Cost-Effective Control Plane Design for Optical Sub-Wavelength Switched Ring Network

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***Abstract*—Optical sub-wavelength switched networks have been attracting attention as a cost-effective solution, especially for bursty metro-area networks. Although such networks fully use wavelength capacity and provide bandwidth flexibility, a stable and/or robust control plane is necessary for dynamic control scenarios. Moreover, the required resources for the control channel are considerable when we aim at high-frequent information gathering to achieve on-demand follow-up control. In this paper, we propose a cost-effective control plane design method for efficient traffic accommodation in future metro networks. This method uses a control-signal mediator that can efficiently suppress the required bandwidth resources.**

Keywords—Optical sub-wavelength switched network; Control plane; Centralized dynamic control; Mediator

I. INTRODUCTION

Network traffic is increasing exponentially; therefore, it is becoming increasingly necessary to create networks cost-effectively in terms of equipment expense and/or power consumption. In access networks, next-generation wired (optical) and wireless (mobile) access technologies have been developed to meet future service requirements. In addition, virtualization technologies have recently been considered as valid approaches for better resource utilization, especially in core networks. These emerging technologies make traffic more bursty, increasing dynamic traffic flow in future metro networks. To respond to this trend, we previously proposed an optical sub-wavelength switched network architecture that can efficiently accommodate traffic in large-scale metro networks [1-2]. Several other related studies have been conducted [3-6] and some cost estimations have suggested the effectiveness of optical sub-wavelength switched networks [7]. Therefore, these technologies can be defined as a promising solution for bursty metro-area networks rather than traditional ROADM and Ethernet over WDM options.

Among related architectures [1-6], there are differences in optical components and the way the WDM channels are used, but each WDM channel in an optical fiber is generally divided into fixed time intervals known as time slots (TSs). Then, at every fixed time period, some TSs can be allocated to each path according to the traffic volume in order to follow the traffic fluctuation. On the other hand, there is a common key challenge with an efficient control plane (C-plane) for intelligent path provisioning and adaptive bandwidth control. Moreover, the required bandwidth resources for the C-plane need to be considered, especially when we assume high-frequent information gathering through in-band signaling to achieve on-demand follow-up control. In this paper, we propose a cost-effective C-plane design method and report on our evaluation of its effectiveness.

II. OPTICAL SUB-WAVELENGTH SWITCHED RING NETWORK

Our assumed network model is a ring-based network that connects core and access networks. The outlines of a single-ring network connected to routers and aggregation switches and a node system (OL2SW-node [1-2]), an example of an implementation of an optical sub-wavelength switching node, are depicted in Figs. 1 and 2, respectively. To enable efficient traffic accommodation, the bandwidth of all paths needs to be controlled by the optimal granularity for traffic fluctuation. Hence, each WDM channel is time-slotted and each path-bandwidth is re-optimized with a brief period based on in-band control signal exchange, which enables WDM channels to be shared by many paths. However, a dedicated C-plane becomes mandatory to manage optical burst transport (avoid burst collisions in optical buffer-less networks) and it must be stable and efficient.

In general, the C-plane can be classified into two main types; centralized and distributed. The network performance between the two types was compared, which revealed that the centralized type is more suitable for higher throughput [8]. In addition, another study clarified that dynamic bandwidth control, in which each path bandwidth is explicitly reserved on a slot-by-slot basis according to signaling (bandwidth request),

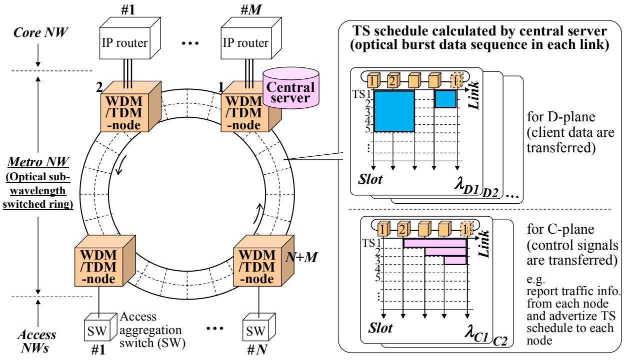


Fig. 1. Outline of network architecture.

