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WDM 기반 2-OLT 구조를 이용한 PON 시스템 보호 및 절체

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Protection/Restoration of PON Systems Using WDM based 2-OLT Structure

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요 약

본 연구에서는 2개의 OLT를 이용한 PON 보호/절체에 관해 제안하였다. 본 제안된 방식을 이용하면 고장 상황에서도 가입자 영역에 서비스를 지속적으로 할 수 있고, 정상적인 동작을 수행할 수 있게 된다. 기존 보호/절체 방식과의 차이점은 제안된 방식의 경우 두 OLT에 다른 파장을 적용함으로써 정상 상태에서 두 OLT를 모두 사용하여 이용 효율을 높인다는 점이다. 보호 모드에서는 Shared-bandwidth 할당 방식을 적용함으로써 효율을 극대화하였다. 성능 분석을 통해 제안된 시스템이 효율적으로 이더넷 기반 PON 시스템의 신뢰성을 높일 수 있음을 확인하였다.

Key Words : Passive optical network (PON), WDM/TDM, 2-OLT PON, Shared-bandwidth DBA, Self-similar traffic

ABSTRACT

In this paper, we propose a protection architecture of passive optical network (PON) system by using two optical line terminals (OLTs). Using this scheme, the network can sustain services to access area and restores normal operation in faulty conditions. Unlike existing systems, the proposed one increases the efficiency of the system by operating both OLTs using different wavelengths in normal condition. During protection mode, a Shared-bandwidth allocation scheme is employed to maximize the utilization efficiency. Performance analysis shows that the proposed scheme can provide reliability to Ethernet-based PON system very efficiently.

Ⅰ. INTRODUCTION

Large capacity PON systems are under development by many research groups[1,2]. Unlike previous PON systems, the protection/restoration of large capacity PON, that mainly serves business buildings, is an important issue since reliability is essential in business applications. A dual-homed two-OLT PON is one way to increase the resilience of such networks [3], which is very effective for protection against catastrophic failures. It works in revertive mode, where a standby OLT is idle during normal condition that leads to waste of bandwidth resource. To improve the bandwidth utilization by

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using all OLTs in normal operation, we propose a WDM based architecture of 2-OLT PON system. In normal status, two OLTs transmit data to different ONU groups using different wavelengths, while in failure status the survived OLT transmits in two wavelengths in turn, thereby replacing the failed OLT.

A new control protocol appropriate for the suggested 2-OLT PON system is proposed. Besides, a revised dynamic bandwidth allocation (DBA) scheme can further improve the performance of the 2-OLT PON in faulty situation[4,5]. We suggest Shared-bandwidth DBA scheme for downstream transmission during fault.

The rest of this paper is organized as follows. Section II introduces system architecture and operation algorithm of the WDM based 2-OLT PON system. DBA schemes for both normal operation and faulty condition are also described. Section III provides simulation results to demonstrate network performance using the suggested DBA schemes. Finally, Section IV concludes our work.

Ⅱ. WDM BASED 2-OLT PON AND ITS OPERATION ALGORITHMS

In the proposed PON system, two OLTs are connected to two ONU groups via one optical distribution network (ODN) as shown in Fig. 1. Each OLT is equipped with two optical sources with different wavelengths, λ_1 and λ_2; one of them is selected at a time and used for carrying downstream data packets. Each ONU group is able to receive only one wavelength, Group1 in λ_1 and Group2 in λ_2. In normal condition, therefore, OLT-1 transmits data packets to ONU Group1 (ONU_1 to ONU_8 in Fig. 1) in λ_1 while OLT-2 to ONU Group2 in λ_2. When one OLT is out of order, the other one replaces it by using the two wavelengths in turn. For instance, in case of the fault of OLT-1 data transmission to Group1 ONUs is halted, hence OLT-2 reinstates this operation and continues data transmission to both groups until fault recovery. Similarly, OLT-1 starts working for both groups of ONUs during fault of OLT-2. In this perspective, this scheme works as 1:1 protection switching. For the upstream transmission, only one wavelength, λ_3, is used; thereby all ONUs should share the time in efficient way and an appropriate encryption algorithm [6] should be used. Wavelength of 1490 nm and 1550 nm can be adopted as λ_1 and λ_2, respectively, while 1310 nm as λ_3 in the proposed system.

