Hierarchical-link Switchable Point-to-Multipoint Networks with Dynamic Route Selection/Dynamic Bandwidth Allocation for Uplink Optimization

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***Abstract*—A novel dynamic resource allocation and route selection algorithms within 250-µs delay in the uplink of physically hierarchical-link switchable point-to-multipoint access networks optimize the number of operating receivers for traffic distribution from 10-Gbit/s to 100-Gbit/s.**

Keywords— Optical access network, TDMA, DBA,

I. INTRODUCTION

A cost-effective mobile fronthaul architecture has a general point-to-multipoint (P-to-MP) configuration that collectively accommodates mobile traffic of multiple 5G base stations with a single optical fiber [1]. Hence, damage to the mobile communication system is severe when a natural disaster occurs [2]. Therefore, a P-to-MP system that is physically resistant to disasters is essential for the operation of highly reliable networks [3]. Furthermore, the low-layer split architecture that performs radio access network (RAN) functional decomposition must have low-latency specifications [4]. These specifications must enable the low-layer split architecture to suppress the communication delay within 20 km between the remote and distribution units within 250 µs [5].

The P-to-MP system centrally manages passive optical networks (PONs) that accommodate various traffic. In this system, a power-saving-oriented protection method with a variable number of operating optical receivers has been proposed. This method dynamically switches the Plumbum Lanthanum Zirconium Titanium (PLZT) optical switch (SW) on the optical line terminal (OLT) at high speed according to the traffic situation on the access side [6]. However, large N × N PLZT optical SWs have numerous centrally located Mach-Zehnder interferometers (MZIs) [7]. Therefore, if any MZI fails the optical SW, the impact on the entire system will be significant. Robust switchable P-to-MP systems with half-split/full-coupling shared link [8] and dedicated/full-coupling shared-link [9] that effectively use the optical coupler's energy have been reported; however, power-saving-oriented optical switching and resource allocation have not been discussed.

This study proposes a robust P-to-MP system by distributing 1 × 2 optical SWs compatible with high-speed operation in the OLT and connecting them to a dedicated link/hierarchical shared link. Furthermore, the proposed dynamic route selection (DRS)/dynamic bandwidth allocation (DBA) algorithm for uplinks uses the time-division multiplexing (TDM) method. Thus, fair time resource allocation can be achieved across all optical node units (ONUs). This effect saves system power by placing the upstream optical receiver in excess OLT to sleep. The DRS/DBA algorithm for P-to-MP systems can switch between dedicated/hierarchical shared links. Its effectiveness is demonstrated by a simulation evaluation of the throughput, average latency, average number of utilized receivers, average link usage rate, and packet loss rate based on dynamic 8ONU traffic. The proposed optical access networks (OANs) differ from general PON and has two physical link topologies: single star type and passive double star type. Optical SW adaptively switches between dedicated and shared links according to the data traffic.

II. PRINCIPLE OF HIERARCHICAL SHARED-LINK SWITCHABLE P-TO-MP OAN

Because upstream and downstream used different wavelengths, the resource allocation was handled independently for each. Herein, we assumed that the maximum bit rate supported by eight ONUs and one optical receiver was M bit/s, and an equal amount of traffic was generated in all ONUs. Assuming that the total generated traffic was P, there were four situations: $P \leq M$ (Case A), $M < P \leq 2M$ (Case B), $2M < P < 4M$ (Case C), $4M < P$ (Case D) in the dedicated link/three-layer shared-link switchable P-to-MP OAN.

Figures 1 (a)–(d) show the time resource allocation of the dedicated link/three-layer shared-link switchable P-to-MP OAN for Cases A–D. In Case A, when optical SW #4 switched to all ONU shared links, only one optical receiver was used; the time allocation for each ONU divides one frame into eight. In Case B, by switching optical SW #2 and #6 to the 4ONU shared link, the number of optical receivers used

