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Design for Low Cost Optical Node with Wavelength Reconfiguration

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Abstract

Two wavelength reconfigurable optical nodes are designed. One for 20km or shorter link length, and the other for up to 60km link length. While the first one requires no dispersion compensation, the latter needs dispersion compensation fiber included in the node, which requires additional optical amplifier to compensate the insertion loss of DCF. We calculate all the optical path losses in both cases using the typical value of optical components in the market to see the feasibility of the designed optical node. The minimum received power in the node is calculated to be -21.5dBm without DCF and -12.5dBm with DCF, respectively. These received powers are above the receiver sensitivity both for OC-48 and OC-192 according to the previous work.

Keywords: *Optical node design, Wavelength reconfiguration, Optical path loss*

1. Introduction

Communications service providers have been faced enormous challenges on several fronts. The pressure to enable new service offerings, upgrade network infrastructure, and deliver profits has been overwhelming. At the same time, the sheer amount of traffic volume, primarily IP data, creates an opportunity for carriers to expand and develop new revenue sources. However, 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 dense wavelength division multiplexing(DWDM) systems [1,2]. DWDM systems for metropolitan networks need to be cost effective in addition to the capability of wavelength reconfiguration.

Most metro core networks today are built on two unidirectional(clockwise and counterclockwise) fiber rings to supply protection against equipment and fiber failures. Figure 1 shows a conceptual 4-node ring network with 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]. An OSC(Optical Supervisory Channel) may be included to carry all the supervisory information such as alarms, status information, performance monitoring parameters, etc., between the nodes [4].

Since DWDM technologies, which are initially used for long-haul networks, has been adopted for metropolitan core networks, various design issues such as crosstalk and dispersion map have been studied analytically or numerically [5,6,7]. However, detailed node structures with the wavelength reconfigurability has not been reported yet. In this paper, we show the wavelength reconfigurable node structures using currently available components in the market with detailed link loss designs.

The organization of this paper is as follows: section 2 describes the high-level architecture of the designed system to have dynamic add/drop access to wavelengths in a 2-fiber ring independent of data format and bit-

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rate. Section 3 shows the calculated all the optical path loss in the node with and without dispersion compensation. Finally, section 4 summarizes and concludes this article.

