Scalable Active Optical Access Network Using Variable High-Speed
PLZT Optical Switch/Splitter

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SUMMARY This paper proposes a scalable active optical access network using high-speed Plumbum Lanthanum Zirconate Titanate (PLZT) optical switch/splitter. The Active Optical Network, called ActiON, using PLZT switching technology has been presented to increase the number of subscribers and the maximum transmission distance, compared to the Passive Optical Network (PON). ActiON supports the multicast slot allocation realized by running the PLZT switch elements in the splitter mode, which forces the switch to behave as an optical splitter. However, the previous ActiON creates a tradeoff between the network scalability and the power loss experienced by the optical signal to each user. It does not use the optical power efficiently because the optical power is simply divided into 0.5 to 0.5 without considering transmission distance from OLT to each ONU. The proposed network adopts PLZT switch elements in the variable splitter mode, which controls the split ratio of the optical power considering the transmission distance from OLT to each ONU, in addition to PLZT switch elements in existing two modes, the switching mode and the splitter mode. The proposed network introduces the flexible multicast slot allocation according to the transmission distance from OLT to each user and the number of required users using three modes, while keeping the advantages of ActiON, which are to support scalable and secure access services. Numerical results show that the proposed network dramatically reduces the required number of slots and supports high bandwidth efficiency services and extends the coverage of access network, compared to the previous ActiON, and the required computation time for selecting multicast users is less than 30 msec, which is acceptable for on-demand broadcast services.

key words: active optical network, PLZT, multicast

1. Introduction

The demands that access networks support multicast delivery are increasing with the spread of broadcast service, including HDTV-based IPTV, Video on Demand (VoD), broadband Internet services, and Voice over Internet Protocol (VoIP). The broadcast services in access networks should be provided in a scalable, flexible, and secure manner according to various requirements.

The Passive Optical Network (PON)\(^{[1]}\) system is widely used as an access network. Gigabit Ethernet Passive Optical Network (GE-PON)\(^{[2]}\) is the representative example of the access network. Figure 1 shows that the PON architecture consists of three components: Optical Line Terminal (OLT), which connects to backbone network; Optical Network Unit (ONU), which communicates with the user terminal; and an optical splitter. One of the current target in access networks is the 10 Gigabit Ethernet Passive Optical Network (10G-EPON)\(^{[3]}\). The advantages of PON systems include low-cost and low-power consumption due to its use of a passive optical splitter. The data transmission of PON systems is that all data is broadcasted by the optical splitter to all ONUs, and each ONU selects its own data from all data. However, they do not provide a scalable, flexible, and high-security architecture. PON systems are limited in terms of the maximum number of ONUs (32) and the maximum transmission distance (20 km) between OLT and ONUs. This is because the optical power is divided at the splitter and decreases as the number of ONUs increases. In PON systems for multicast delivery, the multicast data is broadcasted to all ONUs using an optical splitter. PON systems may increase the bandwidth efficiency for multicast delivery thanks to the broadcast nature. However, they do not provide the local multicast delivery to only required multicast users. Moreover, they are low-security architectures in principle because each ONU receives all signals from OLT. Some ONUs do not belong to the same multicast group receives non-related multicast data from OLT.

PON systems have been extensively studied for next generation optical broadband access networks. Wavelength Division Multiplexing (WDM)-PON\(^{[4],[5]}\) provides high-bandwidth and high-security by allocating a unique wavelength to each ONU. However, WDM-PON does not trans-
mit the multicast data to required users at the same time so that it does not achieve the high bandwidth efficiency when supporting the multicast delivery. Long-Reach (LR)-PON [6], [7] extends the transmission distance and the number of users of PON systems by exploiting optical amplifiers. However, LR-PON consumes highly the power consumption by using optical amplifiers, and its security is low in principle because each ONU receives all signals from OLT just like PON systems.

