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HERMITIAN SYMMETRY BASED FIBER NON-LINEARITY COMPENSATION IN OPTICAL OFDM NETWORKS

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Abstract—Orthogonal Frequency Division Multiplexing (OFDM) is a modulation technique which is now used in most new and emerging broadband wired and wireless communication systems such as standard 802.11a/b/g/n, Digital Video Broad casting Television (DVB-TV), and Long Term Evolution (LTE) in the next mobile generation, due to its capacity in solving the problems of Inter-Symbol Interference (ISI) caused by the effects of the dispersive channel. Very recently researches focus on applying OFDM technology in optical fiber communication systems. Optical OFDM is well suited for high speed transmission systems with high spectral efficiency and attracted significant attention from the optical communication community. One of the major issues that degrade the performance of optical OFDM networks is its fiber non-linearity. Fiber non-linearities represent the fundamental limiting mechanisms to the amount of data that can be transmitted on a single optical fiber. Non-linear effects arise as optical fiber data rates, transmission lengths, number of wavelengths, and optical power level increases. Therefore, the effect of non-linearity in high data rate optical networks needs to be controlled to enhance link performances. In this paper, a non-linearity compensation technique (Hermitian Symmetry) is implemented to improve the performance of OFDM based optical networks. This would provide high spectral efficiency, low ISI and very good Bit Error Rate (BER) performances without increasing the complexity of the network. The optical OFDM transmission system with fiber non-linearity compensation is simulated using Virtual Photonics Integrated (VPI) software.

***Keywords**-OOFDM, BER, ISI, fiber non-linearity, Hermitian Symmetry, optical fiber communication.*

I INTRODUCTION

Electronic Dispersion Compensation (EDC) is becoming an attractive technology for dispersion compensation in optical links [1]. Previously, we have shown that Orthogonal Frequency Division Multiplexing(OFDM), which is widely used to adaptively compensate radio networks, could electronically compensate for dispersion in single mode optical systems [2]. Fiber non-linearities restricted the power per Wavelength-Division Multiplexing (WDM) channel for 4000-km systems [3]**.**Fiber non-linearity affects all types of long haul optical systems, unless the optical power is kept low [5]. Low power requires frequent re-amplification to maintain a sufficient Signal to Noise Ratio (SNR). Thus, it is useful to try to mitigate fiber non-linearity, as the number of optical amplifiers along a link could be reduced. Fiber non-linearity was first proposed using materials with a negative non-linear coefficient [6], which is impractible. Recently non-linearity compensation has been proposed for systems using Hermitian Symmetry application in the field of ofdm. Where the system is modeled but with inverse parameters for dispersion and non-linear coefficients, then the output of the model is fed into the real system using an “optical -IQ” modulator, which can modulate the laser field with a complex coefficient with inphase (I) and quadrature phase (Q) components. Unfortunately, the modeling of the system requires a detailed knowledge of the dispersion map and optical power levels along the system, Real time implementation requires extensive computation, which can only be achieved using look-up tables, rather than adaptively, as would be required in all optical network.

This paper presents a computationally efficient technique for compensation of fiber non-linearities in coherent optical OFDM systems [4], [11], [12]. Simple signal processing at the transmitter can be used to mitigate fiber non-linearities, and this processing does not require exact knowledge of the dispersion map of the system, so it works over a wide range of systems. It can also be tuned with a single variable. The computation cost is similar to that used for dispersion compensation at the receiver [2], which is trivial compared with the computation cost of the Fourier transforms in OFDM. Increase in amplifier spacing of more than 15km is possible for low dispersion fibers. Higher dispersion fibers have less of an advantage, though the non-linear power limit is already high for these fibers before compensation [3].This non-linear power limit is reduced by Hermitian

Symmetrymethodbefore the signal is sent to the fiber. The key advantage of this non-linearity compensation is that optical OFDM is now applicable to greater range of reducing the fiber dispersion and thus increasing the system performance.