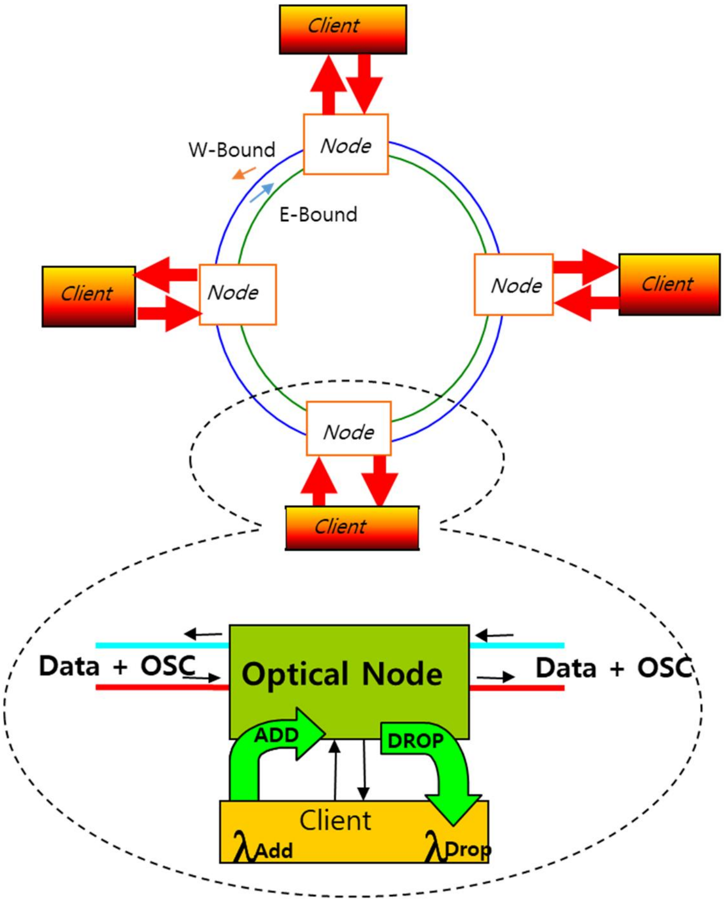

Figure 1. A conceptual 4-node ring network with wavelength reconfiguration

2. High-level Architecture for Dynamic add/drop Access to Wavelength in a 2-fiber Ring

The high level architecture of the optical node is shown in figure 2. The operation and performance of the node is independent of wavelength within C-band(1530 nm to 1565nm), data format and bit rate. An optical supervisory channel(OSC), which carries all the supervisory information, is assumed to be modulated at 1510nm wavelength. Basic building blocks of an optical node should include optical cross connect(OXC) in addition to a pair of wavelength multiplexer/demultiplexer, transmitters and receivers.

2×2 optical switches can be used to add/drop signals, or signal redirect to supply protection against equipment and/or fiber failures. Line fibers coming from a 2-fiber ring network split out OSC at 1510 nm and pass on the remaining data channels (1530nm - 1565 nm) to optical amplifiers where line power (all data channels) are boosted to compensate the optical losses of λ-add/drop routing fabric prior to introducing into it. Optical supervisory channels terminated at transceivers carry the status and control information that are shared among all nodes in the ring. The functions of wavelength mux/demux or filtering and add/drop/continue are taken place at λ-add/drop routing fabric that consists of various optical components such as wavelength filtering devices, optical switches and attenuators. Leaving λ-add/drop routing fabric, added channels and pass through channels are recombined into a single fiber and fed to another optical amplifier, if necessary, to boost signals for the next link. Before returning back into the line fibers of network, data lines and optical supervisory channels are combined. The architecture is designed with capability to survive single failure without impacting traffic by reconfiguration.

