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Modeling and simulative performance analysis of OADM for hybrid multiplexed Optical-OFDM system

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ABSTRACT

In this paper, we demonstrated the transmission performance through simulation for integrated dense wavelength division multiplexing and Optical-OFDM system with OADM including the fiber nonlinearity effect. The effects on transmitted channels, fiber link length, operating optical signal wavelength, optical transmitted signal power, optical signal bandwidth, transmission bit rate, optical received power and bit error rate at the receiving side are observed.

1. Introduction

Over the last decade, fiber optic cables have been installed by carriers as the backbone of their interoffice networks, becoming the mainstay of the telecommunications infrastructure [1]. This cutting edge technology when combined with network management systems and add–drop multiplexers enables carriers to adopt optically based transmission optical networks that will meet the next generation of transmitted bandwidth demand at a significantly lower cost than installing new fiber [2]. Wavelength selective optical add/drop filter is required for adding and dropping a particular wavelength division multiplexing (WDM) channel at each subscriber's node in the WDM based optical access networks [2]. In these WDM based optical networks, dense wavelength division multiplexing (DWDM) technology is necessary for maximizing the limited transmission bandwidth. Add/drop filter used in DWDM based optical networks should have a good reflection characteristic, temperature stability, a narrow spectral bandwidth, and a low implementation cost [3]. For those reasons, many researchers have been proposed various technologies for implementation of the add/drop filter. Commercialized optical add/drop filters comprise many optical passive devices such as fiber Bragg grating, thin film interference filter, circulator, and Mach-Zehnder interferometer. Although add/drop filters including those devices have good operating performances, their cost is too expensive to apply for DWDM based optical access network [4]. However, the achievements of transparent networks which will be implemented for the wavelength multiplexing technology (WDM) within the next years should be conserved when introducing OTDM in addition to the WDM technology [5]. This implies the need of additional elements in the network: time domain optical add-/drop multiplexer (TD-OADM). Moreover, 100 Gb/s CO-OFDM transmission over 1000 km has been demonstrated by groups from the University of Melbourne [6], KDDI [7], and NTT [8]. Because CO-OFDM uses digital-to-analog converters (DACs) at the transmitter and also unique pilot subcarrier-based channel and phase estimation, it offers an extremely convenient way to achieve high spectral efficiency transmission through higher order modulation. 64-QAM in single polarization [9] and 16-QAM in dual polarization [10] have been reported, both of which represent record spectral efficiency for single polarization and dual polarization, respectively, using off-the-shelf commercial components.

In the present work, we have investigated OADM based on DWDM technology for high speed performance of Optical OFDM communication networks. We have taken in to account the bit error rate for added and dropped channels at different fiber link lengths. As well as we have developed OADM for high speed transmission bit rates and products per channel at different optical signal transmitted power. Moreover we have deeply studied the performance evolution of transmitted and received signal powers at different channels at a specific fiber link length.

In this paper a simulation is performed for 12 channel DWDM system integrated with MIMO-Optical OFDM technology. The simulation is carried out using powerful software tools Optsim and MATLAB. After having brief introduction in Section 1, Section 2

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covers the DWDM system integrated with MIMO-Optical OFDM technology and describes the channel properties of optical fiber with dispersion compensated fiber. Section 3 deals with numerical results and analysis. In Section 4 the spectral efficiency of presented system is described. Finally, Section 5 concludes the paper.

2. Modeling analysis

The transmitted signal power can be expressed as a function of transmitted power and fiber loss () in dB/km, and transmission distance in km as the following expression:

$$P_T = P_R e^{\alpha L} \tag{1}$$

where P_R is the received power. Moreover the noise figure of the system after amplification can be:

$$\mathrm{OSNR} = \frac{\lambda_S P_T}{hc\mathrm{BW}_{\mathrm{sig}}\mathrm{NF}} \tag{2}$$

where h is the Planck's constant (6.02×10^{-34} J s), c is the speed of light (3×108 m/s), λ_s is the operating signal wavelength in μm, $\mathrm{BW}_{\mathrm{sig}}$ is the signal bandwidth at which the noise is measured, and NF is the noise figure. The refractive-index of silica-doped fiber link based on empirical equation is given by:

$$n = \sqrt{1 + \frac{k_1\lambda^2}{\lambda^2 - k_2^2} + \frac{k_3\lambda^2}{\lambda^2 - k_4^2} + \frac{k_5\lambda^2}{\lambda^2 - k_6^2}} \tag{3}$$

