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ASE 잡음과 보호구조를 고려한 WDM SHR의 노드확장 한계

정회원 박 영 일*, 채 창 준**

Limit of Node Expandability Considering ASE Noise and Protection Architecture in WDM SHR

Youngil Park*, Chang Joon Chae** *Regular Members*

요 약

WDM SHR을 이용해 통신망을 구축하는 경우 노드의 최대 개수는 망의 보호/절체 구조 및 분기결합장치에 위치하고 있는 광증폭기의 ASE 잡음 등으로 인해 한정된다. 본 논문에서는 ASE 잡음으로 인한 광 신호대 잡음비를 계산하고 이를 바탕으로 망의 보호/절체 구조 및 전송속도에 따른 최대 노드 개수를 계산하였다. 또한 가용 파장 개수에 의해 제한되는 최대 노드수와 비교하였다. 이러한 과정은 향후 WDM SHR의 기술기준 마련 혹은 설계작업에 이용될 수 있을 것이다.

ABSTRACT

The maximum number of nodes in WDM self healing ring network is limited by several factors including network architecture and ASE noise due to EDFAs at each optical ADM node. In this paper, the maximum node numbers for several protection architectures and bit rates limited by ASE are calculated and compared with the number limited by wavelength numbers. Appropriate design rules can be deduced from these results.

Ⅰ. Introduction

A SDH Self Healing Ring (SHR) network is widely used recently, especially in metropolitan areas since it provides high reliability with efficient use of bandwidth at low cost [1]. But, the drawback of the SDH SHR is found when the bandwidth should be increased due to traffic increase. In this case, ADMs of all nodes should be replaced with higher speed equipments or additional ring should be deployed. Therefore, a WDM SHR can be seriously considered for this environment. The number of nodes for the WDM SHR limited by the available number of wavelengths is well studied so far, and several architectures and wavelength assignment algorithms utilizing the limited number of wavelengths are proposed [2,3]. But, the possible number of nodes may be limited more by ASE noise of EDFAs at ADM nodes since the decreased optical SNR degrades the transmitted signal. Furthermore, since the number of cascaded ADM nodes that a certain channel passes through is dependent on the protection architecture of the SHR the node limit is decided by the ring architecture also. This

* 국민대학교 전자공학부 광통신연구실 (ypark@kmu.kookmin.ac.kr)
** 한국통신 가입자망연구소 광통신연구팀 (cjchae@kt.co.kr)
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paper gives an idea about the relationship between the SHR architecture and the node expandability.

Ⅱ. Optical SNR of WDM SHR

Fig. 1 describes the usual optical ADM structure of the WDM SHR. Each ADM is assumed to have two AWGs for channel ADD/DROP between two EDFAs. There can be optical switches for reconfiguration and optical attenuators for power equalization. For 10 Gbps transmission case, dispersion compensation modules (DCM) may be inserted to compensate for the chromatic dispersion, which brings additional loss into the ADM. Table 1 shows the losses of commercial components. As with this table, about 15 dB or 20 dB of optical loss can be assumed for 2.5 Gbps or 10 Gbps WDM SHR, respectively. These types of ADMs are cascaded

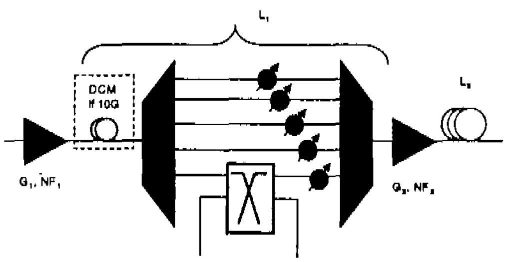


Fig. 1. Structure of each optical ADM

in ring fashion but shown in linear type for understanding in Fig. 2. An added channel passes only the rear (or booster) EDFA of an ADD node while it passes only the front (or preamp) EDFA of a DROP node. N ADMs between both ends are assumed and the EDFAs located in these intermediate ADMs are called optical line amplifiers in this paper. The ASE arised from the first ADM is calculated as in eq. (1)-(2) [4].

$$Pase = A(G_1-1)L_1G_2 + B(G_2-1) \quad (1)$$

$$A = 2n_{sp,1}h\nu_sB_o, \quad B = 2n_{sp,2}h\nu_sB_o \quad (2)$$

Here, $n_{sp,1}$ and $n_{sp,2}$ are the spontaneous emission factors of the two EDFAs, respectively, h the Planck's constant, ν_s the optical frequency and B_o the optical bandwidth. After passing N ADMs the ASE noise becomes [5]

$$Pase = [A(G_1-1)L_1G_2 + B(G_2-1)] \times \frac{1-(L_1L_2G_1G_2)^N}{1-(L_1L_2G_1G_2)} \quad (3)$$

