending on requirements to the network. In this work, we do not focus on how to establish multi-wavelength logical paths and also how to set unique configurations/protocols on each C-plane slice in details, but focus on only a basic architecture suited for SDCN on the OPCI network. (We will consider the way to automatically set unique configurations/protocols on each C-plane slice by means of some autonomous-distributed control mechanism.) For example, as described in Fig. 5, signaling protocol, routing protocol for OCS, path computation, constraints on routes of lightpaths, resource allocation control, wavelength conversions, and so on, can be determined and flexibly changed on each C-plane slice. Since the OCS C-plane is programmable, it does not need to adhere to our conventional autonomous-distributed OCS control mechanism discussed in [3]. Hence, even though large-scale core networks should adopt autonomous-distributed controls, it is possible to adopt and install some centralized control protocols as well as autonomous-distributed controls. Inside the control system, every time the unique configurations and protocols are installed, they are automatically associated with the wavelengths on each C-plane slice. As for controls of optical switches, the OCS C-plane directly sends/receives messages to/from optical switches in order to change the structure of optical connections inside the switches. There will be various protocols to control optical switches: For example, general switch management protocol (GSMP) [8], transaction language 1 (TL1), or other switching control protocols. Note that the function to create C-plane slices performs only reserving/occupying a waveband, and thus does not execute controls of optical switches because C-plane slices are logical paths. When the network tries to establish or release a wavelength path (i.e. a substantial lightpath) by use of the signaling protocol, control of optical switch is executed at each relevant node as described in [3].

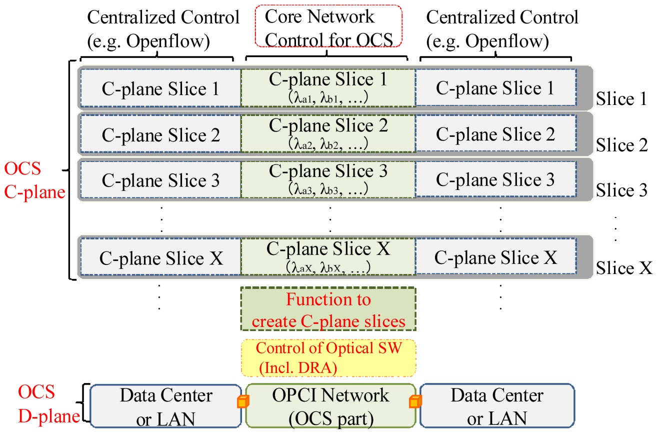

Fig. 4. An image of slicing by OCS network virtualization.

Here, the OPS links transfer not only packet data and OCS control messages (i.e. signaling, routing for OCS, etc) but also messages to create C-plane slices (i.e. establish multi-wavelength logical paths) by means of optical packets with the fixed OPS-waveband [3]. The controllers can distinguish various kinds of signals by checking the packet header field or the contents of messages. In order to identify the C-plane slice related to each OCS control packet, some slice ID can be defined or added to the optical packet format.

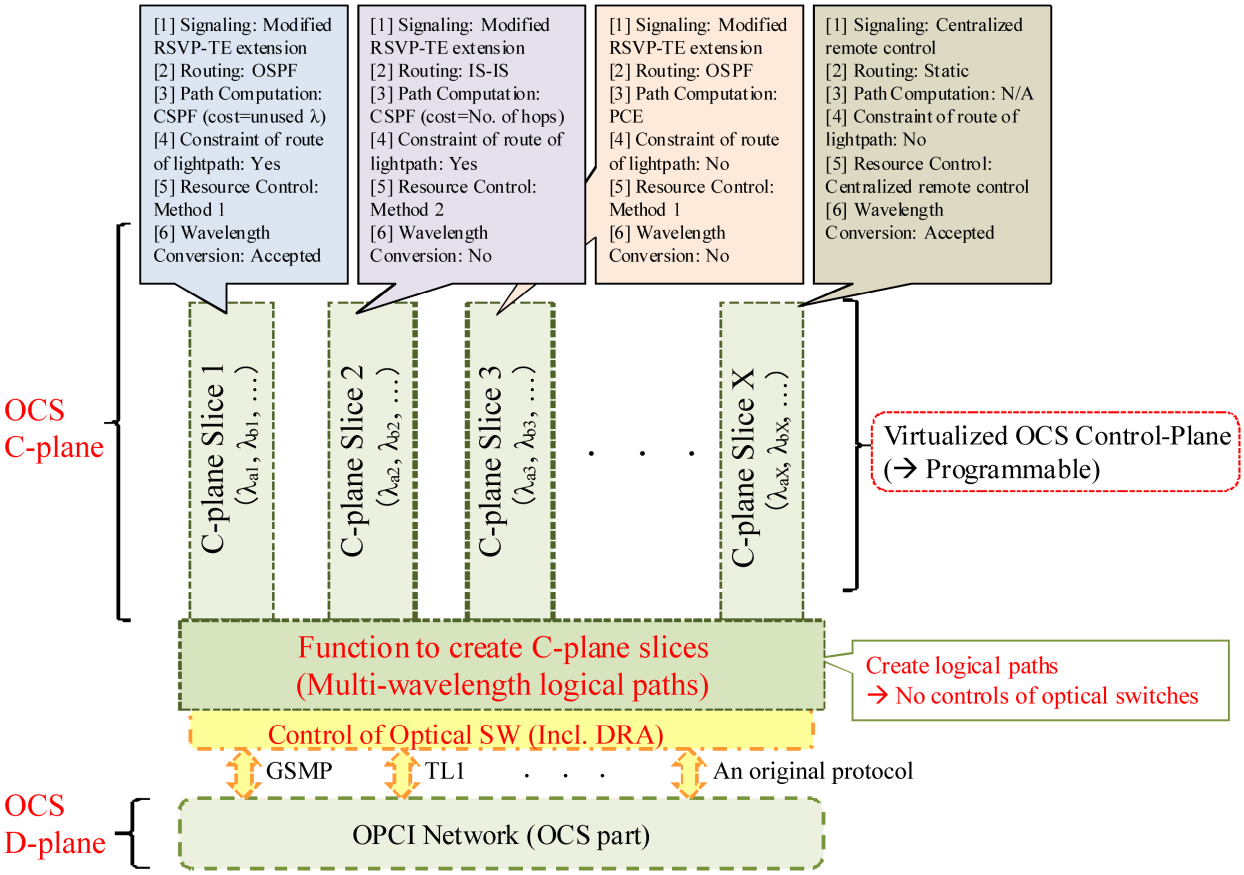

Fig. 5. A basic architecture for SDCN on our OPCI network.

The architecture in Fig. 5 does not yet have a management mechanism, but it may become complicated because the network will need to frequently obtain and manage information on many C-plane slices in real time. Thus, the management system will need high-speed performance and some sophisticated network management protocol. However, in this work, we do not focus on network managements.

IV. CONCLUSION

We presented how to realize SDCN on an autonomous-distributed controlled OPCI network, and introduced a basic architecture suited for it. For OCS network virtualization, we proposed to establish multi-wavelength logical paths as a C-plane slice. After creating a C-plane slice, unique control protocols and configurations (including signaling, routing for OCS, path computation, DRA, and so on) can be flexibly implemented for the C-plane slice on programmable platforms. On each C-plane slice, when the network tries to establish or release a substantial lightpath, control of optical switch is executed at each relevant node.

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