Collision Aware Flow-Based Adaptive Resource Allocation for SDN-enabled SDM Optical Packet Switching Networks

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Abstract

We propose a flow-based adaptive resource allocation in SDM-OPS networks. It attained 24.6% of packet loss probability and 13.8% of the proportion of Degraded Flows compared to baseline methods. Furthermore, its feasibility was verified via functional experiment using real testbed emulated as SDM environment.

Introduction

Owing to the rapidly increasing traffic demand in networks, space-division multiplexing (SDM) has been intensively researched in the last few years to further expand the fiber capacity [1-3]. In recent years, research and development have been conducted on optical packet switching (OPS) networks to realize more flexible and efficient accommodations of services in the time domain [4-7]. Furthermore, active research and development are also being conducted on OPS with SDM environments for improved speed and large capacity of communications [8-12]. The optical packet spatial super-channel (pSSC) framework, proposed in [8], is a promising solution for realizing OPS in SDM environments because the cost of switching nodes can be reduced by jointly switching multiple spatial channels (See Fig.1).

In the current optical device technologies, an optical buffer that enables random access has not been realized. Therefore, load balancing is especially required in OPS networks. In the pSSC

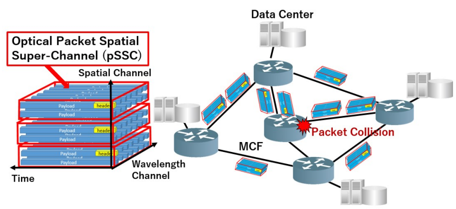


Fig. 1: SDM-WDM OPS Network

framework, the packet length is extremely short because the payload is distributed over multiple wavelength/spatial channels over each link. Therefore, it is difficult to implement complicated load balancing control in pSSC units with extremely fine time granularity. To implement a global load balancing control, a flow unit control with rough time granularity is more suitable than a pSSC unit.

In this study, we propose a flow-based spatial channel resource allocation method considering the load status on the transfer route to reduce the packet loss due to packet collisions. We evaluate the performance of the proposed method via computer simulations and verify the basic function of switching the spatial channel resources in the proposed method using a testbed emulated as an SDM environment.

Related Works

In Ref. [8], a scheme was proposed that constructed an optical pSSC using all wavelength/spatial channel resources in SDM-WDM OPS networks. In the pSSC framework, the granularity of the data to be switched becomes rough by switching the spatial channels jointly in the switching node, thereby reducing the cost of the switching node. Refs. [9][10] demonstrated the high-speed switching of pSSCs on a testbed using the developed pSSC node.

A fractional pSSC switching system design wherein the spatial channel resources were sliced into multiple fractional spatial channel resources was proposed [11][12]. In this framework, the pSSC was transmitted in units composed of fractional spatial channel resources instead of all of the available spatial channel resources. A pSSC collision at a switching node can be avoided by transferring the pSSC to another fractional spatial channel resource in a multi-core fiber. Nevertheless, the packet loss ratio tends to be higher owing to the buffer-less environment.

Proposed Method

To further reduce the pSSC loss due to collision at the switching nodes, we propose flow-based spatial channel resource allocation. In this study, we assume the SDM-WDM OPS networks proposed in Refs. [11][12]. In this network, all spatial channel resources are sliced into multiple fractional resources (hereinafter, referred to as “RU (resource unit)”) and the pSSCs are transmitted via RUs.

In the proposed method, each switching node in the network counts the number of pSSC arrivals for each RU of each output port and manages them in the “Statistical Table”. A software-defined network (SDN) controller collects the latest Statistical Tables from all switching nodes in the network at fixed time intervals. Based on the number of pSSC arrivals obtained from the collected Statistical Tables, the pSSC arrival rate is calculated and updated using the exponentially weighted moving average (EWMA). Based on the pSSC arrival rate, the “Collision Probability” for each RU of each output port in all switching nodes is approximately calculated using the Erlang B formula. Collision probability is defined as the probability that a packet is lost owing to the collision that occurs when the pSSC assigned to each RU arrives at the switching node, and all calculated values are managed in the “RU Load Management Table” on the SDN controller.