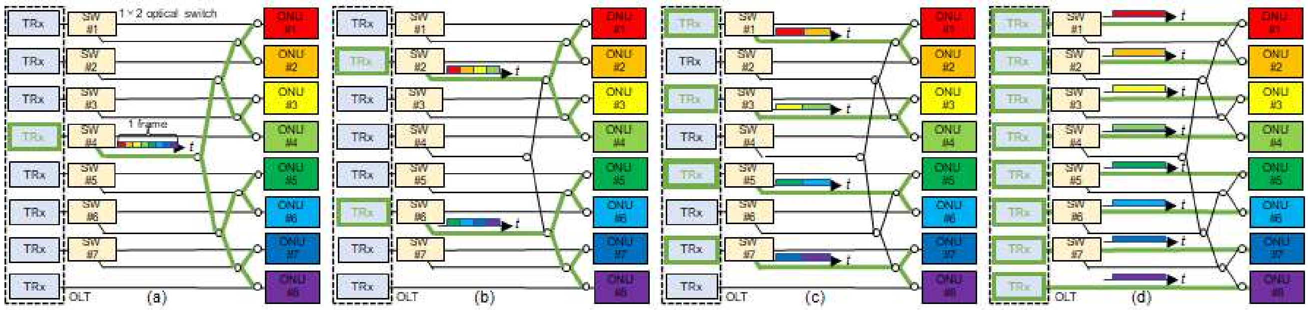

Fig. 1. Dedicated link/three-layer shared link switching P-to-MP OAN configuration (a) all ONU shared link case, (b) all 4ONU shared link case, (c) all 2ONU shared link case, (d) all dedicated link case.

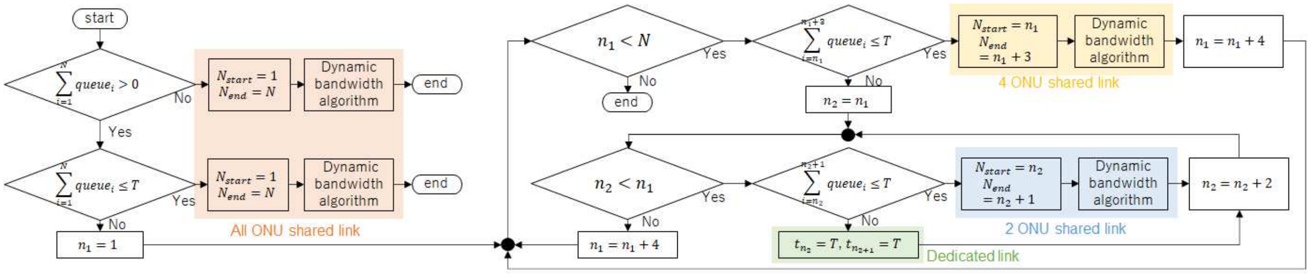

Fig. 2. Flowchart of DRS/DBA algorithm.

became two; the time allocation for each ONU equally divides one frame into four. In Case C, by switching optical SW #1, #3, #5, and #7 to the 2ONU shared link, the number of optical receivers used became four; the time allocation for each ONU equally divides one frame into two. In Case D, eight optical receivers were used when all-optical SWs were switched to the occupied link; the time allocation of each ONU was one frame.

III. DRS/DBA ALGORITHM AND SETTING VALUE

Table 1. Parameter of DRS/DBA algorithm

Parameter	Value
Number of ONUs: N	8
Frame duration [µs]: T	125
Distance ONU-OLT [km]	20
Bit rate [Gbit/s/ONU]	12.5
Traffic load [Gbit/s]	10–100
DBA processing latency [µs]	40
Propagation delay [µs/km]	5
Guard time [µs]	1.216
Switching time [ns]	5
DBA interval [µs]	125
Packet size [byte]	791
Buffer size [Mbyte]	1

The DRS/DBA algorithm adds a dynamic route selection algorithm to the DBA. Figure 2 shows the flowchart of the DRS/DBA algorithm. After selecting the link to be used in the DRS algorithm, the DBA determines the timetable of each ONU. Table 1 summarizes the parameters.

Next, time resources are allocated to each ONU using the DBA algorithm. In the DRS algorithm, the link to be used is determined by the amount of traffic. If all ONU queues are empty, the shared link for all ONUs is selected. If all ONU queues are not empty, determine if all ONU queues can fit in one frame of 125 µs.

(Step A) if the queue of all ONUs can be accommodated in one frame, all ONU shared links are selected. If not, the queue is accommodated in one frame for every four ONUs. **(Step B)** if the queue of four ONUs can be aggregated in one frame, the 4ONU shared link is selected. If not, the queue is accommodated in one frame for every two ONUs. **(Step C)** if the queues of the two ONUs can be aggregated in one frame, the two target ONUs use the 2ONU shared link. **(Step D)** if the queues of two ONUs cannot be aggregated in one frame, each of two target ONUs uses an exclusive link.