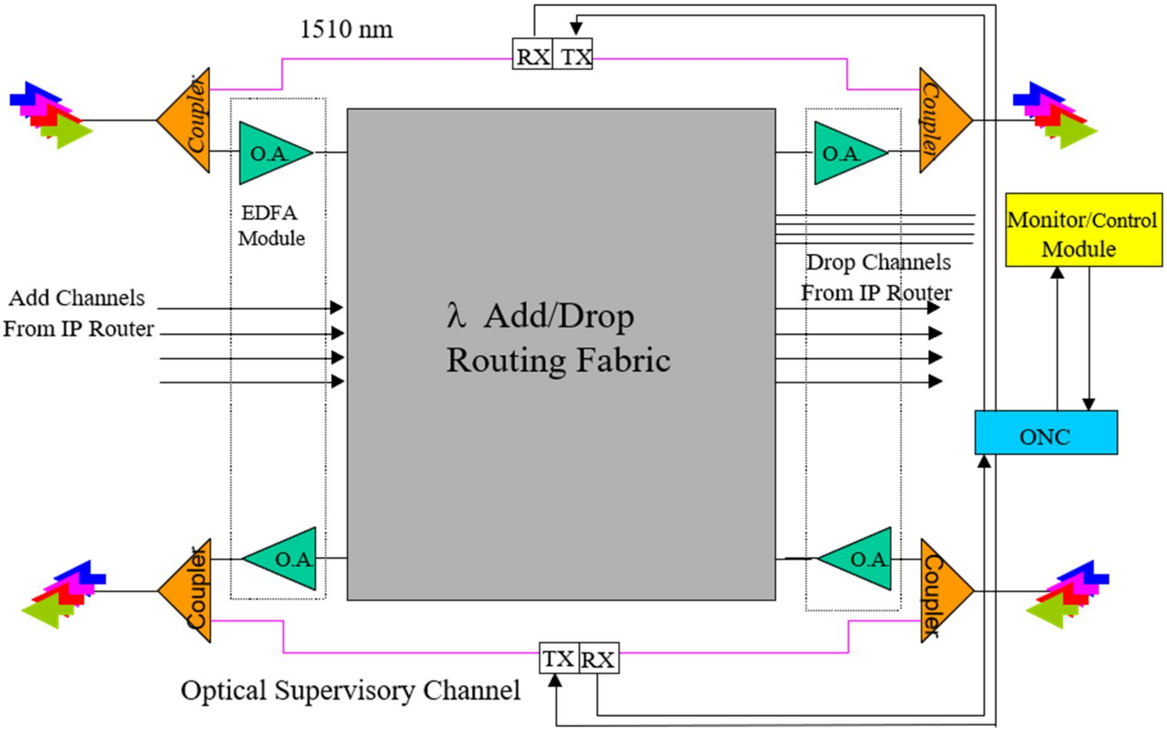

Figure 2. High-level architecture of optical node

In the next section, we will show more detailed structure for the wavelength routing block. 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. Its typical attenuation coefficient and dispersion parameter are 0.25dB/km and 17ps/(nm×km), respectively [8].

3. Optical Node Structures with Optical Path Losses

While wideband long-haul DWDM networks require very high end components to achieve their performance criteria, metropolitan networks may need to consider major limitations only such as power loss and fiber dispersion. For SONET optical carrier level OC-48(R_b=2.5Gb/s) system, it is of importance to consider a low cost design. Therefore, a p-i-n photodiode receiver with a directly modulated transmitter can be used for OC-48 in the optical node [9]. With such a transmitter/receiver pair, it is known that the receiver sensitivity and dispersion penalty for the residual 340ps/nm dispersion are -23dBm(@BER=10^{-10}) and 0.2dB, respectively. For OC-192(R_b=10Gb/s), an avalanche photodiode(APD) receiver with an externally modulated transmitter should be used for a better performance. Higher bit rate is more vulnerable to dispersion, and yet the higher performance transmitter/receiver pair can help to mitigate the dispersion penalty. With such a transmitter/receiver pair, the receiver sensitivity and dispersion penalty for the residual 340ps/nm dispersion are known to be -24dBm(@BER=10^{-10}) and 0.1dB, respectively [7].

Therefore, if the length of link fiber is less than 20km, of which dispersion corresponds to less than 340ps/nm, we can design the optical node without a dispersion compensation component. Figure 3 shows the detailed node structure capable of adding and/or dropping up to 32 wavelengths in the C band without a dispersion compensation component. Various optical path losses due to link fiber and passive optical components in the node are also shown. All the path losses include additional 1 dB loss for fiber splices, which are not shown in the figure.

2×2 optical switches and OXC enables an optical channel to drop, add, or route to any other channel, and an erbium-doped fiber amplifier(EDFA) is used for the compensation of optical power losses. Variable optical attenuator(VOA) is included to compensate the non-uniformity of EDFA's gain curve over C-band(1525nm to 1565nm wavelength range). Over C-band, the gain of EDFA is kept to be 23dB. Therefore the output power of each optical channel is controlled to be 1dBm. All the optical components in the node are available in markets with reasonable prices, and their typical insertion losses are also shown in the figure.

