Resource Efficiency of Multiband Massive Wavelength-Multiplexing Metro Networks with Remotely Located Transceivers

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Abstract: *This paper investigates the impact of remotely located transceivers on the performance of energy-efficient metro networks with programmable wavelength selective switches for end-to-end optical connections. We quantify resource efficiency of the remotely located TRX model.*
Keywords: Optical core/metro network architecture, design, control, and management

I. INTRODUCTION

To achieve the ultra-low latency required by next-generation Beyond 5G (B5G) networks, optical transport networks offering end-to-end direct optical connection are a promising solution [1, 2]. Furthermore, reducing energy consumption in transport networks, particularly metro access networks, handling ever-increasing traffic volumes, is crucial. To address these challenges, all-photonics network technologies have been extensively investigated [3-6]. A key device in reconfigurable add-drop multiplexers (ROADMs) is the contentionless wavelength selective switch (WSS). While it can improve wavelength resource efficiency, this benefit comes at the cost of high complexity and poor energy efficiency. ROADMs with contentionless WSS are therefore may not be optimal especially for metro networks. Given this, low-cost ROADM architectures have attracted significant research interest [4,6,7]. We previously proposed a highly energy-efficient metro network called M3 Wavenet (multiband massive wavelength-multiplexing metro network) [6]. M3 Wavenet utilizes a newly developed contention-based programmable WSS with low power consumption. Although contention WSS can reduce cost and power consumption, network performance may deteriorate due to wavelength contention. WSS performance evaluation has been widely investigated [8,9]. Pavon-Marino et al. conducted the performance comparison of contention and contentionless ROADM [8]. The impact of wavelength contention in add/drop blocks (ADBs) of a ROADM that accommodates transceivers (TRXs) was investigated in [9]. However, these studies do not account for remotely located TRXs. In optical transport networks providing end-to-end optical direct optical connection between users, TRXs are typically installed at user locations, separate from ROADMs, and are remotely connected to them [2,3]. Remotely located TRXs cannot be shared by different users, which may negatively impact the utilization efficiency of network resources, including TRXs. Therefore, in this paper, we evaluate resource efficiency, specifically in terms of connection blocking probability, in metro networks with remotely located TRXs. We aim to clarify the feasibility of the remote TRX model for end-to-end direct optical connection services.

II. MULTIBAND MASSIVE WAVELENGTH-MULTIPLEXING NETWORKS WITH REMOTELY LOCATED TRXS

We present an overview of an M3 Wavenet and then describe models of conventional ROADM architectures and remotely located TRXs.

A. Architecture

M3 Wavenet with remotely located TRXs is illustrated in Fig. 1. The network consists of ROADMs, physical fiber links, and TRXs located at remote user sites. To provide end-to-end optical connection, the network supports 200+ channels per fiber using massive wavelength-multiplexing. The bandwidth of each wavelength channel is relatively narrow (less than 25 Gbps), so we newly developed fine-pitch and highly energy-efficient programmable WSS in support of less than 6.25 GHz switching resolution. Each optical path terminates at a remote TRX located at a user site outside of telecom buildings.

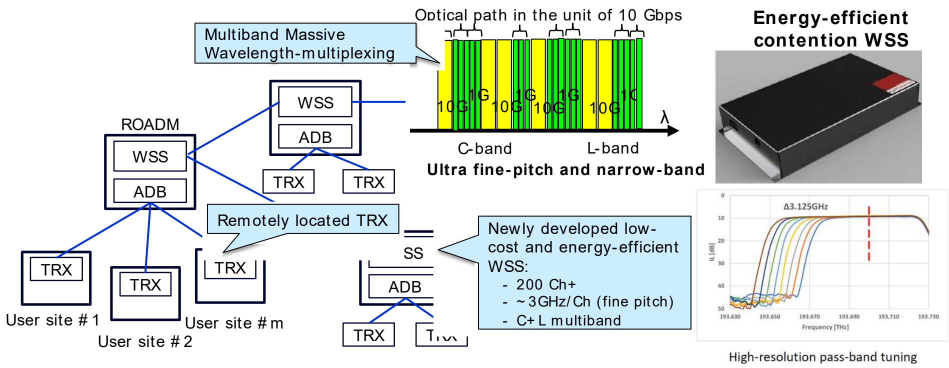

Figure 1 Architecture of multiband massive wavelength-multiplexing metro networks (M3 Wavenet)