Table 1. Optical losses of commercial components

component of ADM	loss
AWG	6 dB
optical attenuator	1 dB
optical switch	1 dB
DCM (40 km comp.)	5 dB
OFD, connectors, etc	2 dB

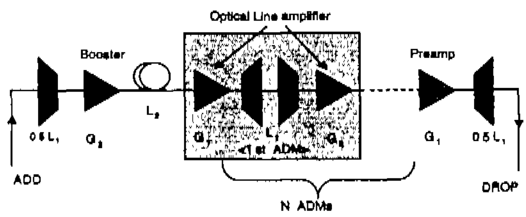


Fig. 2. Cascaded optical ADMs in WDM SHR

Assuming that $L_1L_2G_1G_2 \approx 1$, eq. (3) becomes

$$Pase = N \cdot [A(G_1-1)L_1G_2 + B(G_2-1)] \quad (4)$$

At the destination node it becomes

$$Pase,_{OLA} = N \cdot [A(G_1-1)L_1G_2 + B(G_2-1)] \times L_2G_1\frac{1}{2}L_1 \quad (5)$$

In the same way, ASE noise from the booster and the preamp becomes eq. (6) and (7), respectively.

$$Pase,_{BA} = B(G_2-1) \cdot L_2G_1\frac{1}{2}L_1 \quad (6)$$

$$Pase,_{PA} = A(G_1 - 1)\frac{1}{2}L_1 \quad (7)$$

Then, the total amount of ASE for the drop channel is the sum of eq. (5)-(7) while the signal power is like eq. (8)

$$Psig = Pso(L_2 G_1 L_1 G_2)^N \cdot L_2 G_1 \frac{1}{2} L_1 \approx Pso \cdot L_2 G_1 \frac{1}{2} L_1, \quad (8)$$

where Pso is the signal power after booster amplifier, which amount is decided by amplifier specifications and the number of channels, applied input power, etc. Optical signal to noise ratio (OSNR) of the dropped signal is estimated from eq. (5)-(8). It is maximized when $L_1 G_2 = L_2 G_1 = 1$ rather than $L_1 G_1 = L_2 G_2 = 1$, and the final OSNR, the ratio of the optical signal power to the optical noise power at receiver side measured over an optical bandwidth, is simplified to eq. (9).

$$OSNR = \frac{Psig}{Pase} = \frac{Pso}{(N+1)[A(G_1-1)+B(G_2-1)]} \quad (9)$$

Each parameter used in above equations are listed in table 2. Since $L_2 G_1 = 1$ is assumed G_1 varies with the span length of the ring network,which usually amounts to 40~50 km and the corresponding optical loss is 15~20 dB considering 0.25~0.3 dB/km fiber attenuation, 2 ~3 dB loss at connection points and 3 dB optical margin. G_2 is based on the specification of ADM components shown in table 1. B_o is set to 0.1 nm since OSNR is often measured at this value. Pso, the signal power at a booster EDFA, is assumed to be 1 mW (0 dBm) or 2 mW (3dBm) by considering practically available 32 wavelengths and EDFA output power of 15 dBm ~18 dBm. Using table 2 and eq. (9), transition of OSNR can be calculated and the results are shown in Fig. 3(Pso=1mW) and Fig. 4(Pso=2mW). Comparing two figures, higher Pso value provides better performance, but, at the expense of expensive EDFA with higher output power and

G_1	front EDFA gain	15~20 dB	
G_2	rear EDFA gain	2.5 Gbps	15 dB
		10 Gbps	20 dB
$n_{sp,1}$	spont. emission of front EDFA	1.5	
$n_{sp,2}$	spont. emission of rear EDFA	1.4	
B_o	Optical bandwidth	0.1 nm	
Pso	signal power at booster EDFA	1 mW or 2 mW	