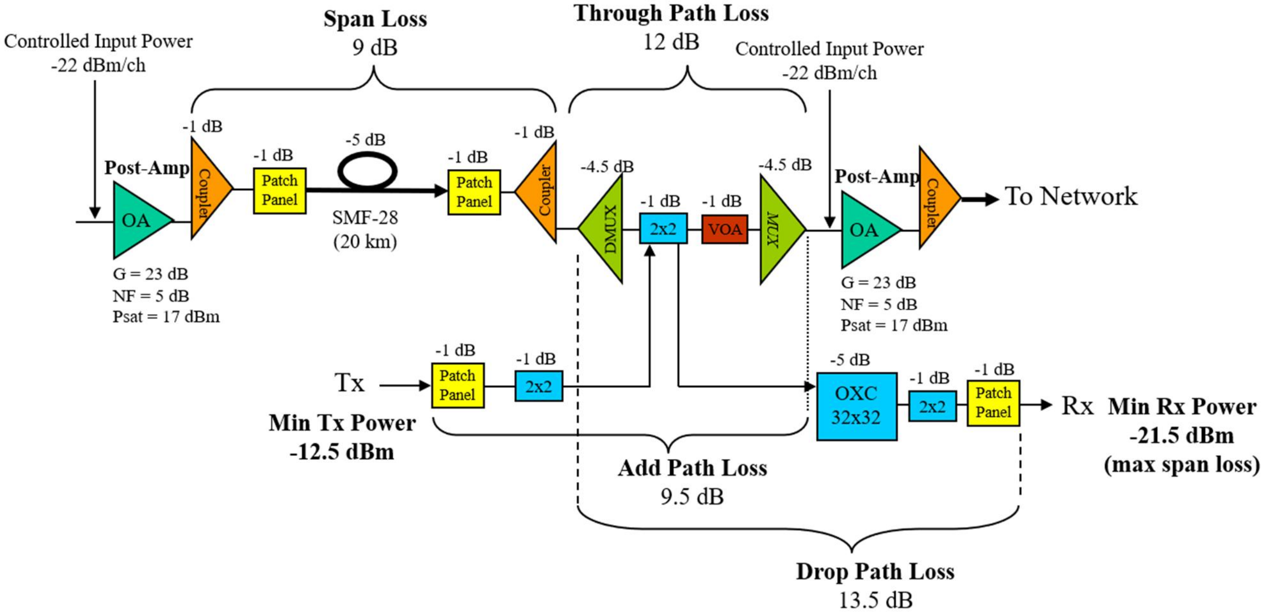

Figure 3. Optical Node Structure Without Dispersion Compensation

The maximum span loss is 9dB with SMF-28, which is the most popular conventional single-mode fiber, and the through path loss within the node is 12dB including 1dB splicing losses. When an optical channel pass through the node, it will suffer maximum 21dB loss. Therefore, one optical amplifier will suffice to compensate both span and through path losses. When an optical channel is dropped at the node, it will suffer 13.5 dB drop path loss in addition to the maximum 9dB span loss. Therefore the minimum receiver power will be -21.5dBm, which is greater than the receiver sensitivities calculated in [7]. To add an optical channel, the transmitter power should be at least -12.5dBm, which can be easily obtained either with a directly modulated transmitter or with an externally modulated transmitter. With the minimum transmitter power and the 9.5dB add path loss, the input power to the optical amplifier will be -22dBm, which makes the output power of the optical amplifier same as the output power of the previous node.

If the fiber length of inter-node is over 20km, a directly modulated optical signal along with a conventional single-mode fiber requires dispersion compensation even with OC-48. OC-192(R_b=10Gb/s) also need to be compensated for the dispersion penalty even with an externally modulated transmitter and an APD receiver. With a dispersion compensation component, additional power loss will be occurred due to its insertion loss. Therefore one optical amplifier is not enough to meet the receiver sensitivity.

Figure 4 shows the detailed node structure with a dispersion compensation fiber(DCF). It has 2 EDFAs to achieve maximum 60km fiber link.