Figure 2 outlines the process of RU allocation to a new flow. When a new flow occurs in the network, the RU Load Management Table in the SDN controller is referenced. Based on the

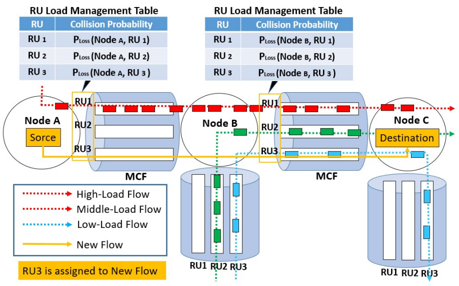


Fig. 2: RU allocation to a new flow

collision probability, $P_{Loss}(Node_n, RU_i)$, at each RU, $RU_i(i = 1, \cdots, S)$, of each output port at each node, $Node_n(n = 1, \cdots, N-1)$, on a predetermined route through which the flow passes, the “Transmission Success Probability” for each RU, $P_{success}(RU_1), \cdots, P_{success}(RU_S)$, is calculated using Equation (1). Transmission success probability is defined as the probability that a packet reaches its destination, assuming that RU_i is assigned to the packet.

$$P_{success}(RU_i) = \prod_{n=1}^{N-1} (1 - P_{Loss}(Node_n, RU_i)) \quad (1)$$

Referring to the transmission success probability, $P_{success}(RU_1), \cdots, P_{success}(RU_S)$, of all RUs calculated by the above procedure, the RU with a high transmission success probability is assigned to the flow.

It should be noted that to suppress excessive load concentration on a specific RU, an “Allowable Threshold,” P_T, is set when determining the RU to be assigned to the flow. With the transmission success probability for each RU, $P_{success}(RU_1), \cdots, P_{success}(RU_S)$, calculated by the above procedure, RU_m with the highest transmission success probability, $P_{success}(RU_m)$, is selected as the candidate RU for the allocation. Then, all values of RU_i that satisfy $P_{success}(RU_i) > P_{success}(RU_m) - P_T$ are added to the candidates, and an RU is randomly assigned to the flow from the candidate RUs, where P_T denotes some margins.

Performance Evaluation

Simulation

The performance of the proposed method was evaluated via computer simulations. We adopted the Kanto topology (11 nodes and 18 bidirectional links) of the JPN-48 model [13] as a test topology. Each link had one Multi Core Fiber (MCF) in each direction, and the number of RUs in each MCF was six. We adopted a gravity model in which the traffic distribution between each node depends on the product of the surrounding population and distance of the node pair. The arrival interval of flows and the generation interval of pSSCs within a flow followed an exponential distribution. The average packet generation interval was randomly determined in the range of 0.0125 to 0.0375 ms for each flow, and the flow average arrival interval was changed as a parameter. The duration of a flow was 5000 ms constantly. The update interval of the RU load information in the proposed method was set to 1000 ms. For simplicity, collision avoidance, such as inter-core switching, deflection routing, or buffering with fiber delay line, was not performed. The length of pSSC was 0.0012 ms and the processing delay during switching was 0.0012ms. In the above simulation environment, the proposed method was compared with the flow-based random allocation and round-robin allocation techniques.

Figure 3 shows the simulation result of the packet loss probability. In comparison to other methods, the proposed method improved the packet loss probability. In the proposed method, when the allowable threshold P_T was set to 0.1% and 1.0%, the performance degradation was suppressed at a high load in comparison to the case of “without the allowable threshold.” The proposed method (P_T=1.0%) demonstrated dramatically smaller packet loss probability, which is 24.6% of the random allocation case on average. In addition, Figure 4 shows the proportion of flows whose packet loss probability exceeds 10^{-3} (defined as “Degraded Flows”). For fair evaluation, the average packet generation interval for each flow was fixed at 0.0250 ms. The proposed method (P_T=0.0%) demonstrated dramatically smaller proportion of Degrated Flows, which is 13.8% of the random allocation case on average.

