A Study of Next Generation Metro-Access Hybrid Scalable Network by Using PLZT Ultra High Speed Optical Wavelength Selective Switch

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Abstract—We have studied a novel optical access network with PLZT (Plomb Lanthanium Zirconate Titanate) optical switches, called ActiON (Active Optical Network), as a next generation access network to replace PON (Passive Optical Network). On the other hand, energy consumption of the present network becomes an important problem today. To resolve this problem, we study an energy efficient metro-access hybrid network by using ActiON. Also, it is necessary to extend a bandwidth capacity of ActiON to realize a scalable network. In this paper, we mainly focus on an energy consumption and a scalability. As a result, the proposed next generation metro-access hybrid scalable network accommodates 600000 users. In the evaluation, we show that proposed network reduces 65 % of energy consumption compare to the present network. Furthermore, blocking ratio of proposed network is lower than a quality assurance of the Internet service in any cases.

I. INTRODUCTION

On the FTTH (Fiber To The Home), PON (Passive Optical Network) is widely used for the optical access network today. Figure 1 shows PON architecture. PON consists of three contents, Optical Line Terminal (OLT) which connects to backbone network, Optical Network Unit (ONU) which communicates with a user terminal and an optical splitter. Currently, to realize 10 Gbps access network, 10 Gigabit Ethernet Passive Optical Network (10GE-PON) [1] is becoming the standard now. The advantages of PON are low-cost and low-power due to a passive optical splitter. However, PON system has limitations of the maximum number of Optical Network Units (32ONUs) and the maximum transmission distance (20km) between Optical Line Terminal (OLT) and ONUs. This is because the optical power is divided at a splitter and decreases as the number of ONUs increases. Moreover, PON system is a low-security architecture in principle because all ONUs receive all signals from OLT. A malicious user can intercept all data.

To resolve these problems, we proposed an active optical access network architecture using PLZT (Plomb Lanthanium Zirconate Titanate) 10nsec high-speed optical switches [2] without optoelectrical conversions. We call this proposed network Active Optical Network (ActiON) [3][4]. Figure 2 shows ActiON architecture. ActiON quadruples the number of subscribers (128 users) per OLT and double the maximum transmission distance (40 km) between OLT and ONUs. OLT sends message to PLZT optical switch to synchronize time slot and switching schedule.

On the other hand, energy consumption of present network was reached 25GW in 2008. In addition, this energy consumption will be 98GW in 2020 due to increase of transmission speed [5]. Figure 3 shows present network model. The Core network is composed of an OXC (Optical Cross Connect), and connect to an OADM (Optical Add-Drop Multiplexer) based metro core network. In the metro area network, an ADM (Add-Drop Multiplexer) based metro access network is connected to the metro core network and the access network. In the investigation of energy consumption of Telecom network [6], the access network is overrepresented of the energy consumption of present network. Furthermore, energy consumption of each network devices will be increasing in near future due to that it is corresponding with its transmission speed. Hence, resolving a problem of the energy consumption of present network is
necessary for saving the earth.

In this paper, we propose the energy efficient next generation scalable network as shown in Figure 4. The proposed network is composed of low energy consumption PLZT optical switches to eliminate many network devices so that it realizes energy efficient network. However, to expand access network to metro area network, larger bandwidth capacity is needed. Thus, we study the metro-access hybrid next generation scalable network by using ActiON.

In the proposed network, OLT is placed under the core network, and RN (Remote Node) is placed between OLT and ONU to realize a two stages tree based network. We consider using WDM (Wavelength Division Multiplexing) technique (e.g. WDM-PON) in the first stage and using ActiON in the second stage to realize the proposed network by hybrid WPA (WDM-PON and ActiON). In hybrid WPA, a tree cannot share a bandwidth with other trees because in the first stage, basically, wavelengths are allocated statically to each RN. Therefore, when a traffic load is getting higher, blocking ratio of the tree with high bandwidth requests is rapidly increasing. To resolve this problem, we use PLZT optical wavelength selective switch which extends present PLZT optical switch to increment a function of dynamic bandwidth allocation. This eliminates blocking ratio compare to hybrid WPA, and also reduces the energy consumption from present network.

II. METRO-ACCESS HYBRID NEXT GENERATION SCALABLE NETWORK

A. Target Settings

According to the MIC (Ministry of Internal Affairs and Communications) Communications News [7], current Japanese Internet traffic is average 40Kbps by using 1Gbps bandwidth capacity of PON with 32ONUs. In this paper, we consider that the Internet traffic will be 10 times larger than today. This is because bandwidth capacity of the access network is changing to 10Gbps. Consequently, we assume an average Internet traffic will be 400Kbps with 10Gbps bandwidth capacity. In the meantime, because 10million broadband users are in Tokyo area, we assume 600000 users are located for one OADM node. According to two assumes illustrated above, target of proposed network is set to 600000 users capacity with 400Kbps average bandwidth request. In addition, blocking ratio of the proposed network keeps 0.003 below due to that a blocking ratio of the Internet service is allowed lower than 0.003 in KDDI Corporation [8].

B. Technique of Access Network Extension

Today, many studies are reported in the access network expansion.