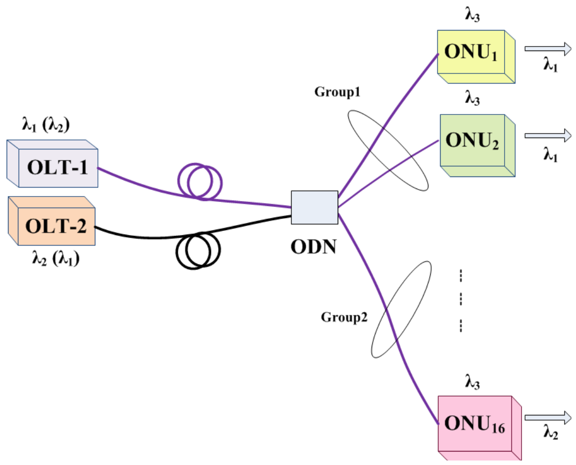

Fig. 1. Proposed architecture of a WDM based 2-OLT PON

Wavelength assignment at the two OLTs is described in Fig. 2. It is seen that each OLT transmits packets to its corresponding ONU group for most of the time in normal condition; OLT-1 in λ_1 and OLT-2 in λ_2. However, a small part of time is assigned to the other ONU group, i.e., λ_2 in OLT-1 and λ_1 in OLT-2, for exchanging control packets such as round-trip time (RTT) measurement. It is needed for fast protection in less than 50 msec required by reliable networks such as SONET.

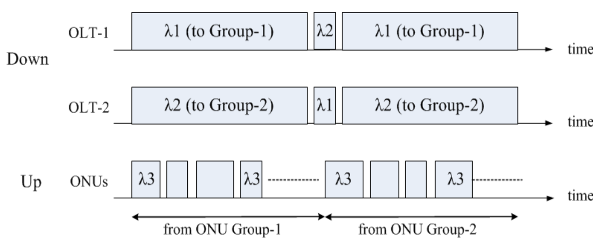

Fig. 2. Wavelength assignment of the proposed 2-OLT PON structure in normal condition

Fig. 3 shows wavelength assignment when fault happens at OLT-1. Since OLT-1 now can't transmit optical signals anymore, OLT-2 uses λ_1 and λ_2 in turn to transmit data to both ONU groups. However, there is no change in upstream transmission since only one wavelength, λ_3, is used in all ONUs regardless of system fault.

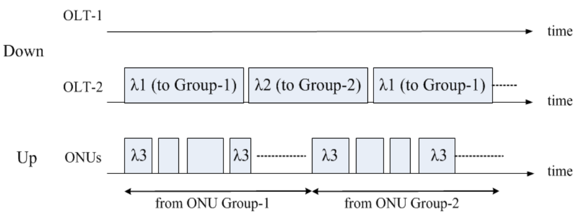

Fig. 3. Wavelength assignment during fault at OLT-1

During protection, there can be different bandwidth allocations schemes toward two ONU groups for the downstream transmission – Fixed-bandwidth alloca-tion (FBA) and Shared-bandwidth allocation (SBA). A fixed allocation means that constant ratio of total time is assigned to each ONU group. Since a whole wavelength is assigned exclusively to a specific ONU group, this FBA scheme is to preserve the half of its original bandwidth during protection. Although the FBA is simple and easy to implement, it has a disadvantage in terms of bandwidth efficiency as it always assigns a fixed size of time slot to each group regardless of the traffic. It wastes considerable amount of bandwidth, especially in bursty environment. As an alternative, we propose a Shared-bandwidth scheme. It reserves a guaranteed downstream bandwidth toward each group, but allows transfer of unused bandwidth between two groups. The transfer is made when one group encounters slot overflow while the other has much empty slots. In consequence, bandwidth share toward each group changes dynamically with load distribution. This scheme restricts bandwidth transfer during heavy load conditions, when each group needs its own reserved bandwidth to achieve guaranteed performance.

