Optik 123 (2012) 1497–1500

Contents lists available at SciVerse ScienceDirect

Optik

journal homepage: www.elsevier.de/ijleo

Optimization of Super Dense WDM systems for capacity enhancement

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ARTICLE INFO

Article history:
Received 8 April 2011
Accepted 15 August 2011

Keywords:
Super Dense Wavelength Division Multiplexing
BER
Bit rate
Nonlinear effects

ABSTRACT

We investigate the performance of the Super Dense Wavelength Division Multiplexed (SDWDM) systems with high spectral efficiency and narrow spacing of the channels and optimization in terms of bit rate up to 15 Gbps, channel spacing as low as 12.5 GHz, number of channels up to 64 and repeater less transmission distance up to 100 km and report high capacity SDWDM systems. We demonstrate the minimal allowed channel spacing and provide recommendations for future SDWDM solutions. The simulation results have shown that the minimum channel spacing for 15 Gbps, 32 channel system need to be not less than 0.35 nm and that for a 10 Gbps system it should be not less than 0.25 nm. The 5 Gbps system gives acceptable results at spacing of 0.1 nm for maximum up to single span of 80 km.

1. Introduction

Innovations in optical fiber technology are enabling transmission of high-speed signals over transcontinental distances without the need for electronic regeneration. It has thus given thrust to networks/systems with higher capacities and at lower costs [1]. To fulfill the enormously increasing capacity requirements especially in long haul optical link communications, it has become imperative to increase the number of channels as well as the data rate per channel. The use of ultra-high bit rate channels for DWDM transmission is an attractive approach in increasing the capacity of future optical networks. In order to maximize the system capacity and to minimize the performance degradation caused by reduced channel spacing, the system needs to be investigated by increasing the number of channels at high bit rates [2]. To get maximum WDM network capacity, the system's design has to take into account other contributing factors such as the transmission distance, signal optical power, fiber linear and nonlinear effects.

Bobrovs [3] reported that the minimal channel interval for 2.5 Gbps DWDM system is 0.2 nm, and that for a 10 Gps system the spacing was not be less than 0.3 nm. S.L. Jansen et al. [4] demonstrated the feasibility of a cost-effective DWDM systems with 100 GHz channel spacing using single-mode fiber (SSMF) without using in-line dispersion with 16 channels and acceptable BER was obtained. It has been reported by H. Suzuki et al. in [5] that 512 channels of 2.5 Gbps signals spaced at 12.5 GHz (0.1 nm) could be transmitted over 320 km of single-mode fiber (SMF). He further investigated the performance of mixed 2.5 Gbps and 10 Gbps optical systems with simultaneous propagation of various modulation formats with 25 GHz (0.2 nm) channel spacing. Kaler et al. [6] quoted the simulation results [7–10] at 0.4 nm for a 32 channel system.

However all the previous research work reported on WDM systems is targeted for data rate of less than 10 Gbps and the maximum channel specifications is also limited for more than 0.3 nm. It also makes optical network management easier. However, a greater advantage is that operation at 15 Gbps and higher makes it possible to achieve higher throughputs than at 10 Gbps. With the existing research based on data rates less than equal to 10 Gbps, the focus is on increasing the channel density with some minimum distance. Our work focuses on decreasing the channel spacing still further lesser than 0.3 nm with existing data rates and graduating towards increasing the data rate of the individual fiber link for more than 10 Gbps with increase in number of channels.

In this paper we extend the work reported by Bobrovs in [3] to further increase the capacity by enhancing the bit rate up to 15 Gbps, decreasing the channel spacing up to 0.1 nm and by increasing the number of channels up to 64. This work is an attempt towards designing an spectrally efficient system with high denser channels and more bit rates/channel.

This paper is organized as follows: in Section 2, the schematic and simulation optical setup is described. Section 3 explains the

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0030-4026/$ – see front matter
doi:10.1016/j.ijleo.2011.11.004

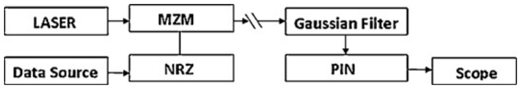

Fig. 1. Schematic setup for DWDM system.

results obtained and Section 4 gives the summary and conclusions followed by references.

2. System model and setup

The schematic block diagram for the DWDM system under investigation is shown in Fig. 1. In this system the transmitters have been varied up to 64 with channel spacing up to 0.1 nm and bit rate varying up to 15 Gbps. The transmitter section consists of data source, electrical driver, laser source and an amplitude modulator.

The schematic set up of the transmitter consists of a number of optical channels driven by CW lasers. The laser source acts as a continuous wave (CW) pump which is realized with distributed feedback (DFB) lasers. The transmitter with low data rates per channel is less complex and easier to realize by direct modulation of a laser diode. The realization becomes more complex with the increasing channel data rate [3]. For the realization of transmission systems with channel data rates larger than 2.5 Gbit/s, the external modulation presents a better solution, because the impact of laser internal chirp on optical signal can be reduced efficiently. External modulation is realized with a $LiNbO_3$-based Mach–Zehnder modulator based on the electro-optic effect. The external modulator is driven by an electrical signal with corresponding data rate e.g. RZ, NRZ. Depending on the electrical driving signal, different transmission speeds can be realized.

