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Numerical Study to Design an Optical Node for Metropolitan Networks

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Abstract

We design a reconfigurable optical node for metropolitan WDM networks, and numerically study the capability of the node in the optical signal level. Unlike a long-haul WDM system, major limitations of metropolitan WDM systems are power loss, fiber dispersion and optical signal-to-noise ratio(OSNR) degradation due to EDFAs. Therefore, we include the behaviors of transmitter and receiver, and fiber, EDFAs, and optical filters(MUX/DeMux) in numerical simulations with varying parameters over wide range. From simulation results, we can identify the maximum span numbers for OC-48 and OC-192 to achieve $BER<10^{-12}$ *using the node structure at various received powers and residual dispersions.*

Keywords: *Metropolitan networks, WDM, Ring network, OSNR, BER*

1. INTRODUCTION

Most existing metropolitan networks are based almost exclusively on Synchronous Optical Network (SONET) ring architectures. These multiple, overlaid SONET rings can be aggregated over a single set of fibers through the use of wavelength division multiplexing(WDM) systems [1]. While many metropolitan core networks utilize existing WDM systems engineered for long-haul networks, WDM systems for metropolitan networks require different aspects of the network, especially the wavelength reconfigurability, in addition to low cost to build. Most metro core networks today are built on two unidirectional(clockwise and counterclockwise) fiber rings to supply protection against equipment and fiber failures [2]. Figure 1 shows a conceptual ring network with 4 nodes capable of wavelength reconfiguration. At any node, any wavelength can be dropped, and can also be added while remaining optical channels will pass through the node [3,4].

In this paper, we suggest node structures with capability of wavelength reconfiguration for OC-48 and OC-192, respectively. Furthermore, we numerically study to find the maximum achievable span number using the suggested structures to obtain a target bit error rate(BER), say less than 10^{-12}.

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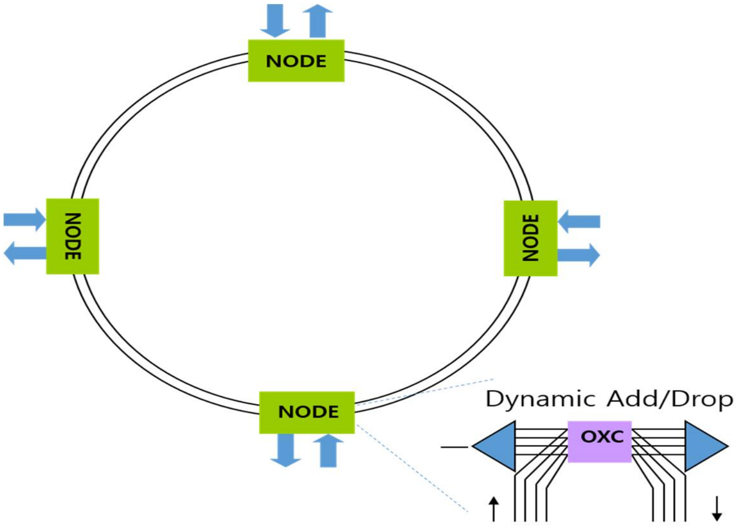


Figure 1. A conceptual ring network with 4 nodes

2. NODE STRUCTURE

We design an architecture of the node with capability of wavelength reconfiguration. Basic function elements of an optical node includes a pair of wavelength multiplexer/demultiplexer, transmitters and receivers. The capability of wavelength reconfiguration inevitably requires optical cross connect(OXC), and 2×2 optical switches can be used to add/drop signals, or signal redirect to supply protection against equipment and/or fiber failures[5]. Two optical amplifiers are included to compensate optical power losses not only due to the insertion of the components, but also due to the power loss by link fibers. If the link length between nodes, i.e. fiber length is less than 20km, and OC-48 is used, we might be able to use only one optical amplifier to save cost. However, in this work, two optical amplifiers in the node are used assuming 40km or longer fiber lengths. Most popular optical amplifiers for metropolitan networks are erbium-doped fiber amplifiers(EDFAs), and we also assume that EDFAs are used for the node. Variable optical attenuators(VOA) are included to compensate the non-uniformity of EDFA's gain curve over C-band(1525nm to 1565nm wavelength range). Dispersion compensation fiber(DCF) should also be included to compensate fiber dispersion, especially for OC-192(R_b=10Gb/s).