To provide a scalable and secure access services, active access networks using packet-based optical switches were presented [8]–[10]. The literatures provide longer transmission distance than previous PON systems and high-security by using optical packet switches without optical buffers. However, analyzing each packet’s header for packet-by-packet switching with Optical/Electrical (O/E) conversions is required. It becomes a bottleneck and is not cost-effective for the 10 or more Gbps high-bandwidth environments. The access network architectures with packet-based switching do not provide transparent transmission without O/E/O conversion. Moreover, they need a large amount of bandwidth of the multicast delivery due to delivering multicast contents to the requesting users by a packet switching. They greatly lowers the utilization rate of the network.

To increase the bandwidth efficiency and achieve transparent transmission without O/E conversion, while keeping the advantages of the active access network [8]–[10], the active optical access network architecture using slot-based optical switches has been presented. It is called Active Optical Network (ActiON) [11]. ActiON employs Mach-Zehnder (MZ) type Plumbum Lanthanum Zirconate Titanate (PLZT) high-speed optical switches [12]–[14]. It replaces an optical splitter, which is used in PON systems, with a slot-based switch to make the optical power loss independent of the splitter number. It quadruples the number of subscribers (128 users) per OLT and doubles the maximum transmission distance (40 km) between OLT and ONUs, compared to 10G-EPON. It also provides a high-security architecture and transparent transmission without O/E conversion because each ONU receives only own data by PLZT switching technology. Moreover, ActiON also supports the multicast slot allocation realized by running the MZ-type high-speed optical switch elements in splitter mode, which forces the switch to behave as an optical splitter [15]. It creatively uses singlecast or multicast delivery with two modes, which are the switching mode and the splitter mode, considering only the number of multicast users.

However, the multicast slot allocation for previous ActiON creates a tradeoff between the network scalability and the power loss experienced by the optical signal to each user. It does not use the optical power efficiently because the optical power is simply divided into 0.5 to 0.5 without any relation to the location of each multicast user.

To provide a scalable, flexible, and secure access network, it is necessary to tune various requirements, which include the transmission distance from OLT to each user, the number of required users, and the transmission method using singlecast or multicast.

This paper proposes a scalable active optical access network using high-speed Plumbum Lanthanum Zirconate Titanate (PLZT) optical switch/splitter. The proposed network adopts PLZT switch elements in the variable splitter mode, which controls the split ratio of the optical power considering the transmission distance from OLT to each ONU, in addition to PLZT switch elements in existing two modes, the switching mode for a normal switching and the splitter mode. The proposed network introduces the flexible multicast slot allocation according to the transmission distance from OLT to each user and the number of required users using three modes, while keeping the advantages of ActiON, which are to support scalable and secure access services. Numerical results show that the proposed network dramatically reduces the required number of slots and supports high bandwidth efficiency services, and extends the coverage of access network, compared to the previous ActiON.

The remaining sections of this paper are organized as follows. Section 2 describes the previous active optical network. Section 3 describes the proposed scalable active optical access network. Section 4 describes the heuristic approach for the multicast slot allocation. Section 5 shows the results of slot allocation via the NLP solver [16]. Finally, Sect. 6 describes our conclusions.

2. Previous Active Optical Network (ActiON)

2.1 Architecture

Figure 2 shows the basic ActiON architecture [11]. Two optical switches (Upstream switch and Downstream switch) are set between the OLT and ONUs.

2.2 Structure of the 1 × 128 PLZT Optical Switch

ActiON exploits Mach-Zehnder (MZ) type Plumbum Lanthanum Zirconate Titanate (PLZT) optical switch elements. Figure 3 shows the structure of a 1 × 128 PLZT optical switch [17]. The 1 × 128 PLZT optical switch sets 1 × 2 optical switch elements in a multistage (7 stages) configuration. The 1 × 2 optical switch element is a MZ type waveguide structure [12]–[14], so the optical signal is switched...
by changing the voltage applied to the electrodes A or B shown in Fig. 4.