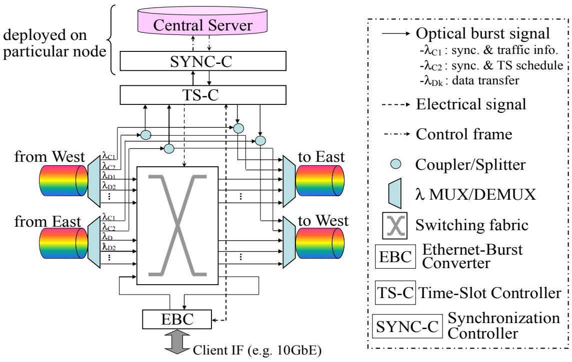


Fig. 2. Example of node (WDM/TDM-node) architecture.

is very effective when the propagation delay is relatively small (e.g. less than a few milliseconds) [9]. This means that on-demand bandwidth control with in-band signaling is effective in almost all metro networks. Although on-demand control is possible when high-frequent information gathering is achieved, high-frequent gathering increases the amount of TS resources for the C-plane. Therefore, a cost-effective C-plane design method needs to be developed for on-demand bandwidth optimization, which leads to economical networks with much fewer WDM channels and less equipment.

III. COST-EFFECTIVE CONTROL PLANE DESIGN

In this section, we present our C-plane design method for on-demand bandwidth optimization with much fewer resources. The main objective in this paper is reduction in bandwidth resources for control signal exchange while suppressing the disadvantages (e.g. additional delay, implementation complexity). We use the concept of mediation function, or "mediator", which was developed and commercialized to implement traffic monitoring in large-scale IP-based core networks [10]. The implementation of the mediator in optical sub-wavelength switched networks and a C-plane design method are described as follows.

A. *Introduction of Burst-data Mediator*

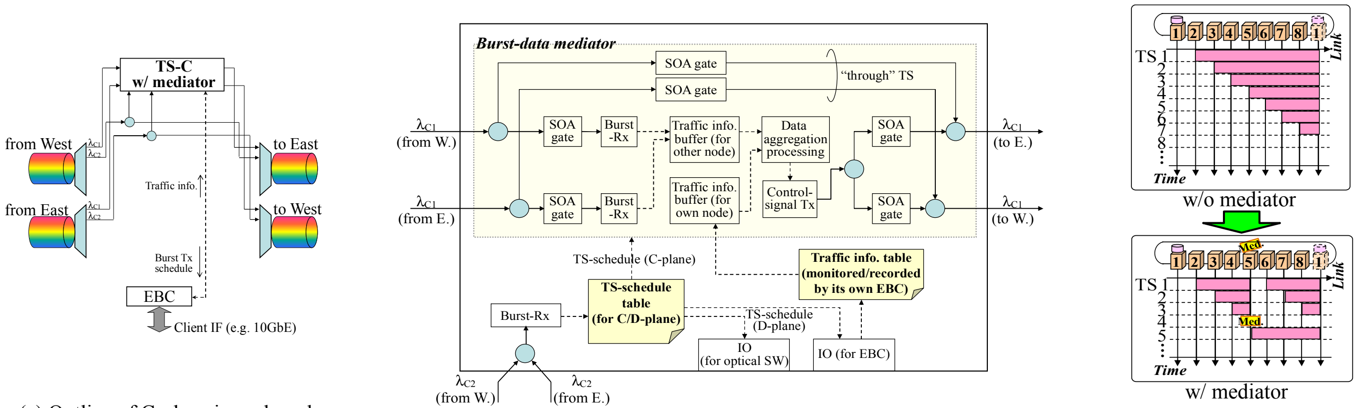
In optical sub-wavelength switched networks, control signals are transferred on an allocated TS(s) on a particular wavelength(s). Therefore, some optical devices that extract the desired TSs/wavelengths are required. In addition, TDM-based (time-driven) electrical components that mediate the control signal are also applied. Examples of the C-plane in the assumed network and the burst-data mediator are shown in Figs. 3(a) and 3(b), respectively. In addition, the difference in the TS used in the C-plane is shown in Fig.3(c). In the "w/ mediator" case, a burst-data mediator is deployed at node 5 and the number of allocated TSs on the link between nodes 8 and 1 is reduced. This can lead to reduction in required resources or more frequent signal transfer with the same C-plane resources.

B. *Control Plane Design Method*

For creating the C-plane, the placement of mediators (hereafter, we define the node at which a mediator is deployed as the mediation node), routes, and TSs for control signal transfer must be determined. The primitive approach, which is used to try all combinations and select the best one to achieve an optimal solution, generally requires unreasonable computation time, which is not suitable for large-scale dynamic networks. Thus, we propose an efficient design method that consists of the following three steps.