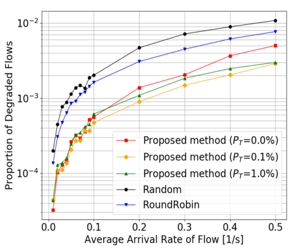


Fig. 3: packet loss probability

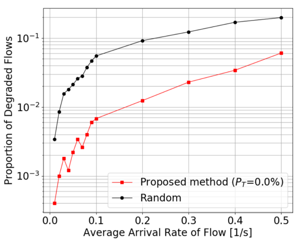
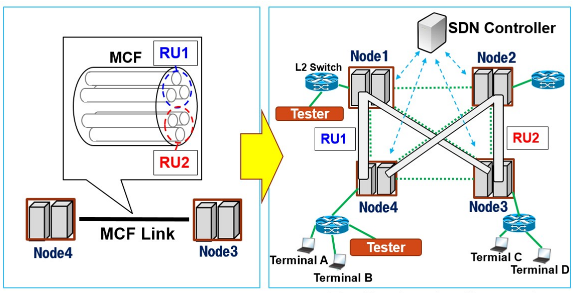


Fig. 4: proportion of degraded flows

Demonstration Experiment using Testbed

To verify the basic functions of the proposed method, we performed a demonstration experiment using the testbed at the Resilient ICT Research Center of National Institute of Information and Communications Technology.

Figure 5 shows the configuration of the testbed. We emulated the testbed as an SDM environment. Because the testbed does not support an SDM optical network, we emulated two different paths from node 4 to node 3 (node 4 → node 1 → node 3, and node 4 → node 2 → node 3) as two RUs (RU1 and RU2) in an SDM optical network. In the above experimental setup, the transmissions of MainFlowA (terminal A → terminal C) and MainFlowB (terminal B → terminal D) were started simultaneously. RU1 (route : node 4 → node 1 → node 3) was assigned to the flow generated in MainFlowA and RU2 (route : node 4 → node 2 → node 3) was assigned to the flow generated in MainFlowB. In MainFlowA and MainFlowB, an active period of 10000 ms for packet generation (in this experiment, we considered such packet groups as a “flow”) and the subsequent pause period of 2000 ms were repeated alternately. Next, using a tester, the heavy load flow (“Interference Flow”) was transmitted on the route of RU1. Consequently, RU1 (at the output port to node 3 in node 1) became overloaded.

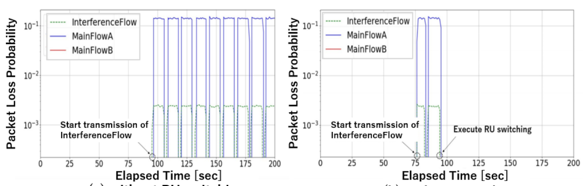


Assumed SDM network **Testbed actually used (Pseudo SDM network)**

Fig. 5: Experimental setup

The SDN controller collected the number of packets that arrived at each node at an interval of 1000 ms and updated the packet arrival rate using the EWMA with a coefficient of 0.1. In this experiment, when the packet arrival rate of RU1 exceeded the preset RU switching threshold (300000 [packet/s]), the load on RU1 significantly increased. Then, the RU assigned to the flow generated in MainFlowA was switched from RU1 to RU2.

Figures 6 illustrate the results for the packet loss probability of MainFlowA, MainFlowB, and Interference Flow “(a) without RU switching” and “(b) with RU switching,” respectively, based on the proposed method. In the case of “(b) with RU switching,” the period of packet loss probability deterioration is shorter than that in the case of “(a) without RU switching,” and it is evident that the average packet loss probability has been improved.



(a) without RU switching (b) with RU switching

Fig. 6: Packet loss probability (MainFlowB has no collision)

Conclusions

We proposed a flow-based adaptive resource allocation method in SDN-enabled SDM optical packet switching networks. We verified the effectiveness of the proposed method through simulations as well as an experiment using a testbed emulated as an SDM environment.

Acknowledgments

This research was supported by the JSPS KAKENHI Grant Number JP17H00734. The authors wish to thank Dr. M. SHIRAIWA, Dr. S. XU, and Mr. W. REN for their technical support.

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