The Nucleus

Implementation of OFDM-RoF at 60 GHz with DCF for Long Haul Communication

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ABSTRACT

In this paper, a new design of optical system is proposed and analyzed which combine coherent OFDM with radio over fiber (RoF) for achieving data rate of 40 Gbps over 150 km Single Mode Fiber (SMF). Optical heterodyne method is used for generation of 60 GHz Millimeter wave. The transmitted RF signal through optical fiber using RoF method is degraded and to compensate it, post compensation scheme of Dispersion Compensating Fiber (DCF) is used. Constellation diagram has been observed after 150 km with and without DCF for performances evaluation of OFDM RoF system. The BER at receiver end is evaluated and from the results it can be concluded that the transmission distance and data rate has been increased

1. Introduction

One of the most prominent applications of the optical fiber technology is the radio over fiber (RoF). In this technology, modulation of light is carried out and modulated light signal is sent over optical fiber [1]. Therefore, RoF architecture is assimilation of radio frequency plus light signal.

The demand of high data rate and large capacity in the field of optical communication creates engrossment in orthogonal frequency division multiplexing (OFDM) [2]. Next Generation Networks (NGN) that needs higher speed, wider bandwidth and multimedia communication such as High Definition(HD) videos and fast file transfer by wireless mode are made possible by OFDM modulation format [2, 3]. Optical OFDM compensates multi-path spread delay by which it shows sufferance to polarization mode dispersion (PMD) and Chromatic Dispersion (CD) [4]. OFDM is a unique type of multicarrier transmission that employs division of higher data rate signal streams into signal streams of lower data rate by transmitting over a number of lower-rate subcarriers (SCs). We may categorize the OFDM both as a multiplexing and a modulation technique which makes it peculiar in its nature. OFDM increases the robustness against not only frequency selective fading but also reduces narrowband interference like inter-symbol interference [5]. Only a fraction of subcarrier would be affected in multicarrier system in case of interference or fading whereas it can fail the whole single carrier system.

OFDM modulation format when applied in optical fiber communications, then the radio over fiber (RoF) systems can be used both for short and long range transmissions with higher data rates [6]. Islam [3], Nadeem [4] and Wei [7] have proposed their system schemes using modulation formats of M-ASK, FSK and 16 QAM but due to low data rates not suitable for NGN networks and not capable to attain transmission distance of over 100 Km.

As mentioned above OFDM uses Sub-Carriers (SCs) for transmission of low data rate streams parallely. IQ modulation is employed for modulation of each SCs of OFDM.OFDM transmitter and receiver uses Fast Fourier Transform (FFT) and Inverse Fast Fourier Transform (IFFT) algorithm respectively [8]. These algorithms plays effective role in providing OFDM higher scalability over high data rates and removes channel dispersion [7, 9].

Radio over fiber (RoF) delivery of multi-gigabits per second (Multi-Gb/s) services is made better possible by incorporating 60 GHz millimeter wave. In contrast to 2.4GHz and 5GHz standards by IEEE802.11ad, 60 GHz has a large unlicensed spectrum of 7 GHz [10]. At 60GHz the RF signals faces high losses in air links (typically 7-9 dBm in mega buildings/ corporate offices) which limits the wireless coverage area in the range between 10-15 m due to high dispersion and fading effects. As optical fibers has huge bandwidth and low attenuation loss, therefore by passage of RF signals across optical fiber in RoF system, transmission distance of 60 GHz RF signals can be extended to several kilometers [11].
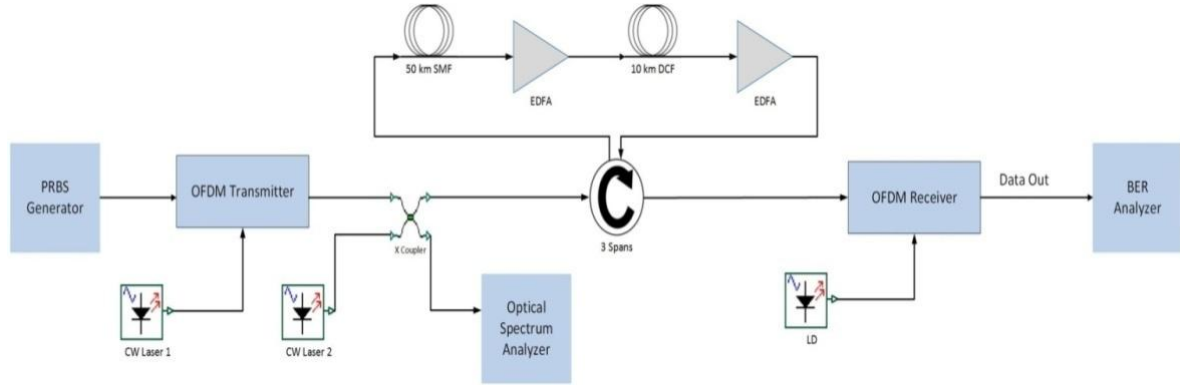
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Fig. 1: System block diagram