The mathematical coefficients of empirical equation is cast as in Ref. [9]. The coefficients are a function of T, ambient temperature in °C, $T0$ is considered as room temperature, and x is the ratio of germanium dopant added to silica fiber to improve its optical performance characteristics. The first and second differentiation of the previous equation w.r.t operating wavelength λ yields as in Ref. [9]. The total pulse broadening for optical system is the square root of the sum of the squares of the transmitter, optical fiber connection, and polarization mode dispersion at the receiving side. That is given by:

$$T_s = \sqrt{T_t^2 + T_{\mathrm{mat}}^2 + T_{\mathrm{PMD}}^2} \tag{4}$$

The material dispersion time of the single mode fiber, T_{mat} which is given by the following equation:

$$T_{\mathrm{mat}} = -\left(\frac{L\Delta\lambda\lambda_s}{c}\right)\cdot\left(\frac{d^2n}{d\lambda^2}\right) \tag{5}$$

where $\Delta\lambda$ is the spectral linewidth of the optical source in nm. The total pulse broadening due to polarization mode dispersion (PMD), D_{PMD} on the transmission distance, L can be expressed as:

$$T_{\mathrm{PMD}} = D_{\mathrm{PMD}}\sqrt{L}, \quad \mathrm{ps}/\sqrt{\mathrm{km}} \tag{6}$$

The maximum transmit power per channel, as a function of fiber link length can be expressed as:

$$P_T = \frac{40,000}{N_{\mathrm{ch}}(N_{\mathrm{ch}} - 1)\Delta\lambda_s L} \tag{7}$$

where N_{ch} be the number of transmitted channels, and $\Delta\lambda_s$ be the channel spacing in nm. For standard single mode fiber, the transmitted signal bandwidth can be determined as:

$$\mathrm{BW}_{\mathrm{sig}} = \frac{0.44}{T_s L} \tag{8}$$

where T_s is the total pulse broadening due to total dispersion coefficient of the system. According to modified Shannon theorem, the maximum bit rate per optical channel for supported number of users, or the maximum capacity of the channel for maximum subscribers is given by:

$$B_{\mathrm{Sh}} = \mathrm{BW}_{\mathrm{sig}} \cdot \frac{\log_{10}(1 + \mathrm{SNR})}{\log_{10}^2} \tag{9}$$

By using MATLAB curve fitting program, the fitting the relationship between the optical received power (Pr) and BER for the added and dropped signal at operating wavelength (λ = 1.55 μm) can be expressed as:

$$\mathrm{BER} = 0.003 \times 10^{-9} - 0.0754 \times 10^{-8} P_R \quad \text{(For added signal)} \tag{10}$$

$$\mathrm{BER} = 0.136 \times 10^{-9} + 0.763 \times 10^{-8} P_R \quad \text{(For dropped signal)} \tag{11}$$

The bit error rate (BER) essentially specifies the average probability of incorrect bit identification. In general, the higher the received SNR, the lower the BER probability will be. For most PIN receivers, the noise is generally thermally limited, which independent of signal current. The bit error rate (BER) is related to the signal to noise ratio (SNR) as follows:

$$\mathrm{BER} = \frac{1}{2}\left[1 - \mathrm{erf}\left(\frac{\sqrt{\mathrm{SNR}}}{2\sqrt{2}}\right)\right] \tag{12}$$

where erf represents the error function. For SNRs ≥ 16 (≈12 dB), the BER can be approximately by:

$$\mathrm{BER} \approx \left(\frac{2}{\pi \cdot \mathrm{SNR}}\right) \cdot \exp\left(\frac{-\mathrm{SNR}}{8}\right) \tag{13}$$

3. Design of 12 channels DWDM system integrated with MIMO-Optical OFDM technology

In current optical fiber communication systems, dense wavelength division multiplexed (DWDM) transmission with 10 Gb/s wavelength channels at 50 GHz channel spacing is an International Telecommunication Union (ITU) standard for long-haul and metropolitan networks. Because 100 Gb/s technology has increasingly become a commercial reality, it is desirable to design future 100 Gb/s upgrades in compliance with the currently installed 10 Gb/s DWDM systems. One of the main limitations for the transparent networks with a large number of nodes is the signal degradation due to transmission through multiple OADMs. The degradation is mainly from (1) the spectral filtering due to narrowing of the overall filter passband and (2) the group delay introduced by the impact of filter phase response. This dispersion leads to pulse distortion, ultimately resulting in transmission performance degradation, and it limits the bit rate. In this section, we describe the feasibility of transmitting 9.953 Gb/s Optical-OFDM signals over transparent 12 channel DWDM systems with the impact of the cascaded four OADMs.

This system in Fig. 1 describes a 9.953 Gb/s 12 channel DWDM system integrated with MIMO-Optical OFDM technology and a 4-channel OADM put in the middle of the fiber link.

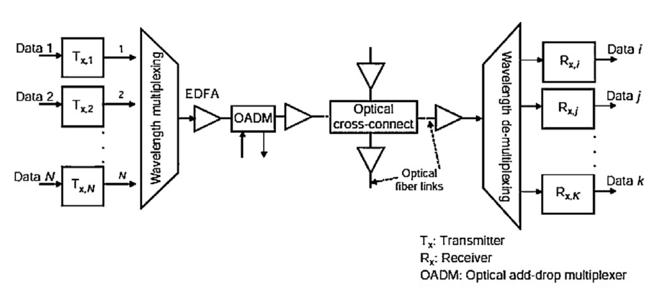

Fig. 1. Conceptual diagram for system's setup [William Shieh].