All the modulated signals are multiplexed by an ideal optical multiplexer whose ports are varied as according to the number of input channels. The output of the multiplexer forms a single fiber output sent over the fiber of a specified distance without any amplification. It is optically filtered such that the optical power within a definite wavelength window is only transmitted and the rest is either reflected or absorbed.

An optical compound sensitivity receiver follows the link which converts the filtered optical signal to electrical signal. The BER estimator and an eye diagram are used to measure and evaluate the system performance [7]. The eye diagram is most commonly used way which gives specific value of BER based on specific bit rates. It is an oscilloscope display of a digital signal, repetitively sampled to get a good representation of its behavior. The optical and electrical spectrum analyzers are used in the beginning and in the end of the optical link.

Operating wavelengths of light sources are arranged so as to form an equally spaced spectrum. The CW laser operates at the wavelength of 1549.5 nm. The data-source in the transmitter section generates a pseudo-random bit stream at the rate up to 15 Gbps which is encoded in the NRZ format where the signal varies between the range of −2.5 V to +2.5 V. A Mach–Zehnder modulator operates in the non-linear mode modulates the optical wavelength with the electrical bit stream.

The link in use is normal Single Mode fiber of varying distances maximum up to 80 km. At the receiver side Gaussian filter with bandwidth half of that of the channel spacing is used. A scope is used to view the eye diagram and BER of the signal demodulated by the PIN diode.

3. Results and discussions

The simulation results are based on solving a complex set of Schrödinger differential equations, taking into account optical and electrical noise as well as linear and nonlinear effects. We used model where signals are propagating as time domain samples over a selectable bandwidth. The Time Domain Split Step (TDSS) method is employed to simulate linear and nonlinear behavior for both optical and electrical components. The Split Step method is used in all commercial simulation tools to perform the integration of the fiber propagation equation.

The output power and BER is greatly affected by longer fiber links, higher bit rates and increased number of channels. The observation is made on 32 channel system with spacing of 12.5 GHz. It is reported that with increased distance, the BER increases with increasing bit rates. Fig. 2 shows the BER trend for various bit rates up to 12.5 GHz.

At such a narrow spacing the maximum link length achieved is 60 km at 7.5 Gb/s. Further the BER bared almost a constant pattern for increased number of channels to 64 at any specific bit rate e.g. 10 Gb/s. The graph in Fig. 3 indicates this at spacing of 0.1 nm for 60 km. The signal quality degradation is clear when number of channels is increased to 64 as shown in the eye diagram in Fig. 4. The BER noted for 64 channels set up at 10 gb/s at 0.1 nm at 60 km is 7.59E−3 which is an unacceptable value. Fig. 5 indicates the

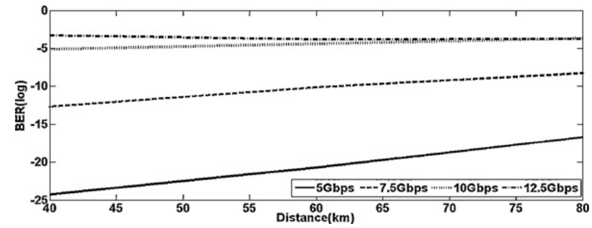

Fig. 2. Optimization of BER vs distance.

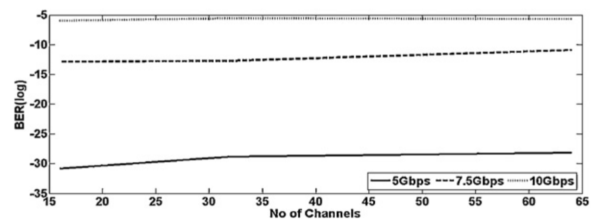

Fig. 3. Optimization of BER vs number of channels.

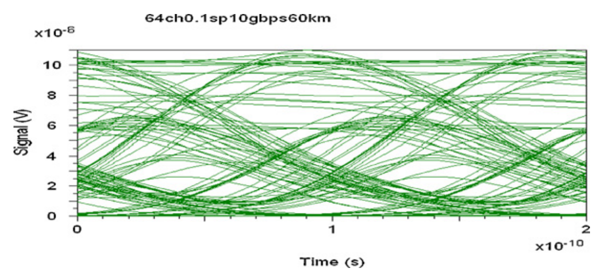

Fig. 4. Eye diagram (64 channels at 0.1 nm).

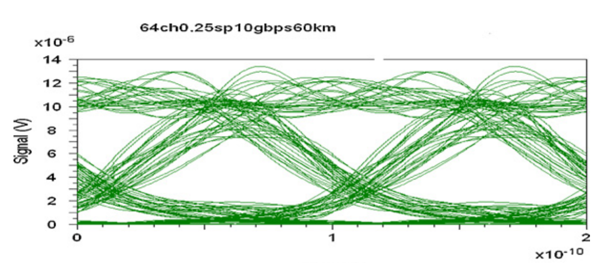

Fig. 5. Eye diagram (64 channels at 0.25 nm).