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On compensation of four wave mixing effect in dispersion managed hybrid WDM-OTDM multicast overlay system with optical phase conjugation modules

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ABSTRACT

This paper investigated the effect of FWM and its suppression using optical phase conjugation modules in dispersion managed hybrid WDM-OTDM multicast overlay system. Interaction between propagating wavelength signals at higher power level causes new FWM component generation that can significant limit the system performance. OPC module consists of the pump signal and 0.6 km HNLF implemented in midway of optical link to generate destructive phase FWM components. Investigation revealed that by use of even OPC module in optical link reduces the FWM power and mitigate the interaction between wavelength signals at variable signal input power, dispersion parameter (β_2) and transmission distance. System performance comparison is also made between without DM-OPC module, with DM and with DM-OPC module in scenario of FWM tolerance. The BER performance of hybrid WDM-OTDM multicast system using OPC module is improved by multiplication factor of 2 as comparable to dispersion managed and coverage distance is increased by factor of 2 as in Singh and Singh (2016).

1. Introduction

In the recent years, advanced optical techniques such as optical orthogonal modulation formats, hybrid multiplexing, hybrid amplification etc. are promising option to cope with the increasing demand of high speed and bandwidth. Optical orthogonal modulation formats are ultimate solution for future optical networks to increase the per channel capacity beyond 400 Gbps/channel as they are less vulnerable to polarization mode dispersion (PMD) and phase noise [1–4]. Also, hybrid multiplexing techniques such as WDM-OTDM, WDM-OCDMA, WDM-OTDM-PON, WDM-OFDM etc. has high spectral efficiency and can increase the overall system capacity within limited available channel bandwidth for long haul communication systems [5–11]. However, self-phase modulation (SPM), cross phase modulation (XPM), inter-channel four wave mixing (FWM) fiber impairments cause system performance degradation at high input power. Moreover, Kerr nonlinearity effects are more severe at such high input power level. Due to Kerr nonlinearity, intensity dependence phase shift induces a new wavelength signal which interacts with chromatic dispersion (CD) and limit the performance [12–15].

In hybrid WDM-OTDM system, four wave mixing (FWM) is one of the significant degradation factor as propagation interaction between different wavelength signals. Most recent reports on methods for compensation of FWM such as dispersion shifted fiber (DSF), non-zero dispersion fiber, equal and unequal channel spacing, dispersion management etc. techniques have been demonstrated for DWDM system. Inspite of optical compensation techniques, there have been many digital techniques such as back propagation (BP) focused on non-linearities compensation. But computation power required for digital signal processing (DSP) is very high and computational techniques are complex to implement. Also, computational techniques increase the bandwidth of signal. Another promising option is to utilize the optical phase conjugation in fiber optical network. In literature, various demonstrations have been proposed to mitigate the transmission impairments such as FWM, XPM, chromatic dispersion, soliton phase jitter and inter-channel nonlinear effects using optical phase conjugation [16–21]. In Ref. [22], Bogoni et al. analyzed the effect of in-band FWM mixing in DWDM system by using efficient channel allocation for non-zero dispersion fiber, single mode fiber (SMF) and dispersion shifted fiber. They have proposed three channel island based on unequal channel allocation to cancel out the FWM crosstalk due to inter-modulation production. Nazarathy et al. [23] achieved the FWM reduction in OFDM system design by using phase array (PA) method. They suggested that higher value of GVD parameter in identical optical

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fiber span will induce destructive phase interference among FWM field generated and improve the WDM-OTDM system performance. Pechenkin et al. [24] have proposed the phase array approach to mitigate the interaction between individual subcarrier of dispersion managed-OFDM system with uniform chromatic dispersion (CD) parameter. Optical phase conjugation (OPC) in midway of optical link encourages the destructive phase interactive between four wave mixed signal and improves the performance of DM-OFDM system. Shoreh et al. [25] utilized the two and three optical phase conjugation modules to cancel out the FWM signal interaction in the coherent-OFDM. They have concluded that by use of OPCs transmission reach can be increased in dispersion unmanaged and dispersion managed by 52% and 37% respectively. Du et al. [26] demonstrated the mid-link optical phase conjugation module having a pump signal and highly nonlinear fiber (HNLF) to compensate the fiber nonlinearities in OFDM system based on the phase destructive interference among optical nonlinear signals.

In this paper, hybrid WDM-OTDM multicast overlay system performance limitations due to FWM effect have been investigated. Optical phase conjugation module is placed in midway optical fiber to counter the interference between FWM signals. We have shown that OPC module in dispersion managed hybrid system has significant effect on system performance. In this investigation, FWM effect induced in first span will be cancel out second span of optical fiber link due to destructive phase interaction in OPC module. Brief introduction about the various FWM mitigation techniques including OPC is given in Section 1. Section 2 gives detail about WDM-OTDM system architecture and optical phase conjugation module in sub Sections 2.1 and 2.2 respectively. In Section 3, analytical analysis of FWM effects and their mitigation by use of dispersion management and OPC has been presented. Section 4 gives detail about system performance compared to without DM and OPC, with DM and with OPC and Section 5 concludes the paper.

