First-time Demonstration of Automatic Service Restoration by Using Inter-Central-Office OLT handover and Optical Path Switching in Metro-Access Network

Takuya Kanai(1), Yumiko Senoo(1), Kota Asaka(1), Jun Sugawa(2), Hideaki Tamai(3), Hiroyuki Saito(3), Naoki Minato(3), Atsushi Oguri(4), Seiya Sumita(5), Takehiro Sato(6), Nobuhiko Kikuchi(2), Shun-ichi Matsushita(4), Takehiro Tsuritani(5), Satoru Okamoto(6), Naoaki Yamanaka(6), Ken-ichi Suzuki(1), and Akihiro Otaka(1)

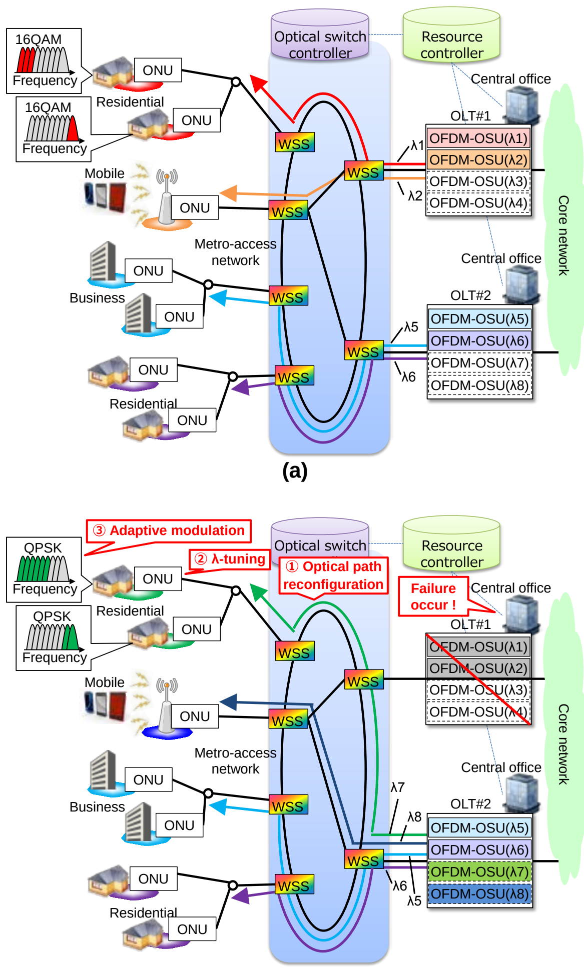
(1) NTT Access Network Service System Laboratories, NTT Corporation, kanai.takuya@lab.ntt.co.jp
(2) Research & Development Group, Hitachi Ltd.
(3) Corporate Research and Development Center, OKI Electric Industry Co., Ltd.
(4) Telecommunications & Energy Laboratories, Furukawa Electric Co., Ltd.
(5) Photonic Transport Network Laboratory, KDDI Research, Inc.
(6) Graduate School of Science and Technology, Keio University

Abstract *The first demonstration of the service restoration technique for metro-access networks successfully shows that ONU accommodated by the disaster-stricken central office is automatically re-connected within 10 sec to another office 20-km away with the same throughput as before disaster.*

Introduction

Along with the wider penetration of fiber-to-the-home (FTTH) services, efficient operation of a large number of network equipment is essential in recent optical access networks. Moreover, the future access network must support, in addition to conventional FTTH service for residential users, multiple access services, such as mobile and business services. Until now, multiple access services have been provided using distinctly different network infrastructures to meet the disparate service requirements. However, to provide them more efficiently, all services should coexist on the same service-adaptive network that can flexibly meet individual service requirements. If multiple access services share an optical fiber network, high resiliency is also essential in case of a disaster so that the network can keep providing services by autonomous reconfiguration of the network resources remaining after a disaster. Furthermore, high optical frequency utilization efficiency should also be achieved to accommodate a large number of services and subscribers, and to address possible optical frequency depletion in future.

To realize these four requirements; efficient operation, multi-service accommodation, high resiliency and high optical frequency utilization efficiency, we proposed the "Elastic Lambda Aggregation Network (EλAN) [1], as shown in Fig.1(a). EλAN targets serving 512 users with a distance of 40-80 km at 10Gbps/λ. EλAN transfers the location of an optical line terminal (OLT) from an access central office (CO) to a metro CO that aggregates the traffic of metro networks. This leads to a fewer number of access COs, and thus, which could result in efficient operation of the network [2]. Additionally, EλAN employs both a digital coherent orthogonal frequency division multiplexing (DC-OFDM) system with adaptive modulation and optical distribution network (ODN) with wavelength selective switches (WSSs). The DC-OFDM system leads to the significant



(b)

Fig. 1: Concept of service restoration in EλAN
(a) Normal state, (b) Disaster state

improvement of optical frequency utilization efficiency. Moreover, by employing the adaptive modulation, the system automatically change the modulation level and the number of subcarriers according to the service requirements and conditions of the ODN in order to achieve multiple service accommodation [1]. Moreover, the introduction of the inter-CO OLT handover function and the optical path switching function, which are controlled by the resource controller (RC) and the optical switch controller, respectively, dramatically improves the resiliency of the metro-access network. However, the service restoration in EλAN has not been achieved yet, and the service restoration time was unclear.

