Experimental Demonstration of Multipath and Continuous Repetition in Optical Packet/Circuit Networks

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Abstract: *We implement and test a highly reliable optical packet transmission using multipath and continuous repetition techniques. We experimentally demonstrate their functionalities in an optical packet network testbed, showing more than 90% decrease of packet loss.*
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I. Introduction

Future 5G and beyond communications will require not only ultra-high capacity, but also low latency and highly reliable data transmission. Optical packet/circuit integrated network is a promising candidate network to support these challenging future network requirements. A possible approach to realize highly reliable communication is to reserve protection resources at optical circuit level (several protection schemes have been studied in optical networks [1, 2]). Another approach is to increase resistance to packet loss and network failures at packet level. Retransmission of lost packets is executed in various network segments, as, e.g., in the mobile transport network, but, since packet retransmission requires packet loss detection and packet retransmission, it might introduce significant additional delay before finishing data transmissions. As an alternative to packet retransmission, packet duplication (or "repetition") has been proposed as a simple yet effective technique to stochastically minimize packet loss, at the expense of an increased capacity utilization. In this paper, we develop an SDN-based Optical Packet/Circuit Integrated (OPCI) node [3] and experimentally demonstrate the functionalities of multipath and continuous repetition using packet-transmission experiments over an OPCI network testbed.

II. Multipath and Packet Duplication for Highly Reliable Transmissions

Several studies focused on how to provision network services that are reliable against link failures[4]. In optical packet-switched networks, not only high resilience to link/node failure but also low packet loss characteristics are important, particularly for latency sensitive communications where long delay caused by retransmission is not acceptable.

This paper investigates how multipath transmission and continuous repetition can help achieving reliable transmission based on optical packet duplication technology in OPCI networks, as shown in Fig. 1. In an OPCI network duplicated packets can be transmitted via multiple paths not only optical to decrease packet loss, but also to provide support against temporal network failure. A key function of this packet-based multipath is to distribute packets over multiple routes to avoid packet losses due to local failures. Another approach is packet repetition transmission in the same route. Different from the first approach, continuous packet repetition does not deal with network failures, but, on the other hand, the packet repetition technique does not cause out-of-order problem. From OPCI node perspective, optical packet repetition rate can be adjusted and improves packet error due to stable optical input power at a receiver node although low packet transmission rate causes relatively high packet loss due to low average optical power in time domain. In this approach, the source node duplicates optical packets and transmits multiple optical packets to the same output fiber using same wavelength channels with minimum guard time. That is, duplicated packets are immediately transmitted after the original packet. This approach can be used if there is enough capacity at output fiber. At the destination node, the node checks the header of optical packets and remove unnecessary duplicated packets.

III. Experimental Demonstration of Multipath and Continuous Repetition Transmissions

We experimentally demonstrate an SDN-based optical packet transmission using multipath and continuous repetition transmission (CRT) in a ring-based OPCI network. Figure 2(a) shows the experimental setup. We used one OPCI controller, four OPCI nodes, four layer-2 switches, two router testers, and two computers. The OPCI controller controls the configuration of each OPCI node and collects the node status and statistics of packet transmissions at each OPCI node (see [3] for more detailed information about the structure of an OPCI node). We adopted iperf2 to measure network-level

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transmissions. UDP packets generated by UT-1 (iperf sender) are sent OPCI-1 and transmitted to UT-3 (iperf receiver). The transmission rate from iperf sender is set to 100 Mbps and duration of packet transmission is set to 10 seconds for each experiment. A router tester continuously generates from 1 Gbps to 10 Gbps Background traffic Flow (BF). Specifically, BF #1 from RT-2 to RT-4 and BF #2 from RT-4 to RT-2 are transmitted to evaluate the impact of optical packet collision at OPCI-2 or OPCI-4. In addition, optical circuit-based connections between each OPCI node are configured over different wavelength channels. We demonstrate 7 optical packet transmission cases as follows.