In SBA scheme, OLTs use their queue status and generation information to make decision on bandwidth release. System load, generation and bandwidth parameters used in this study are described as follows.

$$L = (L_1 + L_2) \text{ and } BW = (BW_1 + BW_2) \quad (1)$$

$$G_1 = (L_1/L) \text{ and } G_2 = (L_2/L) \quad (2)$$

$$R_1 = (BW_1/BW) \text{ and } R_2 = (BW_2/BW) \quad (3)$$

where L is the normalized total downstream load, $L_{1(2)}$ the load towards Group1(2), $G_{1(2)}$ the load generation ratio towards Group1(2), BW the total downstream bandwidth, $BW_{1(2)}$ the reserved bandwidth towards Group1(2), $R_{1(2)}$ the bandwidth reservation ratio for Group1(2) which is made by service level agreement (SLA).

Bandwidth provision from Group1 to Group2 is decided by OLT when Group1 has adequate excess bandwidth ($L_1<R_1$ and $G_1<R_1$) and Group2 needs additional bandwidth ($L_2>R_2$). Released bandwidth from Group1, $BW_{r,1}$, is decided by eq. (4) considering both preset bandwidth ratio (R_1) and generated load (L_1). When total downstream load (L) is less than 1.0, it achieves fairness by securing the bandwidth proportional to generation ratio (G_1). Even in the overload (L>1) condition when the other OLT asks for excessive bandwidth, eq. (4) reserves the bandwidth so that occurred load (L_1) can be transmitted if it is less than the guaranteed bandwidth (R_1). The restriction factor, y_1, is used to keep enough margin at donor Group1. Eq. (5) sets the bounds of y_1 in [G_2,1]. It is introduced to keep a fair bandwidth margin during bandwidth provision, and to diminish the released amount near the preset bandwidth boundary. The active bandwidth of Group1, $BW_{a,1}$ is represented by eq. (6). Bandwidth provision from Group2 to Group1 is performed in similar way.

$$BW_{r,1} = \begin{cases} BW_1 \times (1 - G_1/R_1) \times y_1 & \text{for } L \le 1 \\ BW_1 \times (1 - L_1/R_1) \times y_1 & \text{for } L > 1 \end{cases} \quad (4)$$

$$y_1 = [\tanh(-30L + 30) + 1/2] \times G_1 + G_2 \quad (5)$$

$$BW_{a,1} = BW_1 - BW_{r,1} \quad (6)$$

Fig. 4 outlines a comparison of FBA and SBA. It is assumed that in the first cycle the load ratios, G_1 and G_2, are the same as the reservation ratios, R_1 and R_2, respectively, while they are much different in the second cycle. Since the FBA always assigns constant time slot according to R_1 and R_2, in the second cycle Group1 decimates bandwidth while Group2 endures insufficient bandwidth. This enforces Group2 to transmit only a part of its occurred load. On the contrary, the SBA scheme releases some unutilized reserved bandwidth from Group1 to Group2, which adjusts the slots dynamically according to the incoming traffic. Now both Groups can transmit their entire data.

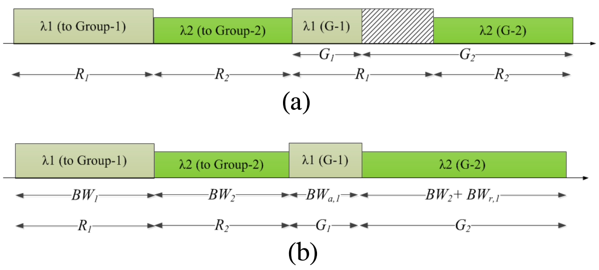

Fig. 4. Downstream Bandwidth Allocation during protection (a) Fixed Bandwidth Allocation (b) Shared Bandwidth Allocation.