In Figure 2, the designed node structure for signals travelling from east to west is shown. All the optical components in the node are available in markets with reasonable prices, and their typical insertion losses are also shown in Figure 2. Additional power loss can be occurred due to fiber splices and connectors. When the node adds an optical signal from the transmitter, it will suffer around 20dB power loss before it reaches the post-amplifier (it is assumed that 7~8dB power loss and 1~2dB power loss due to DCF and due to splices and connectors, respectively). From the output of preamplifier, an optical signal will suffer around 13~14dB power loss before reaching the receiver depending on the exact characteristics of each component. These power losses(add path loss and drop path loss) should be considered in numerical studies in addition to the through path loss(power loss between the two amplifiers) when optical signals pass through the node.

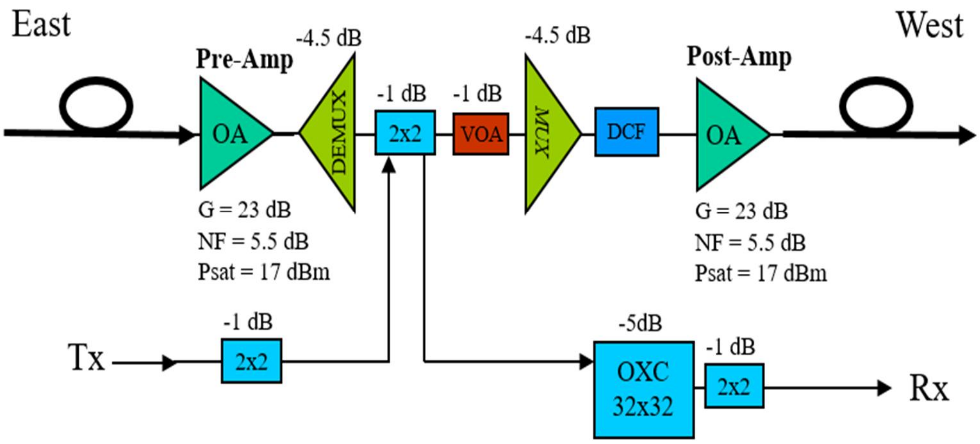


Figure 2. Designed node structure

3. COMPONENT MODELINGS AND NUMERICAL STUDIES

To estimate the maximum achievable span number with the suggested node structure, we model each optical components first. While wideband long-haul WDM networks require very sophisticated modelings of components and transmission effects, numerical simulations of WDM systems for metropolitan networks may require to include only major limitations such as power loss, fiber dispersion and optical signal-to-noise ratio(OSNR) degradation due to EDFAs. The reason for this is the shorter transmission distance and the much lower transmission capacity compared to wideband long-haul WDM networks.

3.1 Receiver Sensitivity and Dispersion Penalty

First, we model transmitters and receivers. For OC-48(R_b=2.5Gb/s) system, it is of importance to consider a low cost design. Therefore, we use a p-i-n photodiode receiver with a directly modulated transmitter in simulations for OC-48. However, for OC-192(R_b=10Gb/s), an avalanche photodiode(APD) receiver with an externally modulated transmitter is used for a better performance. Figure 3 shows BER curves when the received power P_R is changed. With back-to-back (no fiber) systems, we obtain the receiver sensitivity(@BER=10^{-10}) of -23dBm for OC-48 and -24dBm for OC-192, respectively. In a long-haul WDM system, it is relatively easy to compensate fiber dispersion by placing DCFs periodically[6-8]. However, in a metro ring network with capability of wavelength reconfiguration, the dispersion compensation can be a more challenging task because distances(i.e. fiber lengths) between each node are inevitably irregular, which makes it impossible to place DCFs in a regular pattern. Therefore it is important to consider residual dispersions at each node[9].

Figure 3 also shows the effect of residual dispersions on BER. It is assumed that a conventional single-mode fiber (ITU G.652) is used in the network because it has been deployed most widely for terrestrial networks among others. Since the dispersion parameter of a conventional single-mode fiber is around 17[ps/(nm·km)] at the center of C-band, the 340 [ps/nm] residual dispersion corresponds to 20km length of the uncompensated fiber, and the 680 [ps/nm] residual dispersion corresponds to 40km length of the uncompensated fiber, and so forth. The dispersion penalties when the residual dispersion is 1360ps/nm are 1.7dB and 1.8dB for OC-48 and OC-192, respectively. The results are summarized in Table 1.