This paper firstly demonstrates the feasibility of service restoration technique in EλAN, and reports the restoration time obtained by real-time experiments. Automatic restoration within 10 sec was successfully achieved by inter-CO OLT handover and self-reconfiguration of optical paths.

Concept of service restoration in EλAN

Figure 1 shows the concept of service restoration for EλAN. Fig.1 (a) and (b) show the normal state and the disaster state, respectively. The OLT connects to optical network units (ONUs) via optical splitters, feeder fiber, and WSSs. The OLT consists of several OFDM-optical subscriber units (OSUs), which contains different fixed-wavelength transceivers (TRxs) and provides different services. Each OLT contains backup OFDM-OSUs for service restoration. Each ONU selectively receives signals with single wavelength afand some subcarriers (SCs). Additionally, the modulation formats of each ONU are selectively adapted to the highest modulation level that can achieve the required signal to noise ratio (SNR) according to the ODN conditions to achieve high optical frequency utilization efficiency.

When OLT is stricken by a disaster as shown in Fig.1 (b), inter-CO service restoration is automatically executed in the following order. Firstly, optical path reconfiguration using WSSs and controllers (OSC/RC) are executed. Secondly, the wavelength of TRx in ONUs that has been connected with the failed OLT is tuned to the new wavelength of survival OLT in another CO. Thirdly, adaptive modulation is applied according to the service requirements and conditions of ODN of new optical path. For example, in Fig.1 (b), the modulation format is changed from 16 quadrature-amplitude-modulation (QAM) to quadrature phase shift keying (QPSK), and the number of SCs is also changed according to the modulation format shift so that the same throughput as before the disaster can be achieved.

Experimental setup and restoration sequence

Figure 2 shows the experimental setup. Downstream transmission is realized with optical OFDM-TRx while upstream is optical time division multiplexing (TDM)-TRx since burst-mode OFDM-TRx is still under development. We used media access control (MAC) boards and physical coding sublayer (PCS) board in OLTs and ONUs, which had already been reported in ref [3]. In this paper, real-time self-homodyne coherent optical OFDM receiver was used in ONU. In path-1, ONU#1 communicates with OLT#1, using downstream wavelength of λ_{d1} and upstream wavelength of λ_{u1}, via ODN, which is composed of WSSs, 20 km feeder fibers and bidirectional erbium-doped fiber amplifiers (EDFAs) for compensation of optical loss of WSSs and feeder fibers. In path-2 after reconfiguration, ONU#1 communicates with OLT#2, using λ_{d2} and λ_{u2}, via 40-km ODN. In this demonstration, we introduced the RC and the OSC to reconfigure optical paths between OLTs and ONU when a failure at OLT#1 occurs assuming a disaster strike. The network tester sent downstream traffic of 100 Mbps to ONU#1 and measured both throughput and frame loss with and without adaptive modulation.

Figure 3 shows the service restoration sequence consisting of 8 steps. In step-i, OLT

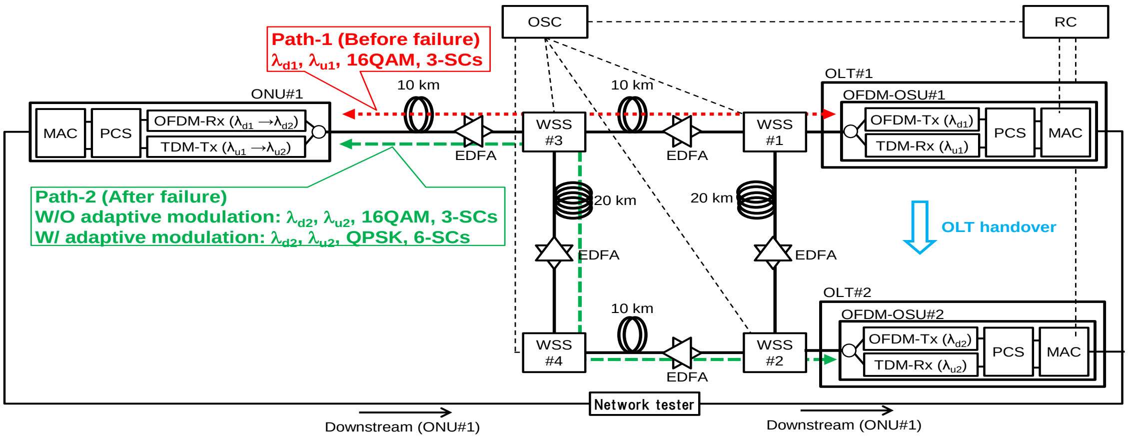


Fig. 2: Experimental setup for service restoration by inter-CO OLT handover and optical path switching.