In the DBA algorithm, allocation is performed such that the allocation amount is fair for each ONU. First, check whether the queue of all ONUs to be allocated is empty. If it is not an empty queue, 125 µs are distributed according to the number of queues for each ONU. Conversely, in an empty queue, 125 µs is allocated evenly for each ONU.

IV. PROPOSED OAN CHARACTERIZATIONS

Figures 3 (a) and (b) show the throughput characteristics of each ONU of the standard PON and hierarchical shared-link switchable P-to-MP OAN. Because the PON has a maximum capacity of 12.5 Gbit/s, it is limited to a maximum throughput of approximately 1.5 Gbit/s per ONU. Contrarily, because the hierarchical shared-link switchable P-to-MP OAN has a maximum capacity of 100 Gbit/s, a maximum throughput of approximately 12.4 Gbit/s is close to the ideal 12.5 Gbit/s for each ONU.

Figures 3 (c) and (d) show the average delay of each ONU of PON, fully occupied optical NW, and occupied link/hierarchical shared-link switchable P-to-MP optical NW, respectively. The delay of the PON up to 10 Gbit/s was within 250 µs, but it increased sharply above 250 µs. Over the traffic of 20 Gbit/s, the delay decreased because the increase in packet loss increased the number of lost packets at the beginning of the queue. Consequently, the wait time for

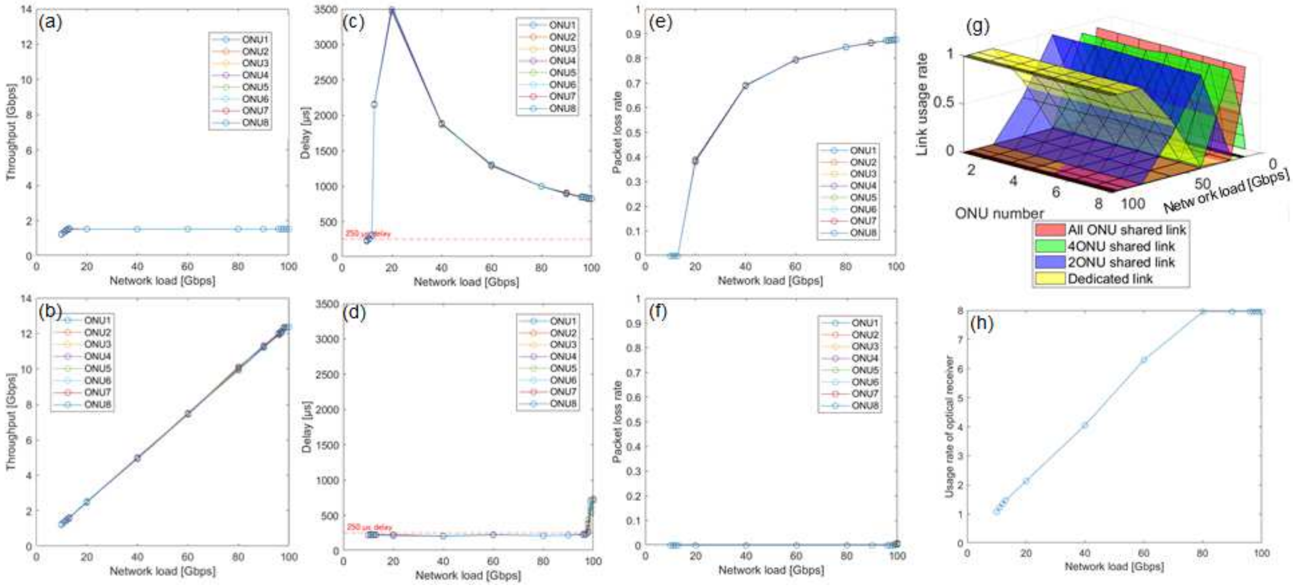

Fig. 3. (a, b) Throughput of PON and switchable P-to-MP OAN, (c, d) delay of PON and switchable P-to-MP OAN, (e, f) packet loss of PON and switchable P-to-MP OAN, (g) average link usage rate, (h) average number of operating receivers.

the queue was shortened for packets that could be sent. The delays of the dedicated/hierarchical shared-link switchable P-to-MP OAN were approximately identical. The generated traffic volume of up to 97 Gbit/s was within 250 μs. Figures 3 (e) and (f) show the packet loss rates of each ONU of the standard PON and hierarchical shared-link switchable P-to-MP OAN, respectively. PON does not have sufficient OAN capacity for the traffic generated. Hence, packet loss increased sharply when the generated traffic exceeded 13 Gbit/s.