Table 2. Parameters of WDM SHR

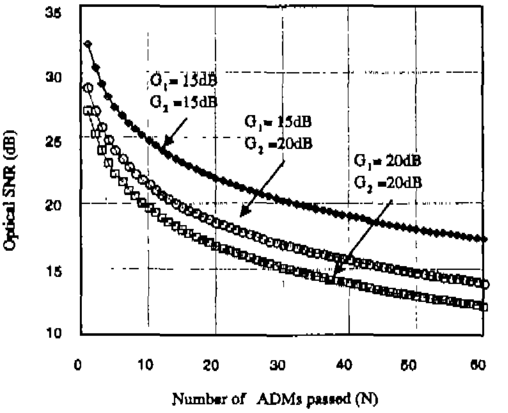


Fig. 3. Transition of OSNR after N ADMs passed (Pso=1mW)

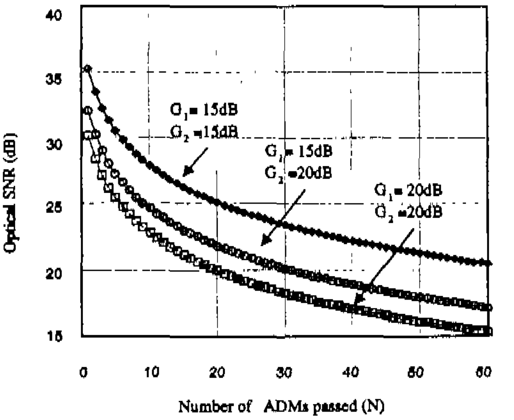


Fig. 4. Transition of OSNR after N ADMs passed (Pso=2mW)

gain. OSNR is not directly converted to electrical SNR since the latter is dependent on the receiver type and modulation scheme. But for currently used IM/DD transmission, OSNRs of over 20 dB for 2.5 Gbps and 23 dB for 10 Gbps transmission are required for commercial communication systems requiring enough margin[6]. These values of OSNR are generally accepted and used as criteria in this paper. The maximum possible ADM numbers that a WDM channel can pass before its drop can be estimated from above figures. But, the node numbers that each channel should pass is a function of ring architecture and several other conditions with WDM SHR also. Therefore, all these relations should be considered to evaluate the node expandibility.

Ⅲ. Maximum node numbers

The number of ADMs that an optical channel passes through before it drops usually increases when in line failure than in normal situation, and the number varies with the protection architecture.

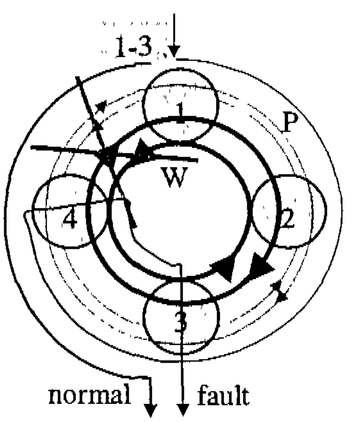


Fig. 5. Restoration of an optical channel from line failure in 4-fiber bidirectional line switched ring

Fig. 5 shows one example, a 4-fiber bi-directional line switched ring (BLSR/4)[1], where only four nodes are shown for simplicity. Only two hops are required for transmission of node1→node3 in normal case(1-4-3), while the number increases to five for line failure case(1-2-3-4-4-3), which is shown clear in Fig. 6. The optical switch is in bar state in normal condition, making the optical signal proceeds in working path. But, when in fault, the optical switch is changed to cross state so that the optical signal is looped back. Note that the optical signal passes the last node twice for looping back. Maximum hop numbers for various types of protection architectures are described in table 3, where 'm' means the total node numbers constituting the SHR and ⌈ ⌉ means quotient. Line protection often requires more hops, sometimes nearly double the node number, for building protection route. Considering both optical SNR degradation and maximum hop numbers, the maximum possible node numbers for various WDM SHRs, based on table 1 and table 2, are illustrated in Fig. 7. Fig. 7(a) is for 2.5 Gbps WDM SHR, where G2 of 15 dB and reference optical SNR of 20 dB are assumed while Fig. 7(b) is for 10 Gbps