In this paper, the architecture of coherent OFDM-RoF system is demonstrated. OFDM-RoF system is used with QPSK (Quadrature Phase shift keying) with the information capacity of 40 Gbps. DCF is used to compensating dispersion and for error free transmission over 150 Km in optical link [9]. For the system performance determination, constellation diagram of the received signal and bit error rate (BER) analyzers are used [12].

To modulate the electrical signal, this design uses the OFDM modulation format. OFDM is a multicarrier modulation (MCM) scheme and at transmitter side it can be mathematically explained as follow [8].

$$s(t) = \sum_{i=-\infty}^{+\infty} \sum_{K=1}^{N} c_{ki} s_k(t - iT_s) \qquad (1.1)$$

$$s_k(t) = \Pi(t) e^{2\pi j f_k t} \qquad (1.2)$$

$$\Pi(t) = \begin{Bmatrix} 1, 0 < t \le T_s \\ 0, otherwise \end{Bmatrix} \qquad (1.3)$$

Where,

S(t) = Subcarrier

c_k =Information of the kth subcarrier

N = Subcarriers number

f_k = Subcarrier frequency

Ts= Symbol period

Π (t) =Function of the pulse shaping

The mth sample of s(t) with sampling period of Ts/N can be described as [8]

$$s_m = \sum_{K=1}^{N} c_k \cdot e^{j 2\pi f_k (m-1) T_s / N} \qquad (1.4)$$

In contrast to the FDM, OFDM uses all the subcarriers which are orthogonal to each other. The orthogonality of the OFDM system is maintained when the following equation is satisfied [8].

$$f_k = \frac{(k-1)}{T_S} \qquad (1.5)$$

Now by putting the value of fk in eq. 1.4 we get [6].

$$s_m = \sum_{K=1}^{N} c_k \cdot e^{j 2\pi f_k (m-1)(k-1)/N} \qquad (1.6)$$

S_K represents the Inverse Fourier Transform (IFT) of the input signal C_K. Now the received signal is $\hat{c}_k$ which is defined as the Fourier transform of $\hat{s}_k$ [8].

$$\hat{c}_k = \frac{1}{\sqrt{N}} \sum_{K=1}^{N} \widehat{s_m} \cdot e^{-j 2\pi (m-1)(k-1)/N} \qquad (1.7)$$

From eq. 1.6, it is evident that OFDM signal comprises by the summation of many subcarriers. Therefore it has the high peak to average power ratio (PAPR) as compare to the single carrier signals [8]

$$PAPR = \frac{max\{|s(t)|^2\}}{E\{|s(t)|^2\}}, t \in [0, T_S] \qquad (1.8)$$

2. System Design

The block diagram of proposed system is shown in figure 1. The design contains 3 major blocks, transmitter, optical fiber transmission medium and receiver. Pseudo-Random-Bit-Sequence (PRBS) generator provide the bit rate of 40 Gbps of the incoming RF signal with the probability equal to 0.5 for 0s and 1s each. A DCF is employed in the optical fiber link for attaining 150 Km transmission distance

For designing and implementation of proposed system, Optisystem V.13 is employed. Global parameters that should be taken into account for the system to work properly are presented by Table 1.