2. System description

2.1. Transmitter and receiver structure of hybrid WDM-OTDM multicast overlay system

Fig. 1 shows the transmitter and receiver configuration of hybrid WDM-OTDM multicast overlay system. In the hybrid system, eight transmitters generate the 120 Gbps polarization and subcarrier multiplexed signal at 100 GHz channel spacing starting from 193.1 THz to 193.8 THz. Each wavelength carries the delayed version four subcarriers 20 Gbps DQPSK modulated data and 40 Gbps polarization shift keying data. Adequate time slots are allocated of $\tau_1 = 0$ s, $\tau_2 = 1/(\text{Bit rate}) \times 1/4$ ns, $\tau_3 = 1/(\text{Bit rate}) \times 2/4$ ns and $\tau_4 = 1/(\text{Bit rate}) \times 3/4$ ns respectively subcarrier DQPSK signal to avoid interaction and polarization controller to maintain the proper orthogonality. The generation and reception of 120 Gbps polarization and subcarrier multiplexed data is given in detail in Ref. [6]. The main utilization of optical orthogonal modulation format in hybrid system is to increase the spectral efficiency and system data carrying capacity. The optical WDM-MUX generated the WDM-OTDM signal and comb's spectrum and timing diagram are is shown in the Fig. 1. The multicast signal modulated with 40 Gbps DPSK modulation technique superimposed on to the WDM multiplexed signal. Extinction ratio of DQPSK is varied to achieve the multicast operation. These superimposed WDM-OTDM signals are transmitted through SMF + DCF and EDFA. Parameters of SMF + DCF and EDFA are given in the Table 1 and Table 2 respectively. In the current investigation, optical phase conjugation (OPC) modules are connected in the midway of optical channel as shown in Fig. 2 to compensate the FWM effects generated in the hybrid WDM-OTDM system. The detail working and architectural setup of optical phase conjugation is given in Section 2.2. At the receiver side, WDM-DEMUX detects the orthogonally modulated signals and polarization controller are utilized to distinguish between subcarrier DQPSK data, PolSK data and the multicast DPSK signal. After demodulation, signals are connected to BER analyzer to validate the system performance.

2.2. Optical phase conjugation modules for compensation of FWM effect in hybrid WDM-OTDM system

A special use of optical phase conjugation module is to generate the conjugate signal and to compensate the FWM effect caused by WDM-OTDM signals interaction while propagating through optical fiber and EDFA. Fig. 2 shows the hybrid WDM-OTDM system with OPC installed in midway of optical link. A Single span of SMF and DCF is of length 40 km + 10 km improves the nonlinearity compensation and EDFA eliminate the fiber losses. To improve the compensation effect two identical optical phase conjugation modules are utilized after pre- and post-compensation circuit and this symmetry is widely used in long haul communication.

Fig. 3 shows the internal structure of OPC module which include the transmitting optical signals (λ_{sig}), 193.1 THz pump signal (λ_{pump}) at input power of 5 dBm, highly nonlinear fiber (HNLF) of length 600 m. λ_{sig} and λ_{pump} are combined using 3 dB optical coupler and passed through HNLF. Parameters of OPC module are given in Table 3. The interaction between λ_{sig} and λ_{pump} will generate the optical conjugate signal (λ_{conj}) as given by

$$\lambda_{conj} = (2 \times \lambda_{pump}) - \lambda_{sig} \quad (1)$$

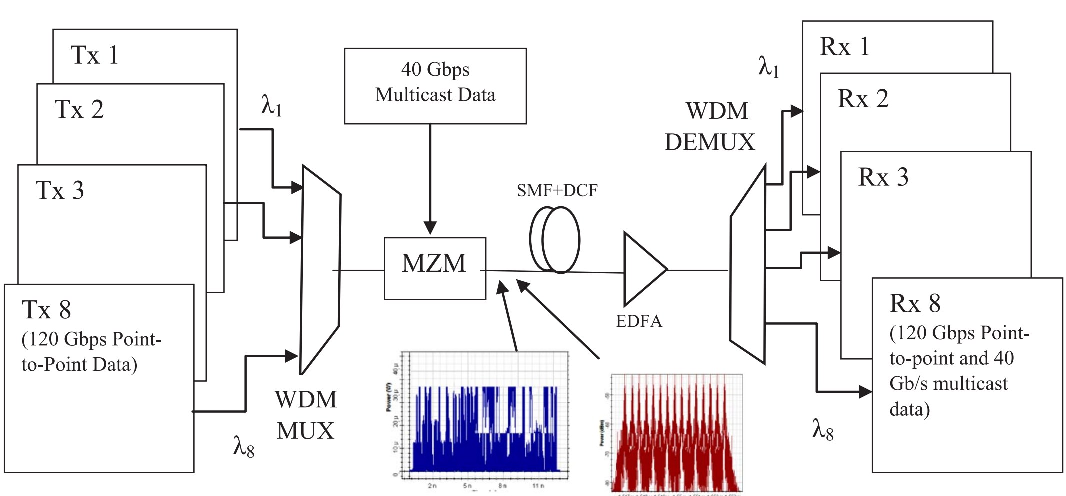

Fig. 1. Architecture of WDM-OTDM optical multicast overlay system [6].