The MZ type optical switch has two modes, the switching mode and the splitter mode. Figure 4 shows the structure of the MZ type optical switch element. The optical signal is output in Y port by applying the voltage to the only electrodes A and the optical signal is output in X port by applying the voltage to the only electrodes B. We call this the switching mode. The optical signal is output in both X and Y ports without applying any voltage to neither electrodes A nor B, where the switch acts as a splitter. We call this the splitter mode. According to user requirements, the switching mode and the splitter mode are creatively used. The downlink data transmission is supposed to be 1 to \( M \) connection, thus the switching mode and the splitter mode are used in the downlink. The uplink data transmission is supposed to be 1 to 1 connection, thus the switching mode is used in uplink. OLT allocates time slots to each ONU and controls the uplink switch, and each ONU transmits the demand traffic in the allocated time slots [11].

2.3 Slot Allocation

In ActiON, the Multi-Point Control Protocol (MPCP) [3] is adopted for compatibility with 10G-EPON (IEEE802.3av) [3]. ActiON exploits the slot switching and supports the multicast slot allocation. The bandwidth is allocated to each user by assigning fixed-length time periods for easy control [18]. This period is called a “slot”. The optical switch is controlled by the unit of “cycle”, which is composed of multiple slots, see Fig. 5. This control of the switches is called “slot switching”.

Multicast slot allocation is realized by running the MZ type high-speed optical switch elements in two modes, the splitter mode and the switching mode. Figure 6 shows the control of switches with the switching mode. A multicast slot is a set of several slots that are used to deliver multicast contents. To simplify the discussion on the slot switching, we focus on the downstream on the multicast delivery. The 1 × 8 PLZT optical switches, which sets 1 × 2 optical switch elements in three-stage configuration, are used. Users (ONUs) #3, #4, #6, and #8 are multicast users. With only switching mode, OLT copies the data for each user and transmits the data to each user by using the switching mode. The number of multicast slots needed is 4, in other words, the number of slots is 12 (\( = 3 \times 4 \)).

Figures 7 shows the control of switches with the splitter mode. With the splitter mode, the OLT multicasts the data to users #3, #4, #6, and #8 by setting the optical switch elements (a, c, and e) to the splitter mode. Just one multicast slot (three slots) is needed to perform the multicast. Singlecast users are served in the switching mode. To decrease the number of the slots, it is necessary to use as many optical switch elements in the splitter mode as possible.
2.4 Limitation of the Previous ActiON

Figures 6 and 7 show the difference in power loss between the switching and splitter modes. The power loss of the optical signal when using the optical switch in the switching mode is taken to be 0 dB; the connection loss is not considered to find an optimum multicast slot allocation, but only the difference of the loss from the splitter mode is considered. This is because the connection loss is constant whichever mode is adopted.

On the other hand, the power loss of the optical signal when using the optical switch element as the splitter mode is 3 dB per switch. In the switching mode, the power loss of the optical signal to each user (#3, #4, #6, and #8) is 0 dB (= 0 dB + 0 dB + 0 dB). In the splitter mode, the power loss of the optical signal to each user (#3, #4, #6, and #8) is 6 dB (= 3 dB + 3 dB + 0 dB), so the optical signal experiences a significant power loss. In the PON system, the power loss of the optical signal per user is required to be at most 15 dB.

The previous ActiON solves an Integer Linear Programming (ILP) problem to maximize the number of multicast users that can receive service in each slot and selects which optical switch elements are placed into splitter mode within the limit on the number of stages for the optical switch.

However, the previous ActiON creates a tradeoff between the network scalability and the power loss experienced by the optical signal to each user. It does not use the optical power efficiently because the optical power is simply divided into 0.5 to 0.5 without considering transmission distance from OLT to each ONU.

To provide a scalable, flexible, and secure access network, it is necessary to tune various requirements, which include the transmission distance from OLT to each user, the number of required users, and the transmission method using singlecast or multicast.

