Flow Aggregation and Migration Scheme Based on Real-time Monitoring for Time-varying Traffic in Optical Networks

Yuan Wen, Wei Guo, and Weisheng Hu
State Key Laboratory of Advanced Optical Communication Systems and Networks
Shanghai Jiao Tong University, China

Abstract— We propose a flow aggregation and migration (AM) scheme for circuit switched optical networks. In our proposed AM scheme, flows could be aggregated into a lightpath to improve bandwidth utilization and be migrated from heavily loaded lightpath to avoid packet loss. The benefits of improved bandwidth utilization and reduced blocking rate are illustrated through simulation results.

1. INTRODUCTION

Nowadays, the transport network is experiencing a challenge of bulky data transfer for large-scale applications, such as E-science computing, data center data back-ups and cloud services [1]. When these applications require high transmission rate (e.g., 10 GE or more), a lightpath with guaranteed bandwidth provided by optical circuit-switched networks becomes an effective solution to meet application performance requirements, such as bit rate, packet loss and latency. However, the bandwidth of a lightpath is often underutilized. A major reason is that flows generated by applications may have a time-varying bandwidth demands, typically, higher traffic volume during daytime and lower traffic volume at night. If a lightpath is dedicatedly used by a flow, this may lead to bandwidth resource waste when flow rate becomes low.

In order to make better utilization of bandwidth resources, we proposed a flow aggregation method implemented by an extended SDN controller [2]. This method is to aggregate multiple fine-granularity flows into a lightpath, whose bandwidth resources have not been fully utilized. In this way, these flows can share the same lightpath and lightpath bandwidth utilization increases. However, the transmission rates of flows vary frequently over time. If the total transmission rate of the flows exceeds the bandwidth of the lightpath, packet loss will occur and transmission quality of flows will degrade.

In this paper, we propose a flow aggregation and migration scheme (AM) based on real-time monitoring to improve bandwidth utilization while guaranteeing transmission performance of the entire network. Our method is to aggregate some fine-granularity flows (with low-priority) into a lightpath with spare bandwidth resources. To guarantee transmission performance, the low-priority flows will be migrated into another lightpath when bandwidth resources of the original lightpath are used up. Since flow migration needs time, we set a threshold to control the maximal load in the lightpath. Once the overall flow rate exceeds the threshold (but still less than the bandwidth of the flightpath), flow migration will be executed to reduce packet loss. Due to the flexible programmability of SDN controller to flow, we can easily complete the flow aggregation and flow migration. We have tested the performance of our extended controller on our testbed. Experimental results show that our extended controller can migrate a flow from one lightpath into another in 2 seconds, with no influence on data transmission delay and packet loss of the original flow (with high-priority). In addition, we can reduce the packet loss of low-priority flows by reducing the threshold. We also conduct simulations, which illustrate that our AM scheme improves the lightpath bandwidth utilization and reduces the blocking rate.

2. SDN BASED IP OVER OPTICAL NETWORKS ARCHITECTURE

As shown in Figure 1, we proposed an SDN based IP over optical networks architecture, where packets are transmitted by SDN switches, and SDN switches are connected by circuit-switched optical connections. Our extended SDN controller controls the SDN switches via OpenFlow [3]. The management plane of the optical network set up a lightpath based on network resource state and application demands. The extended SDN controller can acquire the information of lightpaths in the form of network abstraction by management plane.

In Figure 1, we assume that a high-priority flow (the red line) is transmitted by a 10 Gbps lightpath between two end-systems with guaranteed bandwidth and packet loss rate. The rate

