Performance Evaluation of WDM-RoF System Based on CO-OFDM using Dispersion Compensation Technique
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Abstract—In this paper, we presented a system design that integrates Coherent-Optical-Orthogonal-Frequency-Division Multiplexing (CO-OFDM) with Wavelength-Division Multiplexing – Radio over Fiber (WDM-RoF) together with dispersion compensation technique to offer a data rate of 48 Gbps over more than 80 km Single Mode Fiber (SMF) by multiplexing four 12 Gbps OFDM channels. In the designed system model Fiber Bragg Grating (FBG) was introduced as the filter to encounter mainly the effect of dispersion. Furthermore, we evaluated the performance of CO-OFDM/WDM-RoF design with and without FBG by measuring the Q-factor, Bit Error Rate (BER) and constellation diagram. Finally, based on the simulation results, we conjectured that the use of FBG in the CO-OFDM/WDM-RoF system significantly boost the performance of the system.

Keywords—Radio over Fiber (RoF), Wavelength-Division Multiplexing (WDM), Coherent-Optical-Orthogonal-Frequency-Division Multiplexing (CO-OFDM), Fiber Bragg Grating (FBG).

I. INTRODUCTION
WDM is a multiplexing technique for fiber optic system to multiplex a number of optical carrier signals onto a single optical fiber by using different wavelengths of laser to carry different signals. This technique offers greater capacity by providing higher data rate, flexibility, cost effectiveness and easy upgradability. On the other hand, CO-OFDM has received increased attention as it integrates the advantages of both OFDM and coherent systems. [1] With OFDM, data stream is carried with many lower-rate subcarrier tones. OFDM technique has many key merits, such as, high power and spectral efficiency, high resistant to modal, chromatic dispersion, relative intensity noise, polarization mode dispersion and self-phase modulation. Likewise, coherent optical system promises enhanced performance and dispersion tolerance by improving receiver sensitivity, frequency selectivity and equalization at the intermediate frequency band. [2]

A generic CO-OFDM system includes five basic fundamental blocks: OFDM Transmitter, RF to optical (RTO) up-converter, optical link, optical to RF (OTR) down-converter and OFDM Receiver. [3]

OFDM transmitted signal $s(t)$ is represented as –

$$s(t) = \sum_{k=-\infty}^{\infty} C_k \cdot S_k \cdot (t - iT_s)$$ (1)

$$S_k(t) = \Pi(t) \exp(j2\pi f_k t)$$ (2)

$$\Pi(t) = 1 \text{ when } 0 < t \leq T_s$$

$$\Pi(t) = 0 \text{ when } t < 0, t > T_s$$ (3)

Where, $C_k$ is the $k^{th}$ information symbol at the $k^{th}$ subcarrier, $S_k$ is the waveform for the $k^{th}$ subcarrier, $N_{SC}$ is the number of subcarriers, $f_k$ is the frequency of the subcarrier and $T_s$ is the symbol period. Orthogonality i.e. correlation between any two subcarriers is given by –
Orthogonality between subcarriers can be proved if the following condition is satisfied.

$$f_k - f_l = m \frac{1}{T_s}$$  \hspace{1cm} (5)

In CO-OFDM system, $N_{SC}$ subcarriers are transmitted in every OFDM symbol period of $T_s$. Thus the total symbol rate $R$ for CO-OFDM system is given by –

$$R = \frac{N_{SC}}{T_s}$$  \hspace{1cm} (6)

Bandwidth of OFDM, $B_{OFDM}$ is thus given by –

$$B_{OFDM} = \frac{2}{T_s} + \frac{N_{SC} - 1}{t_s}$$  \hspace{1cm} (7)

Where, $t_s$ is the observed period.

Bandwidth efficiency of OFDM,

$$\eta = 2 \frac{R}{B_{OFDM}} = 2\alpha$$  \hspace{1cm} (8)

$$\alpha = \frac{t_s}{T_s}$$  \hspace{1cm} (9) \hspace{1cm} [4]

Spectrum efficiency can be improved by using higher-order modulation schemes.

However, the use of CO-OFDM can’t fully compensate the nonlinear effects appear in WDM system. That’s why; the use of Fiber Bragg Grating (FBG) in the CO-OFDM/WDM-RoF system is proposed in this paper to improve the performance.

Fiber Bragg Grating (FBG) is one of the most widely used element to compensate dispersion. FBG is a periodic perturbation of the effective refractive index in the core of an optical fiber that generates a wavelength specific dielectric mirror. So, FBG can be used as an inline optical filter to block certain wavelengths. \[5\]

![Fig. 3. Working principle of FBG \[6\]](image)

The simulation used ideal dispersion compensation FBG with user-defined group delay. The transfer function of the filter, $H(f) = e^{j\phi(f)}$ \hspace{1cm} (10)

Where, $f$ is the frequency dependence phase of the filter.

Group delay depends on wavelength as

$$\tau(\lambda) = \frac{\lambda^2}{2\pi c} \frac{d\phi}{d\lambda}$$  \hspace{1cm} (11)

Where, $c$ is the speed of light.