Table 1: Global Parameters used in simulation

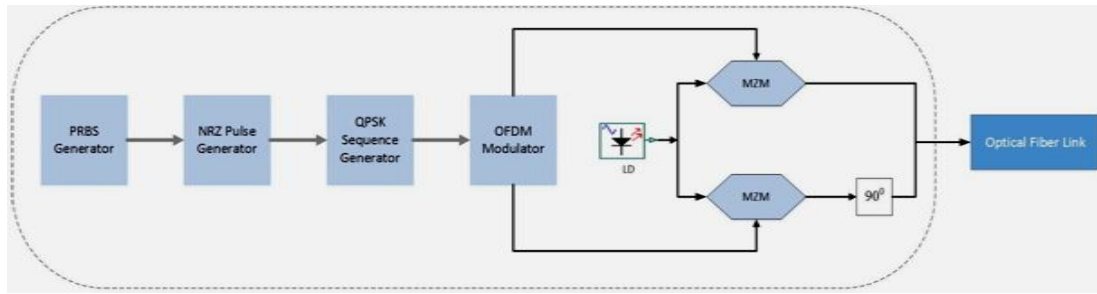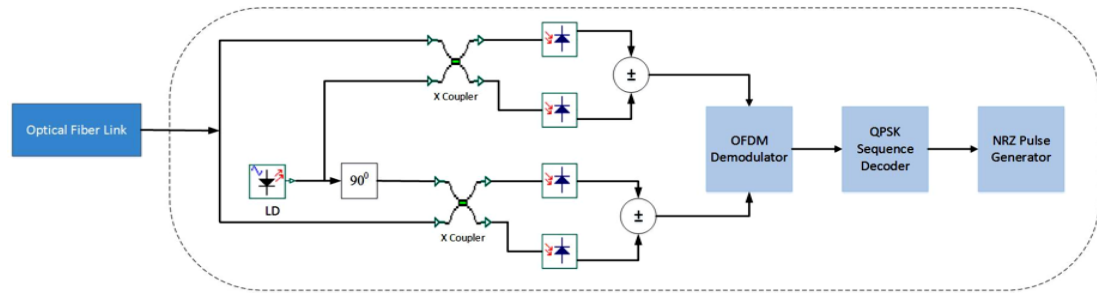| Parameters	Value
Bit rate	40 Gbps
Sample rate	160×10^9 Hz
Length of sequence	8192 bits
Total samples in each bit	4
Number of samples	32768
No. of FFT points	128

Fig. 2: OFDM Transmitter

Fig. 3: OFDM receiver

2.1 CO-OFDM Transmitter

The OFDM transmitter consists of electrical pulse generator, OFDM modulator and an optical modulator (MZM) and is shown in the Fig. 2. The function of OFDM transmitter is to convert electrical signal into optical form and the resulting signal is launched in optical fiber and this section plays the role of RF to optical up-converter (RTO).Coherent OFDM transmitter design is depicted in Fig. 2. RF data for OFDM transmitter is generated by (PRBS) generator. OFDM subcarriers used are 512 and numbers of FFT points are 128. The difference between launched power and received power indicates how much fiber loss has occurred, which is -5.4 dbm at 1550 nm window (193.1THz).

2.2 Optical Fiber Link

The transmission link consist of three spans of single mode fiber (SMF) having 50 Km length, making 150 kms total distance. SMF is used with the attenuation coefficient 0.2dB.Km^{-1}, which works as transmission media. The parameters used for optical fiber (SMF) are shown in Table 2. Optical amplifiers are used to amplify

Table 2: SMF parameters

Parameters	Value
Attenuation coefficient of SMF (α)	0.2 dB.km^{-1}
Dispersion coefficient of SMF (β)	16 ps.km^{-1}.nm^{-1}
Nonlinear coefficient of SMF (γ)	1.3 w^{-1}km^{-1}
Dispersion slope	0.08 ps.nm^{-2}.k^{-1}
PMD coefficient	0.2 ps.km^{-1}
Effective area	93 um^2

the weak signals. Two erbium doped fiber amplifiers (EDFAs) are used for compensating each span loss.DCF is applied in optical link for error free transmission. The DCF parameters are shown in Table 3.

Table 3: DCF parameters

Parameters	Value
Attenuation coefficient of DCF (α)	0.5dB.km^{-1}
Dispersion coefficient of DCF (β)	-80 ps.km^{-1}.nm^{-1}
Nonlinear coefficient of DCF (γ)	5.28 w^{-1}km^{-1}
Dispersion slope	0.08 ps.nm^{-2}.k^{-1}
PMD coefficient	0.2 ps.km^{-1}
Effective area	23 um^2

2.3 CO-OFDM Receiver

The receiver model for CO-OFDM RoF consists of two major parts, the first one is i) optical receiver and the other one is ii) RF receiver. The optical receiver is known as optical to RF down-converter (OTR).The signal after optical transmission medium is detected by PIN photodetector having responsivity of 1A/W and dark current of 10 nA.