II OFDM SYSTEM

A *FDM vs. OFDM*

Frequency Division Multiplexing (FDM) is a technique where the main signal to be transmitted is divided into a set of independent signals, which are called subcarriers in the frequency domain. Thus, the original data stream is divided into many parallel streams (or channels), one for each subcarrier. Each subcarrier is then modulated with a conventional modulation scheme, and then they are combined together to create the FDM signal. In an FDM transmission, the receiver needs to be able to independently recover each of the subcarriers and therefore these signals need to fulfill certain conditions. For instance, they can have non-overlapping spectra so that a bank of filters tuned to each of the different subcarriers can recover each of them independently. However, practical filters require guard bands between the subcarrier bands and therefore the resulting spectral efficiency is low. If the subcarrier signals fulfill the orthogonality condition their spectrum can overlap, improving the spectral efficiency. This technique is known as Orthogonal FDM or OFDM.

Consider a bit sequence with rate R is parallelized into N different channels, each with a different frequency. The total bit rate is distributed in equal parts over each channel at a rate R/N. The data in each channel will be mapped to represent an information symbol and then multiplied by its corresponding frequency. The summation of these parallel information symbols will form one OFDM symbol.

Each OFDM symbol has thus a duration T_S=N/R. Hence, the OFDM signal in the time domain s(t) can be expressed as a summation of each information symbol $C_{i,k}$ being carried in the k^{th} subcarrier within the i^{th} OFDM symbol. Depending on the modulation used for the subcarriers, this superposition of subcarriers forming s(t) can result in complex values, though this case will not be taken into account yet. Then, with the OFDM symbol having a period T_S :

$$s(t) = R\{\sum_{i=-\infty}^{\infty} \sum_{K=0}^{N-1} c_{i\ k}\, e^{j2\pi f_k t}.\mathrm{P}(t-i\mathrm{T_s})\} \tag{1}$$

Where P(t) is an ideal square pulse of length T_S, the number of subcarriers is represented by N and $f_k$is the subcarrier frequency. This frequency has to fulfill the orthogonality condition:

$$f_k = k\left(\frac{1}{T_s}\right) \tag{2}$$

This means that each subcarrier must be separated from its neighbors by exactly 1/ T_S, so each subcarrier within an OFDM symbol has exactly an integer number of cycles in the interval T_S, and the number of cycles differs by exactly one. This way, orthogonality between subcarriers is achieved. This property can be explained for any couple of subcarriers by the following expression:

$$\int_{-T/2}^{+T/2} \cos\left(\frac{2\pi nt}{T}\right)\cos\left(\frac{2\pi mt}{T}\right)dt = 0\,,\ \ m \neq n \tag{3}$$

If m and n are different natural numbers, the area under this product over one period is zero. The frequencies of these waves are called harmonics and for them the orthogonality condition is always fulfilled.

In (1), the OFDM symbol is ideally multiplied by a square pulse P(t), which is one for a T_S-second period and zero otherwise. The amplitude spectrum of that square pulse has a form sinc (πft), which has zeros for all frequencies *f* that are an integer multiple of $1/T_S$. Then, as shown in Figure1, an OFDM symbol spectrum consists of overlapping sinc functions, each one representing a subcarrier, where at the frequency of the k^{th}subcarrier all other subcarriers have zeros.

Note that each subcarrier is centered at f_k and separated by $1/T_S$ from its neighbors. When this happens, the orthogonality condition is being fulfilled so a great spectral efficiency for the transmission is achieved. This way, the subcarriers can be recovered at the receiver without Inter Carrier Interference (ICI) despite strong signal spectral overlapping, by means of the orthogonality condition (3) using a bank of oscillators and low-pass filters for each subcarrier.