Phase, $\phi = 2\pi \int \tau(\lambda) \frac{1}{\lambda^2} d\lambda$ \hspace{1cm} (12) \hspace{1cm} [8]

In our paper, as the solution of long backhaul, WDM-RoF system is considered since RoF offers lower attenuation loss, better coverage and increased capacity, resistance to RF interference, flexibility and reduced power consumption. In RoF system light is modulated by a radio signal and transmitted over an optical fiber link to facilitate wireless access. \[7\] CO-OFDM is used with FBG in order to maximize the bandwidth usage and reduce the effects of nonlinearity. \[9\]

This paper focuses on the implementation and performance analysis of high data rate coherent...
optical OFDM for long haul WDM transmission with FBG. Optisystem 12 simulation tool is used to design and implement the system. Results from Optisystem model shows the performance of OFDM signal through the WDM RoF access network. The system is designed to carry data rate of 48 Gbps having 12 Gbps data at each OFDM channel. Data rate in this system can be increased by increasing the number of WDM channels. The modulation type for OFDM is DPSK for each channel and OFDM demodulator are employed together with coherent detection at the receiver part to receive the OFDM signals over a SMF network transmission. Parameters like Q factor, BER and constellation diagram have been considered. Simulation results show that the proposed system including dispersion compensation scheme exhibits acceptable performance which makes the system suitable for long haul WDM system.

II. METHODOLOGY AND SIMULATION SCHEMATIC

One of the main objectives of this paper is to simulate and model a WDM-RoF system based on CO-OFDM using dispersion compensation technique. Fig. 4 depicts the block diagram of the proposed system.

Fig. 4. Block diagram of our proposed CO-OFDM/WDM-RoF System with FBG

Fig. 4 shows the system design of CO-OFDM/WDM-RoF system with FBG. CO-OFDM transmitter is built with a pseudo-random binary sequence (PRBS) to generate a bit sequence that will approximate the random data characteristics. It is also built with a DPSK (2 bit per symbol) encoder. The DPSK signal is connected to an OFDM modulator with 512 subcarrier and 1024 FFT points. The in-phase (I) and quadrature (Q) of the resulting signal from the OFDM modulator is transmitted to the direct I/Q optical modulator. The I/Q optical modulator consists of two Mach-Zehnder Modulators (MZM) which will modulate the electrical signal from the OFDM modulator to the optical carrier. Here, the centre frequencies of four CW lasers are 193.05, 193.1, 193.15 and 193.2 THz respectively, as shown in Fig. 5 and Fig. 6.

Fig. 5. Simulation schematic of CO-OFDM Transmitter

Fig. 6. Simulation schematic of OFDM module

WDM system consists of four channels to support four OFDM bands. Each OFDM signals has a 12 Gbps bit rate which will provide an
overall data rate of 48 Gbps. Data rate can be increased simply by increasing the number of WDM channels. The resulting optical signal of WDM MUX is then transmitted through the SMF system. The SMF’s dispersion is 16 ps/nm/km. The incoming optical signal from the optical fiber link is separated into four wavelengths by the WDM DEMUX and each wavelength is fed to the FBG having specific wavelength. FBG then filters out the undesired spectrum other than the specific wavelength. Output of FBG is fed to the designed receiver as shown in Fig. 8.

Each receiver consists of coherent detector with a local oscillator which will be identical to the wavelength of the laser transmitter. Each coherent detector consists of two couplers and 2 PIN photodetectors. After detecting the signal by the balanced detectors the signal is send to the OFDM demodulator which has the similar parameters to the OFDM modulator. Finally, the resulting signal is fed into DPSK decoder to create a binary signal.

III. SIMULATION RESULTS AND ANALYSIS

In the simulation, we have employed four types of visualisers and analysers, optical time domain visualiser, optical spectrum analyser, electrical constellation visualiser and BER analyser. Fig. 9 presents the optical spectrum of the WDM output having four wavelengths. Fig. 10 illustrates the time domain output signal of WDM. Furthermore, Fig. 11 and Fig. 12 demonstrate the RF spectrum before and after transmission. Fig. 13 shows the constellation diagram before transmission. Whereas, Fig. 14 and Fig. 15 shows the constellation diagram of 48 Gbps CO-OFDM WDM-RoF system after 80 km without and with FBG respectively. Output of BER analyser is shown in the Fig. 16 and Fig. 17.

Fig. 8. Simulation schematic of CO-OFDM Receiver

Fig. 9. Output of WDM showing optical spectrum of the four wavelengths

Fig. 10. Output of WDM showing time domain representation of multiplexed signal

Fig. 11. RF OFDM spectrum of I/Q components at the CO-OFDM transmitter

Fig. 12. RF OFDM spectrum of I/Q components at the CO-OFDM receiver.

Fig. 13

Fig. 14
Fig. 15

Fig. 13, Fig. 14 and Fig. 15 shows the constellation diagram of CO-OFDM/WDM-RoF before transmission, after 80 km without using FBG and constellation diagram after 80 km with using FBG respectively.

Fig. 16. Q factor and BER pattern after 80km with FBG

Table I

Comparison of Q-factor and minimum BER of CO-OFDM/WDM-RoF system without and with FBG scheme after 80km

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Without FBG</th>
<th>With FBG</th>
</tr>
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<tbody>
<tr>
<td>Q-factor</td>
<td>7.537</td>
<td>9.015</td>
</tr>
<tr>
<td>Minimum BER</td>
<td>1.89x10^{-11}</td>
<td>1.679x10^{-13}</td>
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</table>

IV. CONCLUSION

The approach of this work is to evaluate the performance of CO-OFDM/WDM-RoF system with and without using Fiber Bragg Grating (FBG) in terms of Q-factor, minimum BER and constellation diagram. Constellation diagram in Fig. 15 shows the increase in distance between symbols because of the use of FBG. The Q-factor of the system after 80 km increases considerably as compared to the system without having FBG. Minimum BER also reduces significantly by using FBG which is represented in Table I. This implies that our proposed CO-OFDM/ WDM-RoF system based on FBG displays acceptable performance even after 80 km which makes it a better selection as long haul solution for WDM access networks.

REFERENCES