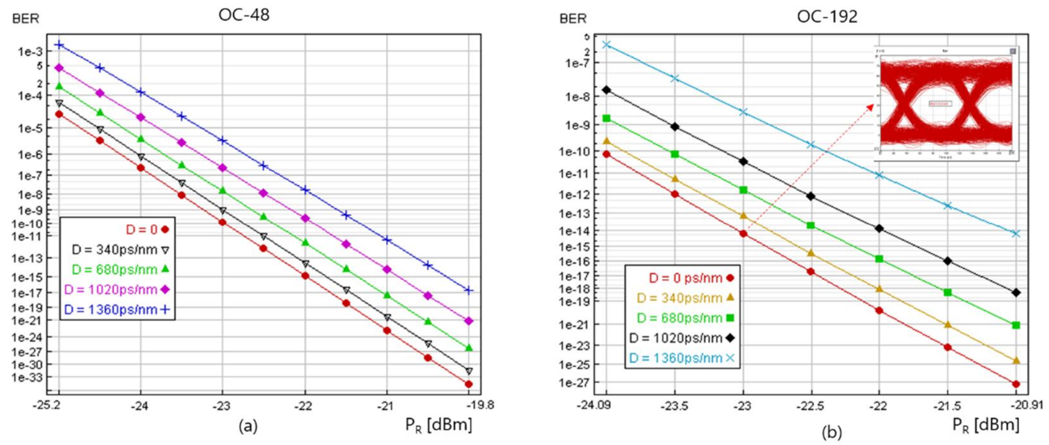


Figure 3. BER curves with residual dispersion of (a) OC-48 and (b) OC-192

Table 1. Receiver Sensitivity and Dispersion Penalty

	OC-48 (p-i-n with Direct-Modulator)	OC-192 (APD with External Modulator)
Sensitivity (@BER=10^{-10})	-23dBm	-24dBm
Dispersion Penalty (D=+1360ps/nm)	1.7dB	1.8dB

3.2 OSNR vs BER

As shown in Figure 2, there are two EDFAs in the designed node. While an optical signal is amplified by EDFAs to compensate power loss, amplifiers add optical noise (ASE: amplified spontaneous emission noise) to the signal. Therefore OSNR degrades as signal pass through the node. The relationship between OSNR and BER is simulated, and the results are shown in Figure 4.

With OC-48, it is observed that BER<10^{-12} can be achieved even OSNR is less than 17dB. However, OC-192 requires 20dB or more OSNR to achieve BER<10^{-12}.