Case 1. Single path #1 (BF #1)
Case 2. Single path #2 (BF #2)
Case 3. Single path #1 w/ CRT (BF #1)
Case 4. Multi-path (BF #1)
Case 5. Multi-path (BF #1 & #2)
Case 6. Multi-path w/ CRT (BF #1)
Case 7. Multi-path w/ CRT (BF #1 & #2)

Cases 1 and 2 are optical packet transmission with neither multipath nor continuous repetition technique. Note that we adjust output optical power to OPCI-2 at OPCI-1 for denser packet transmissions and therefore packet loss occurs if throughput of optical packets is low. Case 3 is the case of continuous repetition transmission using single path (Route #1). At OPCI-1, each packet from UT-1 is immediately duplicated and continuously transmitted to the next node. In Cases 4-7, packets from UT-1 are duplicated and transmitted using two transmission routes (Route #1 and #2). In addition to this multipath transmission, packets are also duplicated in time domain and continuously transmitted to each output link in Cases 6 and 7. In Cases 4 and 6, only background traffic BF #1 is transmitted. In Cases 5 and 7, two background traffic BF #1 and BF #2 are transmitted, i.e., packet loss due to collision occurs along both routes.

We show the results collected by a spectrum analyzer and an oscilloscope at the input of OPCI-3 in Figs. 2(b) and 2(c) respectively. Fig. 2(b) confirms that, not only multiple optical circuit-based connections (optical paths), but also optical packets are present at the measurement point shown in Fig. 2 (a). In this capture, the optical power is lower than other optical paths. This is because optical packets are sparsely transmitted in time domain, therefore the measured average power becomes low. Fig. 2(c) confirms that the duplicated packet is continuously transmitted after original packet with minimum guard time. In addition to this, two packets of background traffic can be seen in this figure. In this case, original and duplicated packets successfully arrived at OPCI-3 without packet loss. Note that, although the transmitted distance of RT-2 background traffic is shorter than that of the main packets from UT-1, we set the optical power level of background traffic lower than the one of main packet stream in order to distinguish packets from UT-1 and RT-2 in an oscilloscope.

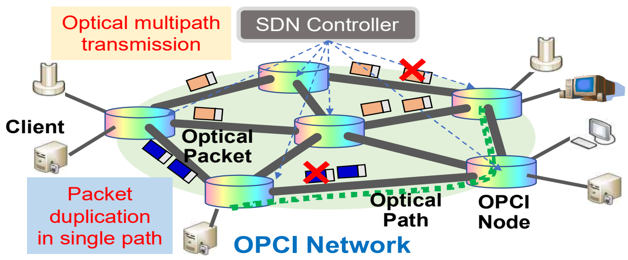

Fig. 1. SDN-based OPCI network with packet duplication.

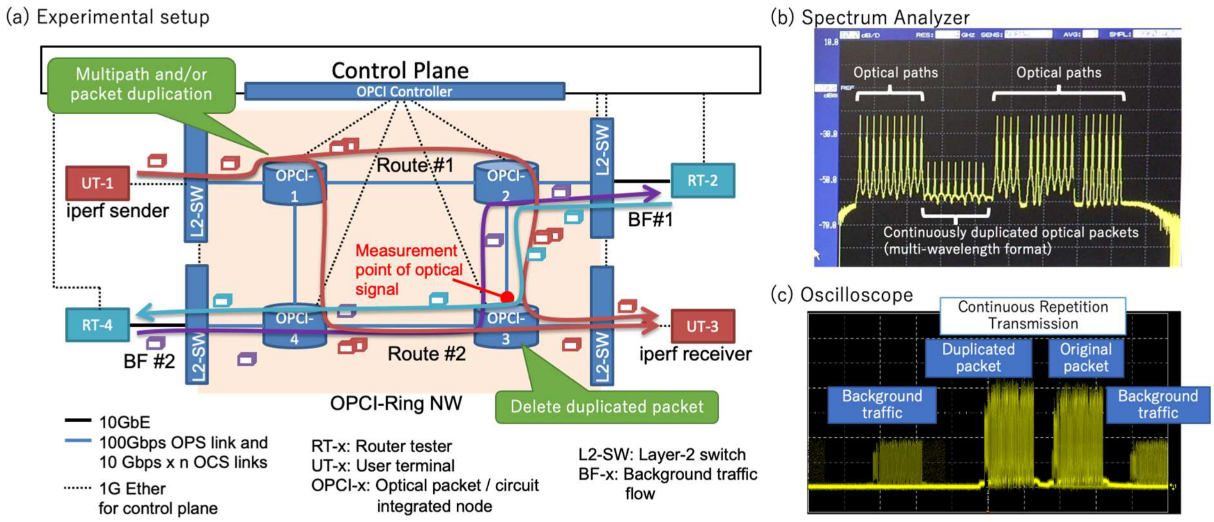

Fig. 2. Demonstration; (a) experimental setup, (b) spectrum analyzer, (c) oscilloscope.