3. Proposed Scalable Active Optical Access Network

3.1 Creating the Variable Splitter Mode

The MZ-type optical switch element is possible to yield the variable multicast state, where the optical power is output in the different split ratio (e.g. 0.6 to 0.4, 0.7 to 0.3, 0.8 to 0.2, 0.9 to 0.1, and so on) by applying the variable voltage to each electrode. We call this the variable splitter mode. The previous ActiON yields only the two modes, which is the switching mode for a normal switching and the splitter mode whose split ratio of the optical power is 0.5 to 0.5.

Table 1 and Fig. 8 show the experiment result of the relationship between the voltage (V) applied to each electrodes and the output (dB) in X port or Y port in three modes, switching mode, the splitter mode, and the variable splitter mode, according to the split ratio of the optical power. The split ratio of the switching mode is (a) and (k), the split ratio of the splitter mode is (f), and the split ratio of the variable splitter mode is from (b) to (e) and from (g) to (j).

In the optical insertion gain, it is set to 0 dB in the switching mode ((a) and (k)) and the optical insertion gain of each other mode (from (b) to (j)) is the difference between the switching mode and the other mode. The optical insertion loss is a negative value in the optical insertion gain. The optical insertion gain of the splitter mode is -3 dB. In the voltage difference, it is set to 0 V in the splitter mode (f) and the voltage difference of each other mode (from (a) to (e) and from (g) to (k)) is the difference between the splitter mode and the optical insertion gain of each mode.

### Table 1 Relationship between the voltage, the output, and the split ratio.

<table>
<thead>
<tr>
<th>Split ratio (X port to Y port)</th>
<th>Voltage difference (electrodes, voltage)</th>
<th>Optical insertion gain (X port, Y port)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Switching mode (a) 1.0 to 0.0</td>
<td>B: 8.0 V, -10.9 dB</td>
<td></td>
</tr>
<tr>
<td>Variable splitter mode (b) 0.9 to 0.1</td>
<td>B: 7.0 V</td>
<td>-9.5 dB</td>
</tr>
<tr>
<td>(c) 0.9 to 0.3</td>
<td>B: 3.5 V</td>
<td>-1.3 dB</td>
</tr>
<tr>
<td>(d) 0.6 to 0.4</td>
<td>B: 2.0 V</td>
<td>-0.1 dB</td>
</tr>
<tr>
<td>Splitter mode (f) 0.5 to 0.5</td>
<td>0 V</td>
<td>-3.0 dB</td>
</tr>
<tr>
<td>Variable splitter mode (g) 0.4 to 0.6</td>
<td>A: 1.0 V</td>
<td>-3.6 dB</td>
</tr>
<tr>
<td>(h) 0.3 to 0.7</td>
<td>A: 4.0 V</td>
<td>-5.3 dB</td>
</tr>
<tr>
<td>(i) 0.2 to 0.8</td>
<td>A: 5.5 V</td>
<td>-6.6 dB</td>
</tr>
<tr>
<td>(j) 0.1 to 0.9</td>
<td>A: 7.5 V</td>
<td>-10.1 dB</td>
</tr>
<tr>
<td>Switching mode (k) 0.0 to 1.0</td>
<td>A: 10.5 V</td>
<td>-25 dB, 0 dB</td>
</tr>
</tbody>
</table>
mode and the other mode.

3.2 Architecture

Figure 9 shows the scalable active optical access network architecture. The proposed network adopts PLZT switch elements in three modes, the switching mode, the splitter mode, and the variable splitter mode. It creatively uses the three modes according to the variable users’ requirements. The users’ requirements include the transmission distance, the number of required multicast users, and the transmission method using singlecast or multicast.

3.3 Multicast Slot Allocation with the Variable Splitter Mode

The proposed network provides the flexible multicast delivery tunable users’ requirement using the variable splitter mode and supports the high bandwidth efficiency services in a scalable network.