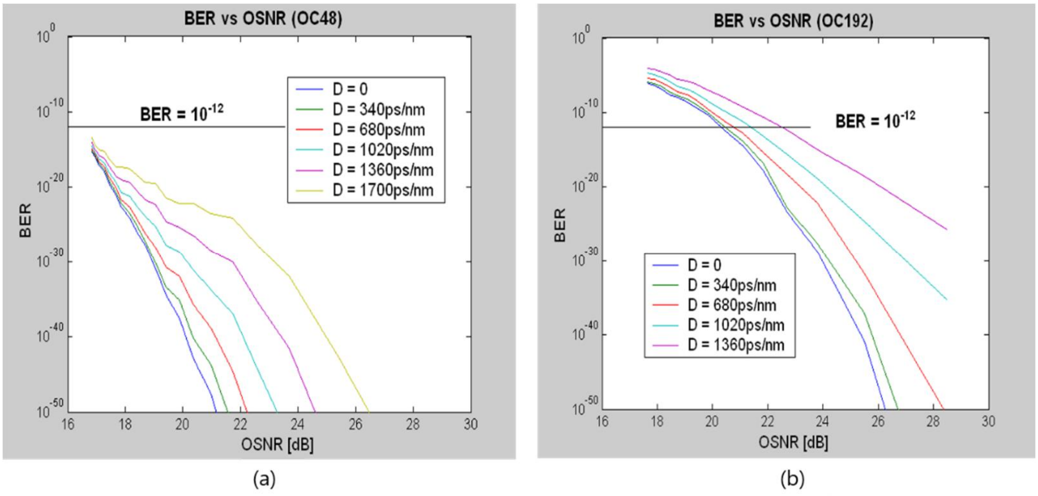
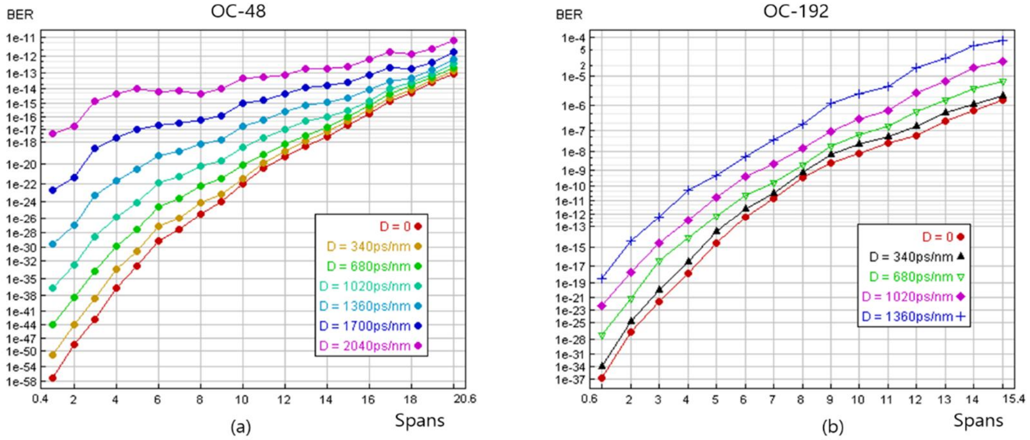


Figure 4. BER vs OSNR with residual dispersion of (a) OC-48 and (b) OC-192

3.3 Span Numbers vs BER

When an optical signal travels one span, it will pass two EDFAs. Figure 5 shows BER curves as a function of traveled span number. When the traveled span number is increased, the effects of residual dispersion on BER are less significant with OC-48. This is because the accumulated ASE noise from EDFAs becomes a dominant impairment as span number increases. However, OC-192 system is much more vulnerable to ASE noise. This is because the bandwidth of electrical filter in the receiver for OC-192 should be around 4 times greatly than the bandwidth of OC-48 receiver.



(a) (b)

Figure 5. BER vs Traveled Span Number (a) OC-48 (b) OC-192

4. SUMMARY AND CONCLUSIONS

We suggest a reconfigurable optical node with optical components which are available in markets. To identify the capability of the node, we studied numerically. Based on the results in the previous section, we can calculate the maximum achievable span number for a target BER. Table 2 summarizes the maximum span number for OC-48 and for OC-192 to achieve BER<10^{-12} at various received powers and residual dispersion values. The received power is relatively insensitive if the received power level is about 6dB greater than the receiver sensitivity. This is because the system performance is mainly limited by OSNR.

It is worth remind that the results of Table 2 are based on the assumption that system performance is mainly limited by dispersion of fiber and ASE noise of EDFA. In real systems, other impairments such as polarization-mode dispersion(PMD) and wavelength offset of laser can limit system performance further[10]. However, the above results can be used for a design tool of a metropolitan WDM networks. In the first stage of network design in optical level, it will help to identify the required DCFs and their positions. In addition, we can estimate system margin and identify the worst in advance.

Table 2. Maximum Span Number for BER < 10^{-12} (a) OC-48 (b) OC-192

(a)

D [ps/nm]	P_R = -12.5dBm	P_R = -15.5dBm	P_R= -18.5dBm	P_R= -21.5dBm
0	>20	>20	>20	11
340	>20	>20	>20	10
680	>20	>20	>20	9
1020	>20	>20	>20	4
1360	>20	>20	>20	0
1700	>20	>20	19	0

(b)

D [ps/nm]	P_R = -12.5dBm	P_R = -15.5dBm	P_R = -18.5dBm	P_R = -21.5dBm
0	7	7	6	5
340	6	6	5	5
680	6	5	5	5
1020	5	5	4	4
1360	4	3	3	2
1700	2	2	1	0

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