Then the signal is passed through the electrical band pass filter to eliminate the noise that added from the fiber. After the optical signal converted to electrical signal and all noise is eliminated, the signal is demodulated with OFDM demodulator to extract the subcarriers. Afterwards, the resulting signal is decoded by QPSK sequence decoder to get the original bits.

3. Results and Discussion

OptiSystem[TM] v13.0 and MATLAB® are used for simulation development and analysis.

A pair of continuous wave (CW) lasers (L1 & L2) operating at frequencies of 193.1 THz and 193.16 THz respectively gives 60 GHz difference at central station (CS) as depicted in Fig. 4.
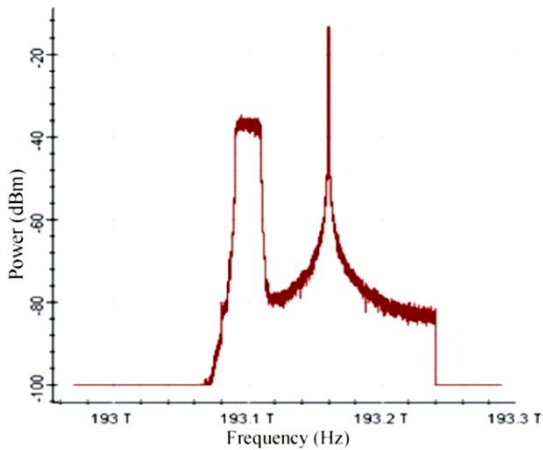

Fig. 4: Optical spectrum output on coupler

The optimized results are achieved when the BER is minimized for Back-to-Back transmission; therefore, input power is set on 10 dBm as shown in Fig. 5.
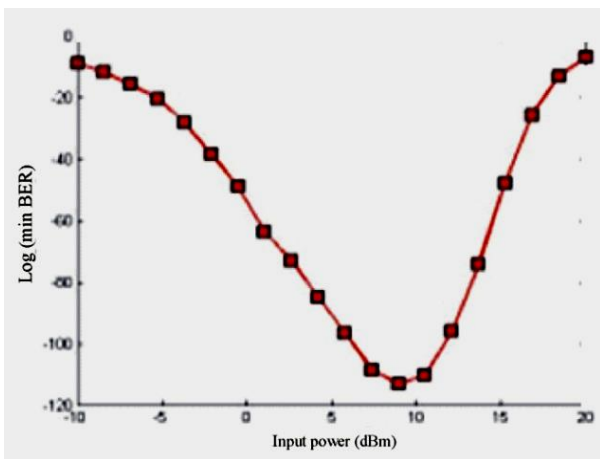

Fig. 5: Graph representing min BER against input power

Three spans of 50Km SMF are used in the designing of optical link having a transmission distance of 150Kms. The Fig. 6 shows the constellation diagram of coherent OFDM system for Back-to-Back (B2B) with no fiber in use and successful signal delivery.

Constellation diagram for system is depicted in Fig. 7 after 150 Km SMF. The figure reflects distortion of signal on comparison with Back-to-Back diagram of Fig. 6. This distortion of signal is happened due to chromatic dispersion and nonlinear effects.
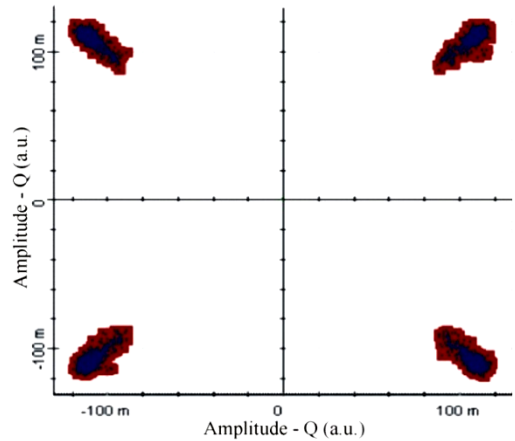

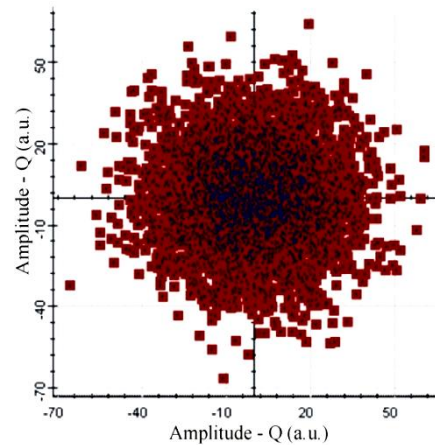Fig. 6: Constellation diagram of coherent OFDM system for back-to-back

Fig. 7: Constellation diagram of system after 150km SMF before using DCF

Post compensation scheme of dispersion compensating fiber (DCF) by placing DCF after SMF is used for error free transmission. Constellation diagram after employing DCF for system at the receiver end is depicted in Fig. 8.