Figures 10 and 11 show the difference of the multicast slot allocation between the previous network and the proposed network. Users #1, #3, and #4 are multicast users. The distance between OLT to user #1 is 12 km and the required maximum optical power loss is 19 dB. The distance between OLT to user #3 is 36 km and the required maximum optical power loss is 7 dB. The distance between OLT to user #4 is 40 km and the required maximum optical power loss is 5 dB.

In the previous network, if the optical switch elements (a and c) are used as the splitter mode, user #4 does not receive the data because the practical power loss (6 dB) is larger than the maximum required optical power loss (5 dB). Only 2 users per a slot are delivered the multicast data and the number of multicast slots is 2 slots. In the proposed
network, the optical switch element a is used as the splitter mode and the optical switch element c is used as the variable splitter mode (0.2 to 0.8). In Table 1, when the split ratio is 0.2 to 0.8, the optical power loss of X port and Y port is 6.6 dB and 0.9 dB. The proposed network is able to control the split ratio of the optical power according to the transmission distance from OLT to ONU of each user by using the variable splitter mode. All users per a slot are delivered the multicast data and the number of multicast slots is 1 slot. To provide high bandwidth efficiency services, it is necessary to carefully select which optical switch elements are placed into which mode, the switching mode, the splitter mode, the variable splitter mode.

4. Heuristic Approach for the Multicast Slot Allocation

4.1 Overview

The proposed network introduces the flexible multicast slot allocation by using three modes, the switching mode, the splitter mode, the variable splitter mode. To maximize the bandwidth efficiency, it is necessary to minimize the required number of slots used to realize the multicast service. The naive approach is to consider all possible combinations for the multicast slot allocation. Let \( x \) be the number of all possible combinations for \( N \) multicast users. \( x \) lies in the range of \( \prod_{k=1}^{N-2-2^{-H}} 2^{(N-(k-1))2^k} \leq x \leq \prod_{k=1}^{N-2} 2^{N-(k-1)} \), where \( H \) is the limit on the number of stages. In this approach, with \( N = 128 \), it is not feasible to obtain the optimal solution within practical time. Therefore, the proposed network takes a heuristic approach. It tries to find the maximum number of multicast users every multicast slot in a sequential manner, without considering all possible combinations. However, it does not always obtain the optimal solution in terms of minimizing the required number of multicast slots. The heuristic approach proceeds shown in Fig. 12.

- **Step 1**: For the first multicast slot deemed available for multicast delivery, the optimization problem that maximizes the number of allocated users is solved using Eq. (1a), Eq. (1b), and Eq. (1c). The satisfied multicast users are eliminated from the set of requesting multicast users.

\[
\text{Step 1: } \text{For the first multicast slot deemed available for multicast delivery, the optimization problem that maximizes the number of allocated users is solved using Eq. (1a), Eq. (1b), and Eq. (1c). The satisfied multicast users are eliminated from the set of requesting multicast users.}
\]

![Fig. 12](image)

**Flow chart of the heuristic approach of proposed network.**

- **Step 2**: If any requesting multicast user remains unsatisfied, the next multicast slot is allocated following Step 1. Otherwise, multicast slot allocation is completed and the necessary number of multicast slots is solved.

4.2 Maximizing the Number of Allocated Users

The necessary number of multicast slots is solved by using two steps for required multicast users. Step 1 in the proposed network is different from in the previous network and Step 2 in the proposed network is the same as in the previous network.

This subsection shows how to solve the optimization problem that maximizes the number of allocated users in Step 1 above. The multicast slot allocation for the proposed network is possible to formulate the optimization problem as a Non Linear Programming (NLP) for details to Sect. 4.2.2. In the multicast slot allocation for the proposed network, the power loss of each optical switch element is calculated according to the following formula. 

\[
\text{Powerloss (dB)} = 10 \times \log_{10}(P_1/P_2), \quad P_1 = P_2 \times S,
\]

where \( P_1 \) is the output of optical power, \( P_2 \) is the input of optical power, and \( S \) is the split ratio. The optical power when receiving the data is solved by multiplying the input of optical power by the split ratio in the number of steps, thus solving the optical power loss of each optical switch element uses non linear equation. On the other hand, in the multicast slot allocation for the previous ActiON, the power loss of each optical switch element is set as a constant value (3 dB), thus it is possible to formulate it [15].