Next we evaluated the performance of each case in terms of packet loss rate, jitter of packet arrival and redundant packet reception ratio. We measured these metrics using iperf2, and repeating the experiment 10 times for each case. Figure 3(a) plots the packet loss rate of each trial. From this figure, while simple transmission in Cases 1 and 2 achieved high packet loss rate, multicast and/or continuous repetition transmission technique can drastically improve the packet loss rate. Among them, Cases 6 and 7, which use a combination of multipath and continuous repetition, can reduce packet loss as 1/100 compared with single path transmission case. Transmission with continuous repetition can also decrease packet loss rate, because a duplicated packet is immediately transmitted after the original packet with minimum guard time, as shown in Fig. 2(c), while background packets are intermittently transmitted in the OPCI network. As a result, even if packet collision occurs, at least one packet from UT-1 can be transmitted without collision and packet loss rate is decreased. Multipath transmission also achieves lower packet loss rate because the same sequence packets, which are transmitted over two separate routes, are rarely lost at the same time. Figure 3(b) shows the average jitter. In these experiments, jitter was observed to be larger than 15 msec in 16 trials out of all 760 trials. In Fig 3(b), we can also see the difference in jitter whether multipath is used or not. In this experimental setup, each fiber link has the same length (and hence propagation delay), so Route #1 and #2 have the same delay. Therefore, two packets through different routes arrive almost at the same time at OPCI-3. Even if an original packet arrived late, the duplicated packet also arrived and therefore jitter is reduced on average. Finally the redundant packet reception ratio is shown in Fig. 3(c). In case of multipath transmission, the redundant packet reception ratio is near to 1.0 while its ratio is 0 in case of single path transmission. From Fig. 3(c), RT-3 received redundant packets in case of using multipath technique. On the other hand, in case of CRT technique, OPCI node successfully remove unnecessary duplicated packets. In summary, these results show that, by using multipath and/or continuous repetition transmission technique properly, the packet loss rate can be drastically improved. These are effective techniques to enhance reliability of latency sensitive communications, as they allow to avoid longer retransmission delay.

IV. Conclusions

Multipath and continuous repetition transmission based on optical packet duplication is investigated in this paper. We experimentally demonstrate their functionalities using OPCI-network testbed and confirm that these approaches can drastically decrease packet loss rate without introducing long delays, which is desirable property for latency sensitive communications in the beyond 5G era.

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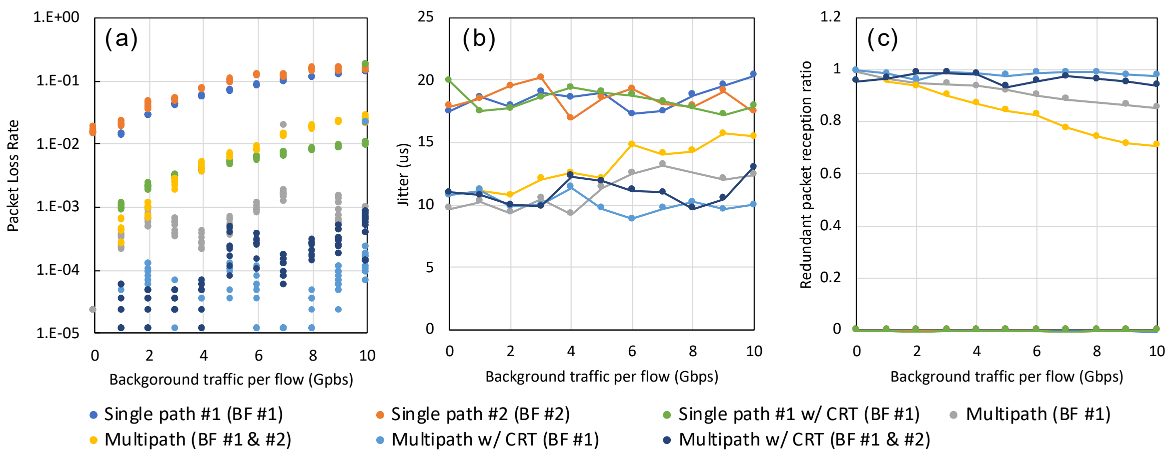

Fig. 3. Results observed on the OPCI network: (a) packet loss rate, (b) jitter, (c) redundant packet reception ratio.