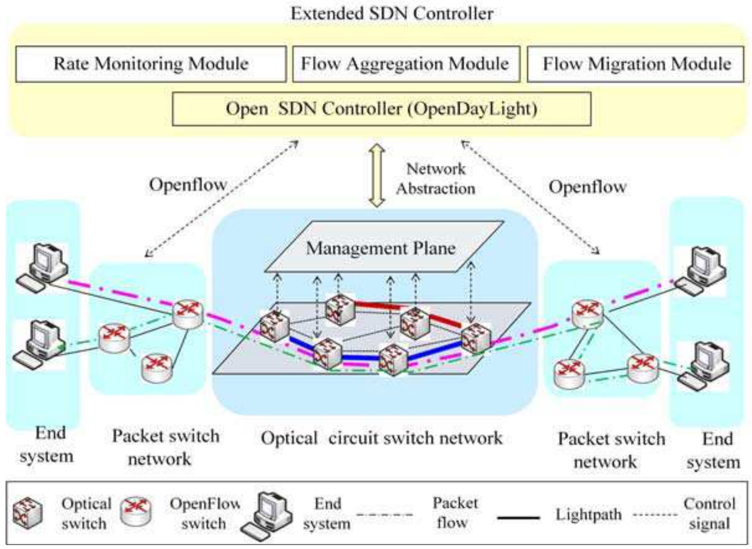

Figure 1: SDN based IP over optical networks architecture.

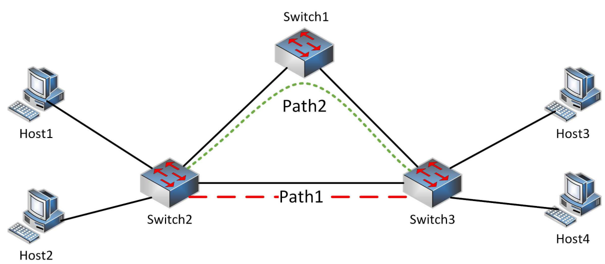

Figure 2: Experiment network topology.

monitoring module will always monitor the transmission rate of all flows, with the assistance of which, the controller could acquire the usage of all lightpaths. When a new low-priority flow (e.g., the green line in Figure 1) arrives, if the lightpath has enough unused bandwidth capacity to transmit the low-priority flow, the controller will use the flow aggregation module to aggregate the low-priority flow into the lightpath in the IP network by configuring flow entry in SDN switch. When the transmission rate of flows increases and finally exceeds the lightpath bandwidth, the rate monitoring module will perceive this event and notify the controller. In order to guarantee transmission performance of the flows, the controller will migrate the low-priority flow from the lightpath into another lightpath which has enough unused bandwidth. If no lightpath could transmit the flow, the management plane of the optical network will set up a new lightpath for the flow.

3. EXPERIMENT ON FLOW MIGRATION TIME

Our extended controller will migrate flow(s) from lightpath when the bandwidth resources are used up to avoid transmission performance decline. However the packet loss will still occur if the transmission rate increases too fast that the controller could not complete the migration of flow in time. Figure 3(b) Illustrates the reason of packet loss, the shaded part represents the lost packets. We define flow migration time as the duration from transmission rate exceeding the lightpath bandwidth to controller accomplishing the migration of flows.

We extend the feature module on the SDN open source controller OpenDayLight [4] and choose Open vSwitch [5] as SDN switch considering its advantages of flexible configuration, low cost, and easy extension. Our experimental network topology is shown in Figure 2, including 4 hosts connected to 3 Open vSwitch through 1 GE interface. High-priority Flow 1 is between Host 1 and Host 3, and low-priority Flow 2 is between Host 2 and Host 4. We use Iperf to transfer UDP flows. In order to guarantee the transmission quality of high-priority Flow 1, we can set priority queue in SDN switch ports, insert the Flow 1 into high-priority queue and insert the Flow 2 into low-priority queue. In this way, the packet loss of Flow 1 will not appear. As shown in Figure 3(a), in Step 1,