4.2.1 Definitions

The nomenclature used in this paper is given below.

- **\( N \)** Number of users. \( N \) is set to \( 2^i \), where \( x \) is a natural number.
- **\( i \)** Switch index, where \( 1 \leq i \leq N - 1 \).
- **\( j \)** Link index, where \( 1 \leq j \leq 2N - 1 \).
- **\( u \)** User index, where \( 1 \leq u \leq N \).
- **\( I \)** Set of \( i \).
- **\( J \)** Set of \( j \).
- **\( U \)** Set of \( u \).
- **\( S_i \)** Split ratio of \( i \)th switch, where \( 0 \leq S_i \leq 1 \).
- **\( L_j \)** Optical power of \( j \)th link, where \( L_1 = 1.0 \).
- **\( R_u \)** Required minimum optical power of \( u \)th user.
- **\( P_u \)** If \( u \)th user receives the optical power, \( P_u = 1 \). Otherwise, \( P_u = 0 \).
4.2.2 Formulation

The NLP problem used to maximize the number of multicast user per multicast slot is described below.

\[
\text{max} \sum_{u \in U} P_u \tag{1a}
\]

\[s.t. L_i \times S_i = L_{2i}, \quad \forall i \in I, \tag{1b}\]

\[L_i \times (1 - S_i) = L_{2i+1}, \quad \forall i \in I, \tag{1b}\]

\[R_u \times P_u \leq L_{m+1}, \quad \forall u \in U \tag{1c}\]

The objective function in Eq. (1a) indicates the selection of the maximum number of multicast users. The constrained condition in Eq. (1b) indicates the relationship between the use of each optical switch element and the optical power. The constrained condition in Eq. (1c) indicates the relationship between required minimum optical power of each user and the actual optical power of each bottom link. As \(L_i\) and \(S_i\) are decision variables, \(L_i \times (1 - S_i)\), the left side of Eq. (1b), is a non-linear term. Therefore, the optimization problem expressed in Eq. (1a), Eq. (1b), and Eq. (1c) is an NLP problem. Figure 13 shows an example of a network configuration of the optimization problem for four users and the following formula shows the constraints of the example.

\[
\begin{align*}
L_1 \times S_1 &= L_2 \\
L_1 \times (1 - S_1) &= L_3 \\
L_2 \times S_2 &= L_4 \\
L_2 \times (1 - S_2) &= L_5 \\
L_3 \times S_3 &= L_6 \\
L_3 \times (1 - S_3) &= L_7 \\
U_1 \times P_1 &\leq L_4 \\
U_2 \times P_2 &\leq L_5 \\
U_3 \times P_3 &\leq L_6 \\
U_4 \times P_4 &\leq L_7
\end{align*}
\]

5. Performance Evaluation of the Proposed Scalable Active Optical Access Network

This simulation evaluated the required number of multicast slots for the proposed scalable active optical access network whose flow chart is shown in Fig. 12 and the average computation time for selecting multicast users in the proposed network. The simulator was coded by using the C language combined with NUOPT Programming Kit [16], which is an NLP solver. Parameters used in our simulation are shown below. The maximum number of ONUs is 128. 10, 30, 50, 70, and 90% of all users (randomly selected) are taken as demanding the same multicast content. The maximum transmission distance from OLT to each user is 40 km. The number of the trials was set to \(10^6\) for each proportion of the multicast users. The \(1 \times 128\) PLZT optical switch has a 7 stage cascade of \(1 \times 2\) optical switch elements. The proposed network is run on the PC whose processor is an Intel Pentium 4 2.80 GHz, and which has 256 MB RAM.