B. *Model Description*

We now compare a conventional shared TRX model with a remote TRX model. As illustrated in Fig. 2, in the conventional model, each TRX is directly attached to a ROADM in the same telecom building. A set of TRXs attached to the same ROADM can be shared by multiple users. On the other hand, in the remotely located TRX model, a set of TRXs accommodated by the same ROADM cannot by shared by different users. This may degrade the utilization efficiency of TRXs and lead to an increase in connection blocking probability.

Next, we describe the WSS model. Contentionless WSS is widely deployed in current ROADMs to improve flexibility and wavelength efficiency. However, these benefits come with higher cost and lower energy efficiency This restricts their application in metro networks. For cost and energy efficient metro networks, we newly developed contention-based programmable WSS as illustrated in Fig. 1. Our contention WSS can operate less than 10 W and support high resolution. A contention WSS cannot accommodate the same wavelength from/to different input/output ports, which may deteriorate network performance in terms of connection blocking probability.

Now we define the problem we are addressing. We quantitatively investigate the impact of the remotely located TRX model and contention WSS in M3 Wavenet. Performance evaluation of contention and contentionless WSS in the remotely located TRX model has not yet been investigated. To clarify these impact on network performance, we establish design principles of metro networks providing end-to-end direct optical connections.

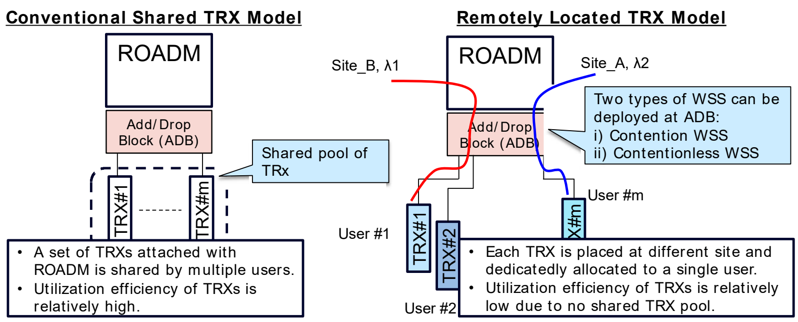

Figure 2 Comparison of conventional shared transceiver model with remote TRX model

III. Performance Evaluation

A. *Aims and Conditions*

We performed extensive simulation experiments to clarify the impact of the remotely located TRX model and highly efficient contention WSS. Before presenting the key results, we describe the aims and conditions of our simulation experiments. The performance evaluation aimed to determine i) how the remotely located TRX model affects overall network performance and ii) how the performance of contention WSS is affected by the remotely located TRX model.

We deployed a fifteen-node multi-ring network where each node accommodates up to eight TRXs. Optical connections were randomly generated in accordance with a Poisson arrival process. We varied the inter-arrival time from 5 to 100 and the number of wavelengths from 8 to 128. Holding time of connections was determined by an exponential distribution, and the service rate was fixed at 1000. We generated about 5,000,000 connections in each experiment. We compared the connection blocking probability of the conventional model with the remotely located TRX model. We deployed two types of WSS: contentionless and contention WSS.