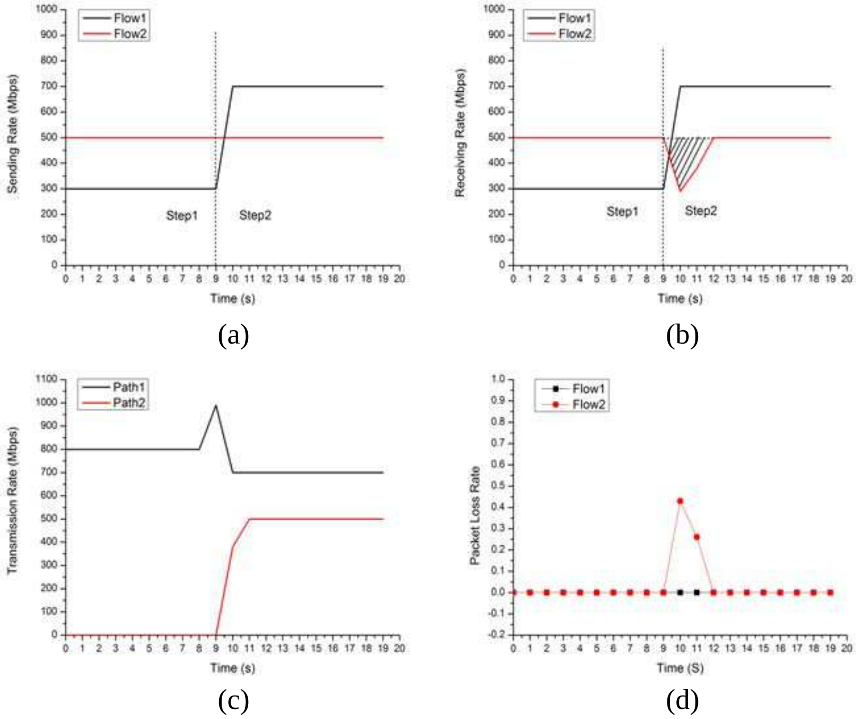

Figure 3: (a) Sending rate of Flow 1 and Flow 2. (b) Receiving rate of Flow 1 and Flow 2. (c) Transmission rate in Path 1 and Path 2. (d) Packet loss rate of Flow 1 and Flow 2.

the send rate of Flow 1 and Flow 2 are 300 Mbps and 500 Mbps respectively, and they share the bandwidth of Path 1 (red line). In Step 2, we increase the send rate of Flow 1 to 700 Mbps, and the total send rate in Path 1 exceeds the bandwidth of Path 1. As we can see in Figure 3(d), Flow 2 has packet loss for two seconds, then it returns to normal because the controller migrates Flow 2 into the Path 2 (green line). This indicates that the extended controller needs about 2 seconds to migrate a flow from one lightpath to another. During the migration, the low-priority flow will have packet loss while the transmission performance of high-priority flow will be guaranteed.

4. AGGREGATION AND MIGRATION SCHEME

Actually, the dynamism of IP convergence flows is smooth, which means that flows rates seldom change rapidly in an instant. To reduce packet loss of low-priority flows, we propose a flow Aggregation and Migration Scheme in the IP-over Optical network. In our scheme, we set a threshold for lightpath, which is a constant used to control the maximal load in the lightpath. When the transfer rate exceeds the threshold, the controller could migrate the flow into another lightpath. As long as the transfer rate does not exceed the bandwidth of lightpath during flow migration (about 2 seconds according to our experiment result), packet loss of low-priority flow could be avoided. We assume that many lightpaths with large bandwidth capacity have already existed for high-priority flow usage, and the transfer rate of the high-priority flows are time-varying. Low-priority request flows arrive dynamically. The workflow is shown as follows.

Step 1: Controller collects information about lightpath.

Step 2: When a new request flow arrives, search the lightpath database to find the lightpaths which have the same source and destination address. Aggregate the flow into one of these lightpaths whose total transmission rate after aggregation does not exceed the threshold. Add the flow into transmission queue and jump to Step 4. If no lightpath is found to aggregate the flow, jump to Step 3.

Step 3: Set up a new lightpath for the request flow and jump to Step 1. If there is no resource available to set up a new lightpath, block the request and jump to Step 2.

Step 4: Acquire the transfer rate of the flows in the transmission queue and update the usage of lightpaths. If the load of a light exceeds the threshold, choose a low-priority flow to migrate. We treat it as a new request flow and jump to Step 2.