Ⅲ. PERFORMANCE ANALYSIS DURING PROTECTION

Performance of two-OLT PON during protection is investigated for a system with sixteen ONUs that are divided into two groups. Each ONU has 1 MB queue, while each OLT has two separate 10 MB queues toward two groups of ONUs. It is assumed that packets are sent in Ethernet frames[7]. The queues are simple first-in first-out (FIFO) type. Table I summarizes system parameters of the analysis. It is assumed that load is evenly distributed in two OLTs.

Matlab® is used for the simulation where data packets are generated by a self-similar traffic model. To generate this traffic, we used the method described in [8], where the resulting traffic is obtained by aggregating multiple sub-streams; each consists of alternating Pareto-distributed on/off periods. Load distribution among sub-streams follows table II, which reflects real IP data traffic including recent applications such as P2P, instant messenger, video, and VoIP[9].

Table 1. System parameters used in the simulation

Parameter	Description	Value
C	Network capacity	1 Gbps
N	Number of OLTs	2
n	Number of ONUs	16
R1:R2	Bandwidth reservation	0.5 : 0.5
Q	Buffer size at OLT	20 MB
q	Buffer size at ONU	1 MB
T	Cycle time	2 ms
Tguard	Guard time	1μs
Gate/Report	Control message	64 Byte

Table 2. Packet Size Distribution

Packet size	Byte (%)	Packet(%)
0-64	2.66	25.96
65-128	3.61	22.78
129-256	5.73	14.47
257-512	10.10	7.88
513-1024	37.02	15.08
1025-1518	40.88	13.83

According to the SLA, we reserved 50% of total downstream bandwidth for Group1 and Group2, respectively. Average delay and throughput are analyzed and plotted with respect to total downstream load. Fig. 5 illustrates the average delay performance. FBA(A%:B%) in the figure indicates that FBA scheme is used, and A% of total generated load is transmitted to Group1 while B% to Group2. It is seen that FBA(50%:50%) shows the smallest delay since load generation ratio matches bandwidth reservation ratio. The FBA delay, in the other hand, rises abruptly as generation ratio deviates from bandwidth reservation ratio, such as FBA(70%:30%). However, the delay of Shared scheme is not much affected by load variation since bandwidth is shared in efficient way by the two OLTs. It is shown that Shared(70%:30%) is very close to that of Shared (50%:50%) or the best result of FBA, i.e. FBA(50%:50%). Delay of each group is illustrated separately in Fig. 6. In this figure, Group1(FBA,A%) indicates average delay toward Group1 using FBA when A% of total downstream load are transmitted to this Group. Delay becomes very critical for FBA scheme when the reserved bandwidth is less than the real traffic load; this problem is eased in Shared scheme as it controls bandwidth according to the real load. High delay slope is found at load 0.9 of Group1(Shared,70%), much higher than with FBA scheme, while Group2(Shared,30%) shows a little more delay than FBA, due to bandwidth transfer to Group1. It indicates that efficient transfer of unused bandwidth is made from one group to the other.

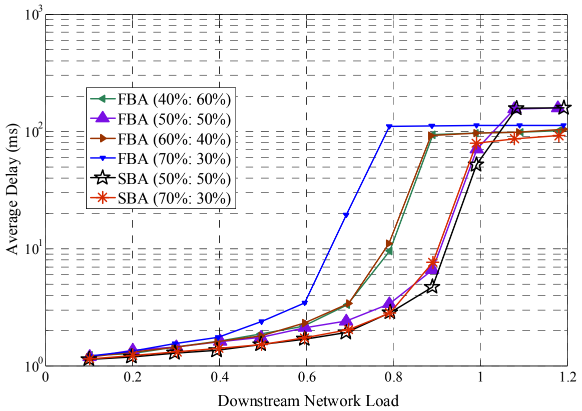

Fig. 5. Downstream delay during protection when bandwidth reservation ratio is 0.5:0.5.