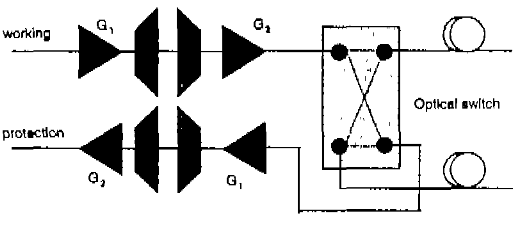
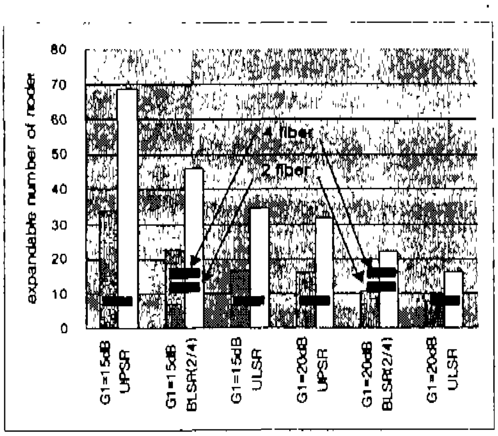


Fig. 6. Protection using optical switch : normal (bar state), failure (cross)

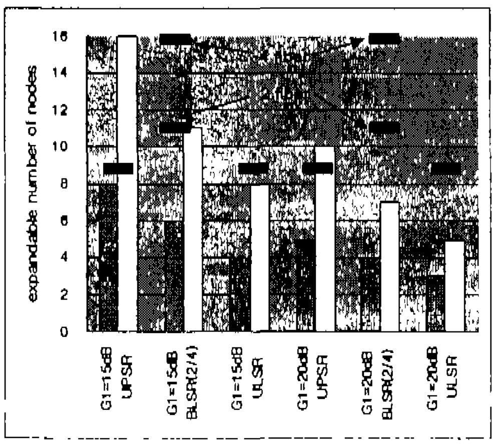
Table 3. Maximum hops during failure (m: total node numbers)

WDM-SHR type	Protection	Max. hops
BLSR/2,4 (2,4 fiber bidirection)	Line protection	(m-1) + ⌈m/2⌉
ULSR (2 fiber unidirection)	Line protection	2m-2
UPSR (2 fiber unidirection)	Path protection	m-1



Gadm=15 dB, OSNR=20 dB (for 2.5 Gbps transmission)

(a) G2=15 dB, OSNR=20 dB assumed for 2.5 Gbps transmission



Gadm=20 dB, OSNR=23 dB (for 10 Gbps transmission)

(b) G2=20 dB, OSNR=23 dB assumed for 10 Gbps transmission

Fig. 7. Maximum possible node numbers considering restoration from failure (left bar for P_{so}=1mW, right bar for P_{so}=2mW, cross bar for limit by wavelength)

WDM SHR, where G2 of 20 dB and reference optical SNR of 23 dB are applied.

Ⅳ. Discussions

As with Fig. 7. UPSR architecture is best from the viewpoint of ASE because the maximum passed ADM numbers remain the same even after switching due to line failure. As the signal power from booster, P_{SO}, is increased from 1 mW to 2 mW, the node numbers are increased almost double. To increase the channel power further keeping 32 wavelengths makes the total EDFA output power beyond safety limitation[7]. Another major factor that limits the node numbers is the available number of wavelengths. For full mesh connection with m nodes, required number of wavelengths is $m(m-1)/2$ for unidirectional, $(m^2-1)/8$ {or $m^2/8$ for even node number) for 4-fiber bidirectional and $(m^2-1)/4$ {or $\lceil m^2/8 \rceil \times 2$ for even node number} for 2-fiber bidirectional type. The feasible node numbers with 32 wavelengths are marked with small cross bars in Fig. 7 for comparison and shows that node expandability is limited more by wavelength for G1 of up to 20 dB in 2.5 Gbps WDM SHR, while by ASE for 10 Gbps WDM SHR.

For summary, the effect of ASE accumulation should be carefully considered to satisfy the transmission performance of the WDM SHR, especially for 10 Gbps systems whose ADM node may require more gain than the 2.5 Gbps case for compensating the loss from a dispersion compensation module. The protection architecture should be chosen considering ASE effects. The calculation done in this paper can be a design rule for WDM SHR.

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박 영 일 (Youngil Park) 정회원
1987년 2월 : 서울대학교 전기공학과 졸업(공학사)
1989년 2월 : 서울대학교 전기공학과 졸업(공학석사)
1995년 5월 : Texas A&M University 전기공학과 졸업(공학박사)
1995년 8월~1999년 2월 : 한국통신 가입자망연구소 선임연구원
1999년 3월~현재 : 국민대학교 전자공학부 전임강사
<주관심 분야> WDM 전송장치, 광소자, 광센서

채 창 준 (Chang Joon Chae) 정회원
한국통신학회논문지 제 21권 1호 참조