5. DEMONSTRATION AND SIMULATION

We deploy an experiment to demonstrate our scheme. The experimental environment is the same as in Section 3. In this experiment, we set the threshold as 90% of path bandwidth capacity. As shown in Figure 4(a), in Step 1, send rates of Flow 1 and Flow 2 are 300 Mbps and 500 Mbps respectively, and they are transmitted normally. In Step 2 we increase the send rate of Flow 1 to 450 Mbps. As shown in Figure 4(d), both flows are also transmitted normally without any packet loss. However,

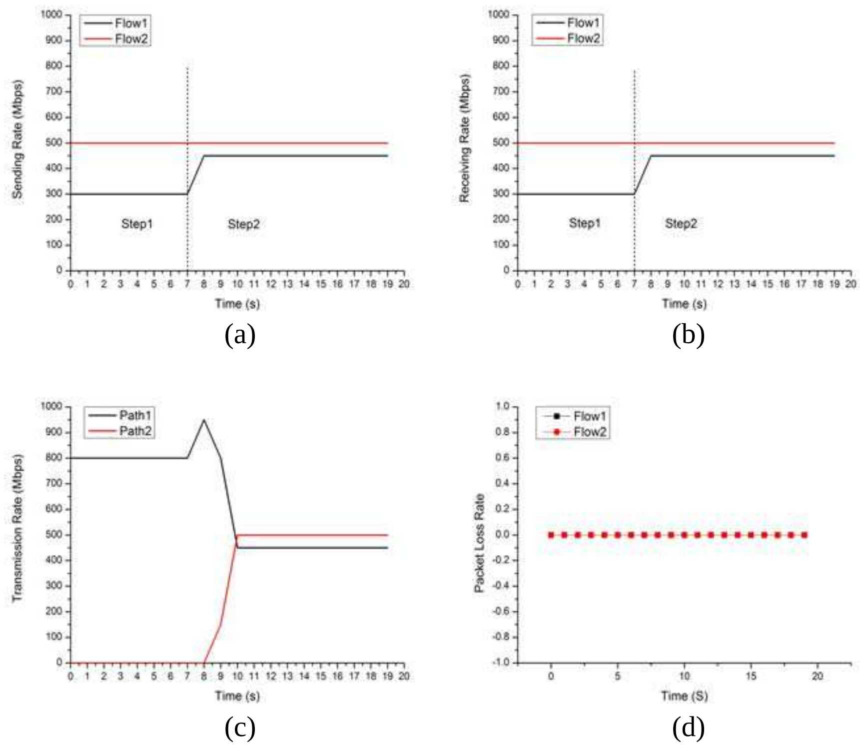

Figure 4: (a) Sending rate of Flow 1 and Flow 2. (b) Receiving rate of Flow 1 and Flow 2. (c) Transmission rate in Path 1 and Path 2. (d) Packet loss rate of Flow 1 and Flow 2.