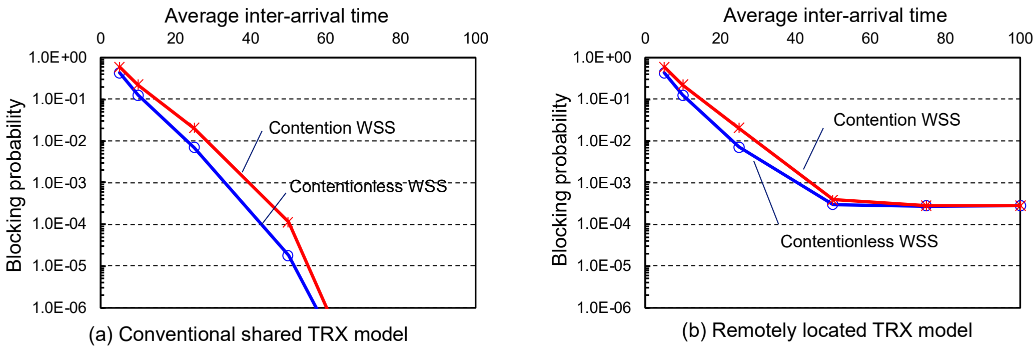

Figure 3 Performance comparison of conventional model with remotely located TRX model with contention/contentionless WSS

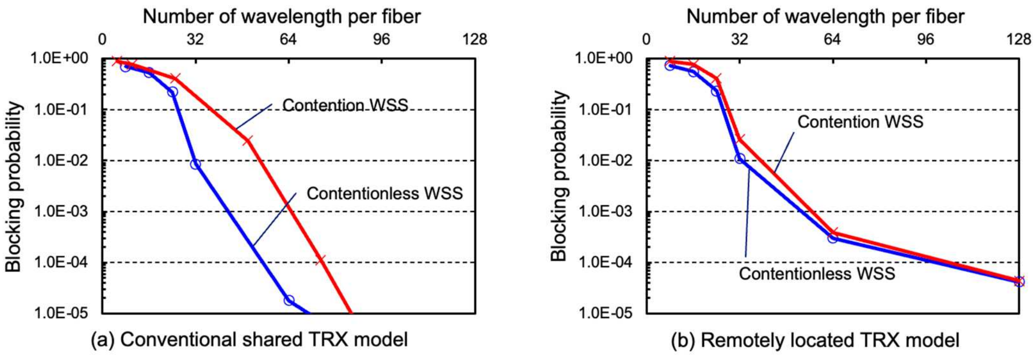

Figure 4 Dependence of connection blocking performance on the number of wavelengths per channel

B. Impact of remotely located TRXs and contention WSS

First, we investigated the resource efficiency of the conventional model with the remotely located TRX model while varying the average inter-arrival time of connections. For each experiment, we deployed contention/contentionless WSS and 64 wavelengths per fiber. The results are shown in Fig. 4. In the conventional model, the blocking probability rapidly decreased as the average inter-arrival time increased. Conversely, in the remotely located TRX model, the blocking probability leveled off around 10^{-4} or higher. This occurs because blocking is caused by the unavailability of ports at an ADB, in addition to wavelength resource exhaustion. If a user engaged in a call and a new connection request is made to that user, the request will be blocked at an ADB port. Approximately 30% of blocking was attributed to ADB ports in the case of contention WSS. If we remove the effects of blocking on ADB ports, we can improve the resource efficiency of the remotely located TRX model.

Next, we investigated the dependence of connection blocking performance on the number of wavelengths per channel. The results are shown in Fig. 5. The number of wavelength was varied from 8 to 128. In both models, blocking probability was sufficiently low when the number of wavelengths is 64 or higher. Regarding performance with contention WSS, if the number of wavelengths is 64 or higher, there is no significant difference in performance between contention and contentionless WSSs. Note that the threshold (i.e., 64 wavelengths) is entirely dependent on the number of TRXs in the network.

In summary, if metro networks support a large number of wavelengths per fiber, the remotely located TRX model can achieve sufficient blocking performance, such as 10^{-3} or below. Moreover, we can further reduce network cost and energy consumption by deploying contention WSS instead of contentionless WSS when using 64 or more wavelengths.

IV. CONCLUSIONS

This paper investigated the resource efficiency of multiband massive wavelength-multiplexing metro networks with remotely located transceivers, focusing on blocking probability. It was clarified that the remotely located TRX model can achieve acceptably low blocking probability with 64 or more wavelengths per fiber. It was also demonstrated that deploying contention WSS in networks with a high wavelength count can further reduce both network cost and energy consumption.

ACKNOWLEDGMENT

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