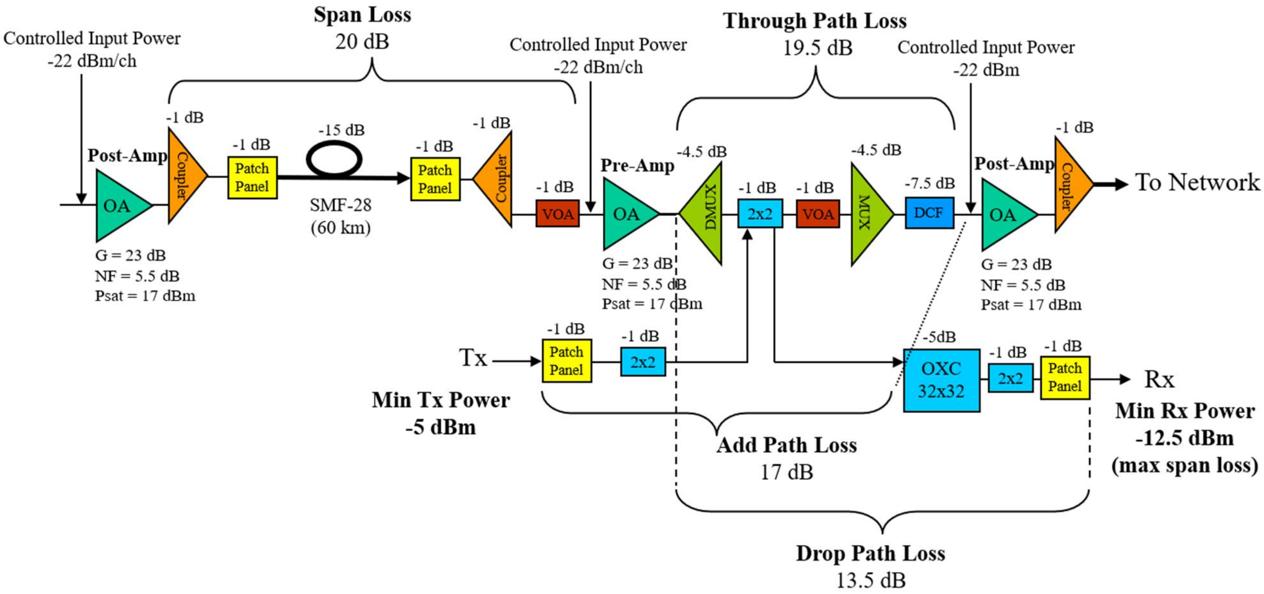

Figure 4. Optical Node Structure With Dispersion Compensation

Span loss can be up to 20dB depending on the length of link fiber. A VOA is used to control the power of an optical channel to be -22dBm at the input of the pre-amplifier in the node. While the drop path loss remains same as before, the received power can be at least -12.5dBm, which is much higher than the previous one with single EDFA. Both the through path loss and the add path loss are increased by 7.5dB due to the insertion of the dispersion compensation fiber. The VOA in the through path control the power level of the through path channel at the input of the post-amplifier to be -22dBm.

To add an optical channel, the transmitter power should be at least -5dBm.. Even though the required minimum transmitter power is higher than the previous one in Figure 3, it can also be easily obtained either with a directly modulated transmitter or with an externally modulated transmitter.

4. Summary and Conclusions

In this paper, we suggest the high-level architecture of the optical node capable of wavelength reconfiguration which can be used in a ring network. We also design two node structures, one with maximum 20km fiber link and the other with maximum 60km fiber link, with optical components available in the market. With 20km or longer links, fiber dispersion should be compensated. In the node design, a DCF module is used for dispersion compensation, which is the most popular way of dispersion compensation. However, with DCF, two optical amplifiers instead one are required to compensate the additional power loss due to the DCF.

We also calculate all the path losses of an optical channel by using the most typical insertion losses of the optical components. With one EDFA(without DCF), the through path loss, the add path loss, and the drop path loss are 12dB, 9.5dB, and 13.5dB, respectively. With two EDFAs(with DCF), the through path loss, the add path loss, and the drop path loss are 19.5dB, 17dB, and 13.5dB, respectively.

In this work, we mainly focused on power losses of various optical components in the node. Therefore, in the future, it is necessary to investigate the effects of various imperfections of optical components such as nonlinearity of DCF, gain and power transient of EDFA on the system performance.

Acknowledgement

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