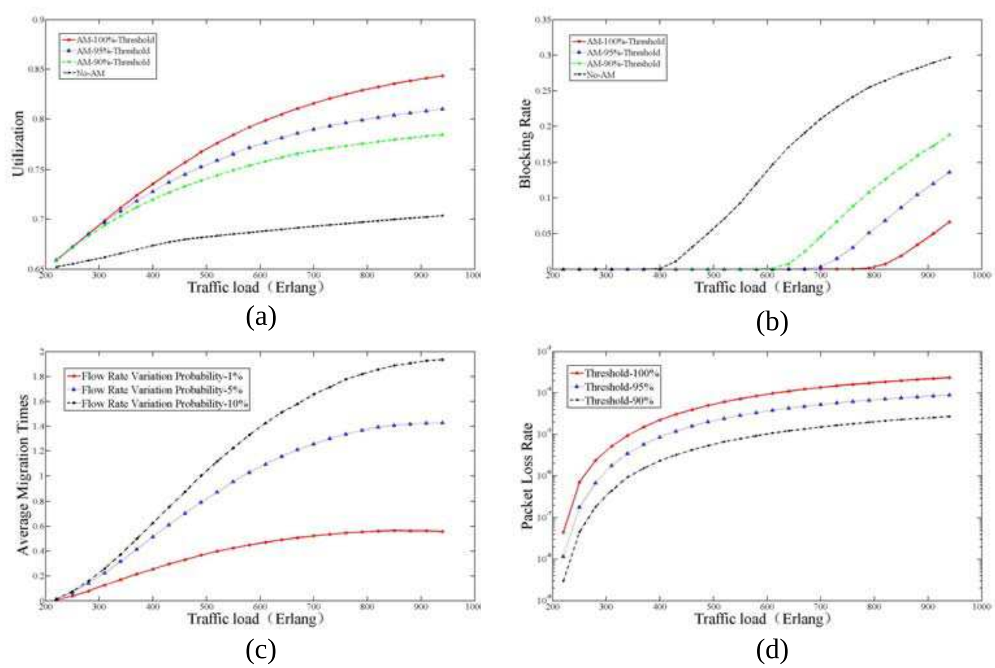

Figure 5: (a) Utlization vs. traffic load. (b) Blocking rate vs. traffic load. (c) Average migration times vs. traffic load. (d) Packet loss rate vs. traffic load.

from Figure 4(c) we can see that Flow 2 has been migrated into Path 2. This experiment results suggests that as long as the total transmission rate does not exceed the lightpath bandwidth, we can migrate a flow from a lightpath into another without any packet loss with the assistance of a pre-specified threshold value.

In order to evaluate our proposed scheme, we conducted simulations over 14-node NSFNET. We assumed that initially each link has a bandwidth of 320 Gbps. 200 lightpaths with 10 Gbps bandwidth has already existed in the network and each lightpath has a high-priority flow. The arrival of requests follows the Poisson distribution with rate λ. Source node and destination node are randomly generated among the 14 nodes. The bandwidth of request low-priority flows is 1 Gbps, and the duration time of the request chosen from an exponential distribution with a mean value of 1000 s. We assume that transmission rate of both high and low priority flow will fluctuate between 50% and 80% of the request bandwidth. If a request cannot be delivered successfully, we consider it to be blocked. We analyze our scheme in terms of lightpath utilization and blocking rate.

Figure 5(a) shows the lightpath utilization rate performance of our AM scheme and traditional bandwidth allocation policy which allocates a single lightpath for every flow under various traffic loads. We observe that our AM scheme increases the lightpath utilization compared to traditional policy. This is because the flow aggregation makes use of unused bandwidth resources of lightpath. and the lightpath utilization increases as the threshold increases. Figure 5(b) shows the blocking rate performance of our AM Scheme and tranditional bandwidth allocation policy under various traffic loads. We can observe that our scheme has lower blocking rate than traditional bandwidth allocation policy. That is because many flow can share same lightpath using our scheme, the network can transmit more request flow. Figure 5(c) shows the average times of migration. We can observe that every flow in the network will be migrated 1.5 times in average. This will not degrade the performance of controller. Figure 5(d) shows the packet loss rate of our scheme. We can observe that the packet loss rate will decrease as the threshold reduces. As a result we can reduce the packet loss rate by reducing the threshold when packet loss rate is high.

6. CONCLUSION

In this paper, we proposed a flow aggregation and migration (AM) scheme for optical networks. Flows could be aggregated into lightpath with spare bandwidth resources and be migrated from heavily loaded lightpath. Experimental results show that we can guarantee the transmission quality of high-priority flows and reduce packet loss of migrated low-priority flow under our scheme. Simulation result shows that our AM scheme improves lightpath bandwidth utilization and reduces blocking rate. We can also reduce the packet loss rate of low-priority flows by reducing the threshold.

REFERENCES

1. Smarr, L., "The OptIPuter and its applications," *LEOSST*, 151–152, 2009.
2. Guo, W., B. Wang, Y. Jin, et al., "Joint optimization of transmission performance and bandwidth utilization based on software defined networks," *Optical Fiber Communications Conference and Exhibition (OFC)*, 1–3, 2014.
3. McKeown, N., T. Anderson, H. Balakrishnan, et al., "OpenFlow: Enabling innovation in campus networks," *ACM SIGCOMM Computer Communication Review*, Vol. 38, No. 2, 69–74, 2008.
4. http://www.opendaylight.org.
5. http://openvswitch.org.