Step 1. Mediator placement: First, we present a comparative method called "equally distributed" which deploys mediators on equally-spaced nodes in terms of hop number and ties are randomly broken. This simple method is suitable for a uniform network model (e.g. logically full-meshed). However, realistic networks have geographical differences in terms of population, number of subscribers, and link distance. Specifically, the amount of the control signals (e.g. bandwidth request) of each node generally depends on the number of connections and subscribers, then its distribution is far from uniform in realistic networks. Moreover, metro networks generally differ from the full-meshed model because metro networks are asymmetric aggregation networks in many cases. Therefore, we stretch the concept of this simple method and try to equalize the amount of aggregated control signals at each mediation node. This method selects a mediator placement that minimizes the standard deviation of each aggregated control signal amount from mediation node combinations of which the number of nodes between mediation nodes is less than a particular threshold (in this paper, 4 is set).

Step 2. Route/TS assignment for each node (control signal to mediation node): For reducing the design time complexity, in



(a) Outline of C-plane in each node at which mediator is deployed.

(b) Functional schematic of burst-data madiator.

(c) Example of TS allocation for C-plane (in 8-node ring).

Fig. 3. Introduction of burst-data mediator to C-plane in optical sub-wavelength switched network.

descending order of node ID, we apply the shortest routes and assign the available TSs in the well-known first fit manner.

Step 3. Route/TS assignment for mediation node (signal to server-deployed node): In the same way as in the previous step, in descending order of node ID, we apply the shortest routes and assign the available TSs in the first fit manner.

IV. PERFORMANCE EVALUATION

We conducted several computer simulations to evaluate the effectiveness of our method. We assumed the network model as described in Sec. II. The tested physical topology was a single bi-directional ring with four connected IP routers. The geographical placement of nodes (two types; connected to the IP router and connected to the access switch) was randomly selected, where the ring circumference was smaller than 400 km. The number of subscribers on each node was randomly determined, i.e., connection requests or logical paths were also randomly generated between the IP router and access switch. The TSs for control signal exchange were assigned, where the capacity of each wavelength was 10 Gbps (= 100 TS). First, we evaluated the required C-plane bandwidth resources against the number of mediators in a 128-node network to clarify the general effect of mediator introduction. Fig. 4 plots the average amount of required TSs for the C-plane, which is normalized by the result when no mediator was introduced. The results show that the proposed method can drastically suppress the required resources and even the simple "equally distributed" method can achieve 40-% reduction. The difference between the proposed and equally distributed methods results from non-uniformity of the network in terms of the amount of control signals. This reveals that the equalization of aggregated control signal amount with the proposed method is effective in suppressing the required bandwidth. Please note that the difference between the proposed and equally distributed methods becomes smaller with the number of nodes connected to the IP router because it gets closer to a uniform full-meshed model, which is not explicitly discussed in this paper. On the other hand, mediators naturally result in additional cost in terms of node equipment; thus, the number of mediation nodes should be lower. We therefore set the number of mediation nodes to eight and evaluated the number of TSs for the C-plane, which is shown in Fig. 5. The proposed method allowed the maximum network size to be more than three times larger when the admissible number of TSs for the C-plane was 50 in the assumed model. Consequently, we investigated the effectiveness of the proposed method, and cost-effective C-plane design was achieved.

V. CONCLUSION

We introduced a burst-data mediator to an optical sub-wavelength witched network and proposed an efficient control-plane design method. Our method selects the adequate mediator placement to equalize the amount of control signal exchange throughout the network. The numerical results suggested that the required bandwidth for the control plane can be suppressed significantly. Therefore, our method will be effective in creating future metro networks cost-effectively.

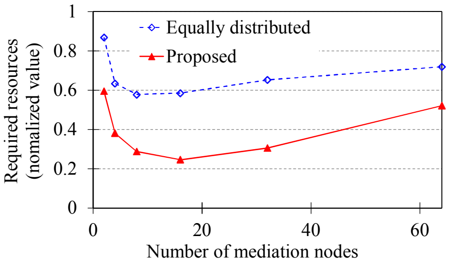


Fig. 4. Required C-plane bandwidth resources in 128-node ring network.

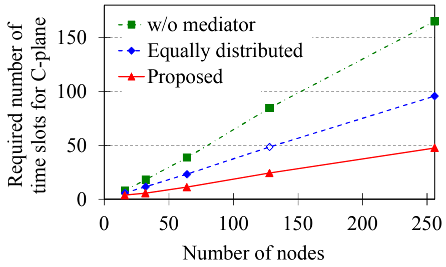


Fig. 5. Required number of TSs with 8 mediation nodes.

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