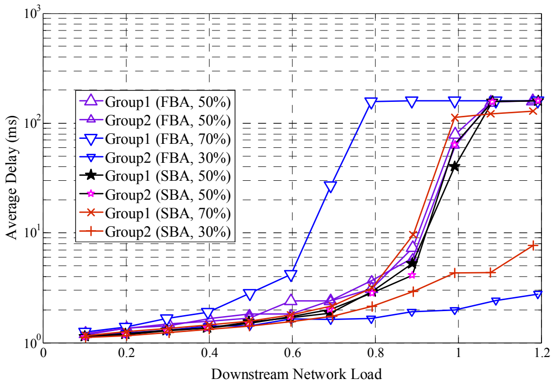

Fig. 6. Downstream delay during protection toward individual group when bandwidth reservation ratio is 0.5:0.5.

It is found that the Shared scheme can increase the bandwidth utilization efficiently. In uneven traffic generation like Shared(70%:30%) it provides more than 10% of throughputs compared to FBA(70%:30%) as seen in Fig. 7. Throughput toward each group of ONUs is shown in Fig. 8. It is observed that throughputs of both Group1(Shared,70%) and Group2(Shared,30%) are increasing until load of 1.0; after then throughput of Group1 decreases since Group2 restores its own bandwidth from Group1 to guarantee its 50% share.

Ⅳ. CONCLUSIONS

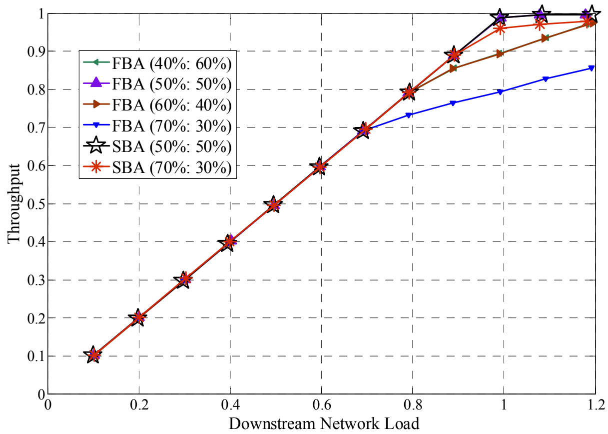

Fig. 7. Downstream throughput during protection when bandwidth reservation ratio is 0.5:0.5.

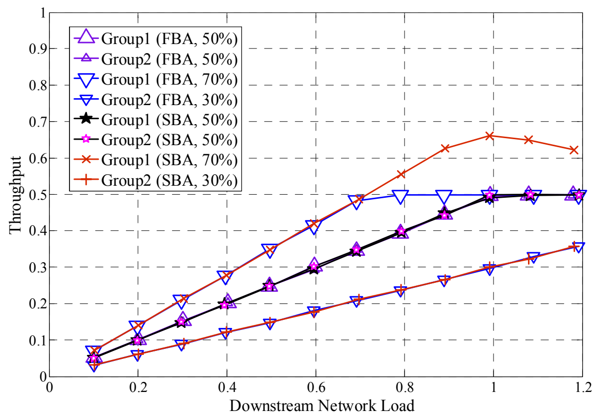

Fig. 8. Downstream throughput during protection toward individual group when bandwidth reservation ratio is 0.5:0.5

In this paper, we proposed a 2-OLT PON system based on WDM in implementing reliable and bandwidth efficient optical access network. Both OLTs are used in the data transmission in normal condition, while one of them replaces the other OLT during fault condition. Therefore, no OLT is in idle status, increasing the bandwidth efficiency compared to dual homing protection scheme. An appropriate bandwidth allocation algorithm as well as a wavelength assignment scheme is suggested. The Shared-bandwidth scheme is used to improve the bandwidth efficiency during protection and its performance is analyzed by simulation. It is expected that the proposed protection scheme will enhance the survivability of next generation high speed PON systems like 10 Gbps or 40 Gbps PON, that are expected to be used in business area.

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