alerts OLT failure to RC after detecting link downs of ONUs by using multi-point control protocol (MPCP) timeout mechanism. In step-ii and iii, RC determines new OLTs connecting with each ONU and requests OLT handover to OSC. In step-iv and v, OSC calculates optimum optical path and available frequency grids considering multiple service requirements (bitrate, quality of transmission, and latency etc.), and then requests to change path settings to WSSs. After step-v, WSSs changes path setting. In step-vi, OSC gives information of OLT handover to RC. In step-vii, RC gives information of reconfiguration, such as new optical path. In step-viii, discovery gate is sent to ONU#1 from OLT#2 with wavelength of λ_{d2}. The required time for detecting link down after failure is 1 sec, and a few seconds for step-i to step-vii. We used wavelength-swept discovery process in OLTs and ONU [4]. To switch the receive wavelength of self-homodyne DC-OFDM receiver in ONU, optical switch is used to switch the local light source from transmitter of OFDM-OSU#1 (λ_{d1}) to OFDM-OSU#2 (λ_{d2}). The wavelength sweeping time in ONU receiver was emulated using the MAC board. The wavelength sweep speed was assumed to 0.5 sec/λ, and the total number of wavelengths was also assumed to 16.

Experimental results

We confirmed the feasibility of inter-CO OLT handover and optical path switching techniques for service restoration, and evaluated the restoration time using prototype of EλAN. To emulate a disaster-stricken OLT, we disconnected the fiber at the optical interface of OLT#1. Fig. 4 shows the measured downstream throughput of ONU#1. We successfully confirmed that the ONU#1 connected with OLT#1 via path-1 was automatically re-connected with OLT#2 via path-2 as soon as the failure occurred. The duration between link down and link up was 9.5 sec. Since the detection time of link down and the total time of wavelength sweep of ONU receiver were 1.0 sec and 8.5 sec, respectively, the measured time was reasonable with designed value. Thus, the demonstration showed that the service accommodated in the failed office was automatically restored within 10 sec to another office 20km away. Furthermore, since fiber length of optical path was changed from 20 km to 40 km by reconfiguring optical path from path-1 to path-2, modulation format and the number of SCs were adaptively changed from 16QAM/3-SCs to QPSK/6-SCs (red line in Fig. 4). Thus, thanks to the adaptive modulation, no degradation in throughput was observed after restoration. However, without adaptive modulation (blue line in Fig. 4), measured throughput was decreased by almost half because of SNR degradation. These results confirmed the feasibility of service restoration maintaining the throughput by using the inter-CO OLT handover and optical path switching techniques in EλAN.

Conclusion

We experimentally demonstrated the feasibility of service restoration using prototype testbed of metro-access network for multiple service accommodation. We firstly showed that the service accommodated in the disaster-stricken office was automatically recovered within 10 sec to another office 20km away by using inter-CO OLT handover and optical path switching techniques. Moreover, thanks to the introduction of adaptive modulation DC-OFDM system, the same throughput as before the disaster was also achieved.

Acknowledgements

This work is supported by a project of NICT, Japan.

References

[1] S. Kimura, “Elastic Lambda Aggregation Network (EλAN) –Proposal for Future Optical Access Network–,” Proc. OECC2013, WP4-4.

[2] J. Prat, et al., “Results from EU Project SANDRA on 10G Extended Reach WDM PONs,” Proc. OFC2010, OThG5.

[3] Y. Senoo, et al., “Real-time Demonstration of Fairness-aware Dynamic Subcarrier Allocation for Adaptive Modulation in Elastic Lambda Aggregation Network,” Proc. OFC2017, Th2A.31.

[4] S. Kaneko, et al., “First System Demonstration of Hitless λ-Tuning Sequence for Dynamic Wavelength Allocation in WDM/TDM-PON,” Proc. OFC2014, W3G.6.

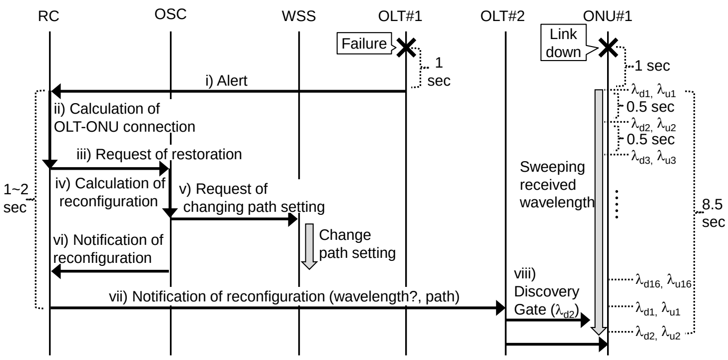


Fig. 3 Sequence of service restoration

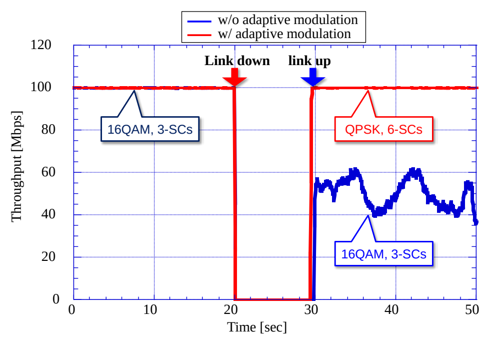


Fig. 4: Measured throughput (ONU#1)