Figure 14 shows that the more the proposed network employs patterns of the variable splitter mode, the more the number of multicast slots is possible to be reduced, by using comparison of the number of multicast slots required between the proposed network and the previous network. To maximize the bandwidth efficiency, it is necessary to minimize the required number of slots used to realize the multicast service. The transmission distance from OLT to ONU is 10, 20, 30, and 40 km, which is randomly selected. According to the transmission distance, the required minimum optical power of each user is designated. The proposed network has two types, one type using four patterns of the variable splitter mode, whose split ratio is 0.6 to 0.4 (0.4 to 0.6), 0.7 to 0.3 (0.3 to 0.7), 0.8 to 0.2 (0.2 to 0.8) and 0.9 to 0.1 (0.1 to 0.9) and the other type using all patterns of the variable split-
Table 2  Average number of multicast users.

<table>
<thead>
<tr>
<th></th>
<th>Average number of multicast users which can be delivered per one slot</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proposed network</td>
<td>5.3 users</td>
</tr>
<tr>
<td>previous network</td>
<td>2.6 users</td>
</tr>
</tbody>
</table>

Fig. 15  Comparison of the number of multicast slots required of the proposed network, according to the location of each user.

6. Conclusions

This paper proposed an scalable active optical access network using variable high-speed Plumbum Lanthanum Zirconate Titanate (PLZT) optical switch/splitter. The proposed network assumes the use of cascaded PLZT optical switch elements that are run in the newly described variable splitter mode, which controls the split ratio of the optical power according to the transmission distance from OLT to each ONU. The proposed network introduces the flexible multicast slot allocation according to the transmission distance from OLT to each user and the number of required users using three modes, keeping the advantages of ActiON, which are to support scalable and secure access services. Numerical results show that the proposed network dramatically reduces the required number of slots and supports high bandwidth efficiency services and extends the coverage of distance including 20, 30 and 40 km and the other type is a variable distance from 10 to 40 km, as the conditions in Fig. 14. The proposed network employs all patterns of the variable splitter mode, whose split ratio is variable form 0 to 1. In 10G-EPON, the maximum number of ONUs is 32 and the maximum transmission distance is 20 km. In the proposed network, the maximum number of ONUs is extended to 128 and the maximum transmission distance is extended to 40 km. In the proposed network whose transmission distance is 20 km, the required number of multicast slots is only a few slots larger than that of 10G-EPON within 30 users. This means that the proposed network provides comparable performances to 10G-EPON when the number of users is small, while the proposed network extends the limitation of the number of users for 10G-EPON to 128. Compared to the proposed networks whose type is a constant distance including 20 and 30 km, the proposed network whose type is a variable distance from 10 to 40 km increases the number of multicast slots. Compared to the proposed networks whose type is a constant distance including 40 km, it reduces the number of multicast slots. The proposed network increases the bandwidth efficiency more in the environment, where there are various users whose transmission distances are different.

Table 3  Maximum computation time for selecting multicast users.

<table>
<thead>
<tr>
<th>Proportion of multicast users</th>
<th>Computation time for selecting multicast users</th>
</tr>
</thead>
<tbody>
<tr>
<td>10%</td>
<td>20 msec</td>
</tr>
<tr>
<td>30%</td>
<td>20 msec</td>
</tr>
<tr>
<td>50%</td>
<td>25 msec</td>
</tr>
<tr>
<td>70%</td>
<td>30 msec</td>
</tr>
<tr>
<td>90%</td>
<td>25 msec</td>
</tr>
</tbody>
</table>

Table 3 shows that the maximum computation time for selecting multicast users is less than 30 msec. This computation is supposed to be used when multicast applications are connected, thus approximately 30 connections per 1 sec (= 1000 msec/30 msec) is the well suits on-demand broadcast services.
access network, compared to the previous ActiON, and the required computation time for selecting multicast users is less than 30 msec, which is acceptable for on-demand broadcast services.

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References


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