In [9], one CO (Central Office) controls 7 times bigger area than current PON via RN (Remote Node). This network can reuse current tree based PON architecture. Also, this network can extend a distance between OLT and ONU because an optical amplifier is placed in each RN.

In [10], RNs are placed as a ring topology, and each RN has some access network trees below. This study uses WDM (Wavelength Division Multiplexing) technique, and each RN has some static wavelengths. A wavelength is allocated for one access network tree so that it is easy to calculate DBA (Dynamic Bandwidth Allocation) in OLT. In this study, target is set to 10000ONUs with 64wavelengths.

Besides these studies, research challenges for scalable access network are reported [11]. Common features of these studies are; they have a relay station like RN for extending a distance, and they use WDM technique for larger bandwidth capacity.

C. Study of Access Network Extension by Using ActiON

In section II-B, all studies use RN and WDM technique. Figure 5 shows hybrid WPA (WDM and ActiON) that ActiON replaces PON in architecture of studies in section II-B. Hybrid WPA has two stages; CO-RN, and RN-ONU. In the first stage, some static wavelengths are allocated to each RN via AWG (Array Waveguide Gratings). In the second stage, some ActiON trees are placed below each RN. This hybrid WPA extends a distance and bandwidth capacity by using RN and WDM technique. Moreover, this network reduces major amount of the energy consumption due to eliminating many devices in present network.

On the other hand, to use this scalable network, ONUs must be used in different situations (e.g. at home, at hotel,
or at company). Hence, bandwidth request from each user will be changing based on situations and time, and total bandwidth request in each RN is heterogeneous. However, in hybrid WPA, because each RN is allocated static wavelengths, although there is one RN which has extremely high total bandwidth request, the RN cannot share the vacant bandwidth with other RNs. As a result, blocking ratio of the overloaded RN will be higher than others.

To resolve this problem, we propose dynamic bandwidth allocation capable energy efficient new generation scalable network.

D. Composition of Proposed Network

Figure 6 shows a composition of the proposed network. In the proposed network, we realize 600000 users capacity scalable network by dynamic bandwidth allocation and two stages structure. To do dynamic bandwidth allocation, we use PLZT optical wavelength selective switch which is placed in CO. In each RN, only MPCP (Multi-Point Control Protocol) messages are processed electrically, so data transmission is processed in optical.

E. Composition of PLZT Wavelength Selective Switch

Figure 7 depicts a composition of the PLZT wavelength selective switch which is placed in CO. An incoming optical WDM signal from Master OLT is divided to each wavelength by AWG. Each divided signal is connected to the PLZT optical switch, and switching the signal in slot time. The signal switched by PLZT optical switch is combined again by AWG, and transmitted to RNs. Hence, CO can transmit a data in slot time on each wavelength.

F. Composition of RN

Figure 8 shows a composition of RN. The proposed network is composed by two stages; Master OLT in CO to Master ONU in RN, and Slave OLT in RN to ONUs. Master OLT controls Master ONU in each RN, and Slave OLT controls ONUs. In RN, the WDM signals from CO are divided to private wavelength for MPCP messages and public wavelengths for data transmission. The private wavelength is connected to Master ONU. A number of ONUs that one OLT device have to control is same number as present ActiON due to that this network is composed by two stages. In consequence, a difficulty of DBA when controlling large number of ONUs is resolved. Then, the public wavelength is connected to ONUs without OEO process via optical wavelength converter and optical amplifier. Also, by using optical wavelength converter, users can use the same ONU device as present ActiON.

G. Discovery Process

To learn LLID (Logical Link ID) and MAC (Media Access Control) address of all ONUs, Master ONU reports LLID and MAC address which are gathered from Slave OLTs to Master OLT. Discovery Process is depicted in Figure 9. In this figure, discovery process of present ActiON [3] is used between Slave OLT and ONUs. Besides, information of found new ONU is reported to Master OLT by using communication channel periodically.

H. Bandwidth Request Technique

Figure 10 illustrates a bandwidth request technique. Also, Figure 11 shows a sequence of bandwidth request. Here, we explain specific order of bandwidth request below.

1) ONU informs bandwidth request to Slave OLT by a report message.
2) Slave OLT executes DBA, and reports total bandwidth request to Master ONU.
3) Master ONU informs total bandwidth request of Slave OLTs to Master OLT by a report message.
4) Master OLT allocates wavelengths and bandwidth to each RN, and reports it to RNs.
5) Master ONU distributes given total bandwidth proportionally to each Slave OLT.
6) Slave OLT reports transmission time to ONUs.
7) ONU sends a data in given transmission time.

By using this technique, Master OLT is able to transmit a data directly to ONU.

III. EVALUATION

A. Energy Consumption

In this section, we evaluate energy consumption of proposed network, hybrid WPA, and present network as shown in Figure 3 except core network. Simulation parameters is shown in Table I. The parameter of each network device is referred to [6] and an actual survey.

Figure 12 shows the result of this simulation. According to Figure 12, the proposed network reduces 65% of energy consumption compare to present network. In addition, energy consumption of the proposed network is 4.2% higher than hybrid WPA due to that the proposed network uses more PLZT optical switches. However, this difference is small enough compare to present network.