Optical amplifiers are used in each span to compensate loss. Two EDFAs having Noise-Figure (NF) 5 dBm each and gain of 10 dBm and 5 dBm respectively, EDFAs parameters are shown in Table 4.

Coherent detection of signal is done at Base-Station (BS) by Local-Oscillator (LO) having frequency equal to operating frequency of Continuous-Wave (CW) laser (L1). The signal obtained at output of Pin Photo-Detector (PD) is the result of beating two CW lasers (L1 and L2), L1 operating at 193.10 THz and L2 operating at 193.16THz giving 60 GHz frequency difference as 193.16 THz − 193.10 THz = 60 GHz. For suppressing distortions of band and retrieving desired band at receiver end, digital Band-Pass-Filter (BPF) is used.

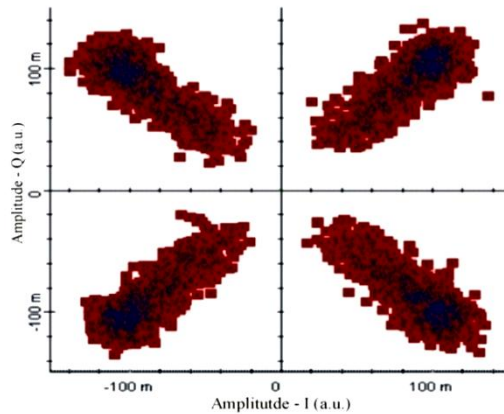Fig. 8:   Constellation diagram after employing DCF at 150Km

Table 4:   EDF as parameters

Parameter	EDFA 1	EDFA 2
Operation mode	Gain control	Gain control
Gain	10 dBm	5 dBm
Noise Figure	6 dBm	5 dBm
Power	12 dBm	10 dBm

In Fig. 9 the optical power received is plotted against BER of signals of demodulated millimeter wave Radio over Fiber (RoF). The graph shows considerable improvement in BER with respect to received optical power and ultimately enhances the Q factor.
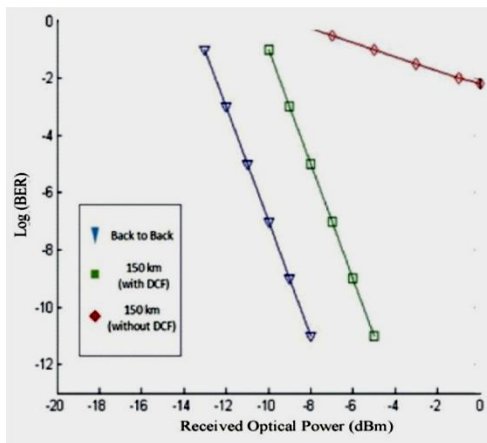

Fig. 9:   BER against the received optical power

From the results it is evident that the purposed system scheme attains transmission distance of 150 Km having data rate of 40 Gbps using QPSK as modulation format then earlier schemes of Islam [3] which attain transmission distance 50 km having data rate 24 Gbps using M-ASK modulation format, Nadeem [4] which attain transmission distance of 80 km having data rate 8Gbps using FSK modulation format 26.54 and Wei [7] which attain transmission distance of 100 km having data rate 26.54 Gbps using 4-QAM modulation format.

4.   Conclusion

RoF system of 60 GHz with QPSK-OFDM modulation format at 40 Gpbs has been proposed. Optical heterodyne mixing of QPSK modulated signal has been utilized with a non-modulated free running laser to achieve millimeter wave. From the results of constellation diagram, it is clear that long haul transmission of SMF is made possible by using DCF to mitigate the dispersion. Higher elastic bandwidth availability and commendable transporting ability has been achieved by the system by virtue of OFDM and coherent receiving mechanism. Downstream signal has a good constellation and low BER at transmission distance of 150 Km. In future, higher order modulations schemes (8-QAM and 16-QAM) can be employed for improving the performance of system.

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