Approximately 90 % of packets were lost at 100 Gbit/s. Contrarily, the hierarchical shared-link switchable P-to-MP OAN had sufficient capacity for the traffic generated; therefore, packet loss hardly occurred.

Figure 3 (g) shows the average link usage rate of the hierarchical shared-link switchable P-to-MP OAN. Approximately all ONU shared links were selected when the generated traffic was 10 Gbit/s. As the amount of induced traffic increased, the usage rate of 4ONU shared links increased. At 20 Gbit/s, all ONU shared links were no longer selected and most 4ONU shared links were selected. As the usage rate of 2ONU shared links gradually increased up to 50 Gbit/s, 4ONU shared links were no longer fixed at 50 Gbit/s and 2ONU shared links were mainly set. Subsequently, the usage rate of the dedicated link increased. When it reached 80 Gbit/s, approximately only the dedicated link was used. Figure 3 (h) shows the average number of optical receivers for the hierarchical shared-link switchable P-to-MP OAN. The number of optical receivers used was the same as the number of links. The average optical receiver utilization tended to increase linearly as the generated traffic increased. When the generated traffic was 60 Gbit/s, it moved back and forth between the 2ONU shared link and the dedicated link described above. If all ONUs used the dedicated link, eight units were required; if the 2ONU shared link was selected, four units were required. Therefore, the average number of receivers operated was six.

V. CONCLUSIONS

We compared the proposed dedicated link/three-layer shared-link switchable P-to-MP OAN to a standard PON. The hierarchical link switchable P-to-MP OAN using the proposed algorithm exhibited a throughput of 95 % or more of the maximum capacity of the OAN; furthermore, it reduced the number of optical receivers used. Moreover, we showed that a delay of 250 μs was satisfied in the traffic volume within 80 % of the maximum capacity of the OAN.

REFERENCES

[1] A. Napoli, Z. Stevkovski, J. D. M. Jiménez, E. J. E. Zuleta, J. Bäck, J. Pedro, J. Rodriguez, R. Diaz, J. Carrallo, A. Mathur, J. P. F.-P. Gimenez, F. Masoud, and D. Welch, "Enabling Router Bypass and Saving Cost using Point-to-Multipoint Transceivers for Traffic Aggregation," *Proc. OFC,* W3F.5, 2022.

[2] M. Kobayashi, "Experience of Infrastructure Damage Caused by the Great East Japan Earthquake and Countermeasures against Future Disasters", IEEE Commun. Mag., vol. 52, no. 3, pp. 23-29, Mar. 2014.

[3] Z. Zhou et al., *Proc. OFC*, Tu2G.4, San Diego, Mar. 2022. Z. Zhou, J. Wei, K. A. Clark, E. Sillekens, C. Deakin, R. Sohanpal, Y. Luo, R. Slavík, and Z. Liu, "Multipoint-to-point data aggregation using a single receiver and frequency-multiplexed intensity-modulated ONUs," *Proc. OFC,* Tu2G.4, 2022.

[4] S. Zhou, X. Liu, F. Effenberger, and J. Chao, "Low-Latency High-Efficiency Mobile Fronthaul With TDM-PON (Mobile-PON)," J. Opt. Commun. Netw. vol. 10, A20-A26, 2018.

[5] 3GPP TR 38.801 V2.0.0, Mar, 2017.

[6] K. Tokuhashi, D. Ishii, S. Okamoto, and N. Yamanaka, "Hybrid Passive/Active Optical Access Network Architecture that Reduces OLT Power Consumption," Cyber Journals: Multidisciplinary Journals in Science and Technology, Journal of Selected Areas in Telecommunications (JSAT), vol. JSAT June Edition, no. 3, pp. 1-9, June 2012.

[7] K. Nashimoto, D. Kudzuma, and H. Han, "Nano-second response, polarization insensitive and low-power consumption PLZT 4x4 matrix optical switch," *Proc. OFC*, OThD3, Mar. 2011.

[8] T. Kodama, T. Goto, T. Nakagawa, R. Matsumoto, "Bypass/backup-link switchable coherent point-to-multipoint configured WDM-PON system with shared protection," *Optics Express*, vol. 30, no. 7, pp. 10502-10512, Mar. 2022.

[9] S. Eguchi, T. Nakagawa, and T. Kodama, "Cost-effective edge-side single LD-drive protection with reflection blocking for single star/passive double star link switchable point-to-multipoint full-duplex fiber transmission," *Proc. ECOC*, Tu5.49, Basel, Sept. 2022.