<table>
<thead>
<tr>
<th>Devices</th>
<th>Energy Consumption</th>
</tr>
</thead>
<tbody>
<tr>
<td>ONU</td>
<td>5W</td>
</tr>
<tr>
<td>OLT</td>
<td>100W</td>
</tr>
<tr>
<td>L2SW</td>
<td>3.21KW</td>
</tr>
<tr>
<td>Network Gateway</td>
<td>1.1KW</td>
</tr>
<tr>
<td>SONET ADM</td>
<td>1.2KW</td>
</tr>
<tr>
<td>Edge Router</td>
<td>4.21KW</td>
</tr>
<tr>
<td>OADM</td>
<td>450W</td>
</tr>
<tr>
<td>Optical Amplifier</td>
<td>20W</td>
</tr>
<tr>
<td>PLZT Switch</td>
<td>13W</td>
</tr>
</tbody>
</table>

B. Blocking Ratio

In this section, we evaluate blocking ratio of proposed network and hybrid WPA. Simulation parameters are shown in Table II.

A blocking ratio is calculated by Erlang B.
| TABLE II  
SIMULATION OF BLOCKING RATIO PARAMETERS |
<table>
<thead>
<tr>
<th></th>
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<tbody>
<tr>
<td>Number of Wavelengths</td>
</tr>
<tr>
<td>Number of COs</td>
</tr>
<tr>
<td>Number of Users</td>
</tr>
<tr>
<td>Request Distribution</td>
</tr>
<tr>
<td>User Distribution</td>
</tr>
<tr>
<td>Heterogeneous Bandwidth Request</td>
</tr>
<tr>
<td>Average Bandwidth Request</td>
</tr>
<tr>
<td>Slot Size</td>
</tr>
<tr>
<td>Number of Requests per ONU</td>
</tr>
<tr>
<td>Simulation Time</td>
</tr>
</tbody>
</table>

\[ B = \frac{a^n}{1 + \frac{a}{m} + \frac{a^2}{m^2} + \cdots + \frac{a^n}{m^n}} \]  \hspace{1cm} (1)

In this formula, \( n \) points number of wavelength, \( a \) points erlang, and \( B \) points blocking ratio. Also, erlang is calculated by using formula below.

\[ a = \frac{r \times o}{s} \]  \hspace{1cm} (2)

In this formula, \( r \) points number of requested slots, \( o \) points number of request per ONU, and \( s \) points total number of slots in simulation time.

In each RN of the proposed network, number of wavelengths that each RN can use is limited to 3, 5, and 8. In hybrid WPA, wavelengths are allocated to each RN statically.

Figure 13 shows result of the evaluation. In this evaluation, maximum wavelengths are set to 40, and bandwidth request at each RN is homogeneous.

In Figure 13, hybrid WPA exceeds 0.003 which is a quality assurance of the Internet service. This is because hybrid WPA allocates static wavelengths to each RN, and it means 40 wavelengths are not enough for distributing a bandwidth. On the other hand, the proposed network suppresses blocking ratio compare to hybrid WPA. When the number of usable wavelengths in each RN are set to 5 or more, blocking ratio of the proposed network can keep the line lower than 0.003.

Next, we evaluate a blocking ratio with heterogeneous bandwidth request at each RN. In this simulation, to resolve insufficiency of bandwidth in hybrid WPA as shown in Figure 13, number of wavelengths that hybrid WPA can use is set to 120. In the proposed network, maximum wavelengths are set to 40, and number of usable wavelengths at each RN is set to 5. Figure 14 shows result of the evaluation.

In Figure 14, while bandwidth request at each RN is homogeneous, hybrid WPA can keep the line lower than 0.003. However, in the case of heterogeneous bandwidth request at each RN, hybrid WPA exceeds the line. Contrarily, the proposed network can keep the line in any cases.

In the large network, ONU must be used in different situation, so bandwidth request from ONUs are changing in every second. Therefore, the proposed network that always keeps the quality assurance of the Internet service is effective compare to hybrid WPA.

IV. CONCLUSION

Active access network, called ActiON is capable of expanding number of users and distance due to PLZT optical switch. In this paper, to resolve a problem of energy consumption in present network, we studied a technique of ActiON extension. Hybrid WPA which is using RN and WDM technique realized energy efficient network. However, while bandwidth request at each RN is heterogeneous, blocking ratio was increased because of static wavelength allocation. To resolve this problem, we proposed dynamic bandwidth allocation capable next
generation scalable network by using PLZT optical wavelength selective switch. Finally, we evaluated energy consumption and blocking ratio. In the evaluation of energy consumption, the proposed network was 4.2 % higher than hybrid WPA, but reduced 65 % of energy consumption compare to present network. In the evaluation of blocking ratio, the proposed network could keep the line lower than 0.003 which is a quality assurance of the Internet service. This is because we used dynamic bandwidth allocation capable PLZT wavelength selective switch.

As a future work, we need to consider a technique to control many PLZT optical switches, cost, and reliability.

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REFERENCES