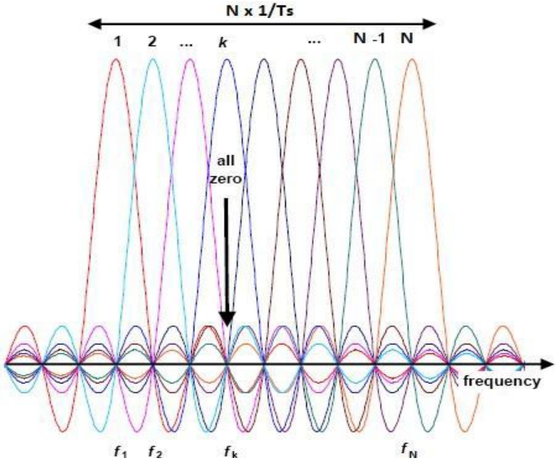

Figure1. Spectrum of an OFDM symbol

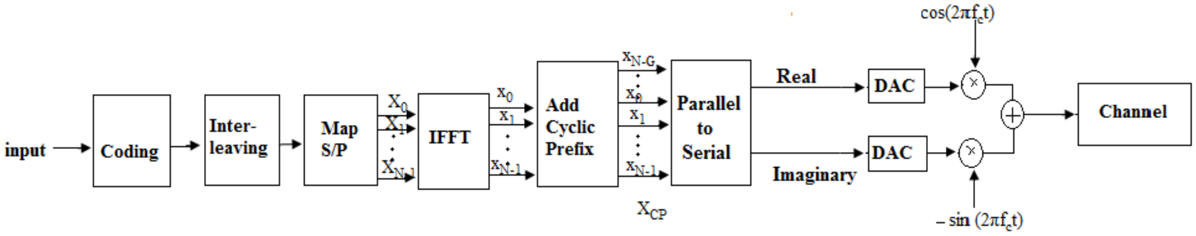

Figure2. Block diagram of OFDM Transmitter

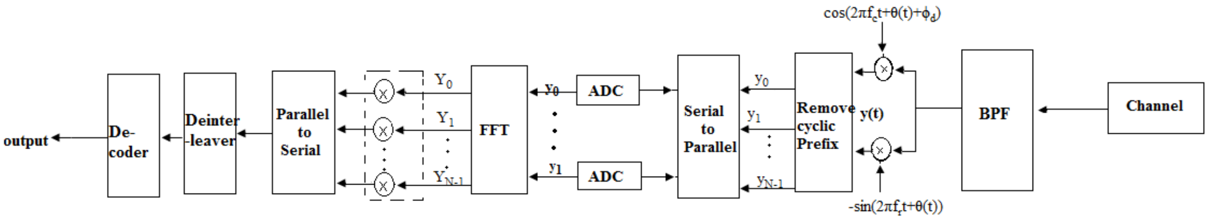

Figure3. Block Diagram of OFDM Receiver

B Digitalized OFDM signals

Generation of an OFDM signal with a large number of subcarriers following the analogue method presented before leads to an extremely complex architecture involving many oscillators and filters at both the transmit and receive ends. In present-day OFDM transmissions, though, this complexity is reduced by transferring it from the analogue to the digital domain.

To see this, take Equation (4), where just one OFDM symbol of the signal s(t) in (1) is sampled at an interval of T_S/N . Then, the nth sample of s(t) becomes:

$$s\left(\frac{nT_s}{N}\right) = \sum_{k=0}^{N-1} c_k e^{\frac{j2\pi f_k nT_s}{N}} = \sum_{k=0}^{N-1} c_k e^{\frac{j2\pi kn}{N}} = F^{-1}\{c_k\} \quad (4)$$

Where F^{-1} is the Inverse Fourier transform, and n [1,N]. Thus, it can be said that the discrete value of the transmitted OFDM signal s(t) is merely a simple N-point Inverse Discrete Fourier Transform (IDFT) of the information symbol c_k . The same case can be applied atthe receiver, where the received information symbol c_k will be a simple N-point Discrete Fourier Transform (DFT) of the received sampled signal. This superposition of independent modulated subcarriers is typically performed by the Inverse Fast Fourier Transform (IFFT) where the input channels are spaced equivalently according to equation (2). In fact, IFFT/FFT blocks in an OFDM system are mathematically equivalent versions of an IDFT and a DFT of the transmitted and received OFDM signal, with the advantage of providing lower computational implementation.

Because of the orthogonality property, as long as the channel is linear, the OFDM receiver will calculate the spectrum values at those points corresponding to the maximum of individual subcarriers. Then, the received subcarriers can be demodulated through an FFT operation without interference and without the need for analogue filtering to separate them, which makes OFDM not only efficient but also easy to implement in practical transmission systems. Hence, it can be said that the modulated OFDM signal can be obtained by performing the IFFT operation to the symbols to transmit and then using a DAC to convert the digital signal into an analogue signal at a sampling rate T_S. Ideally, this D/A conversion should convolve each temporal sample by a sinc function. This ideal shaping is translated into a perfectly rectangular filter that removes the alias in the frequency domain where f_N is the Nyquist frequency, which will be the highest frequency component of the OFDM signal. This ideal filter will remove the alias generated due to the sampling process, leaving the fundamental signal untouched.

The contribution of the different sinc pulses at each of the samples of the OFDM symbol results in a perfect square pulse of the OFDM symbol, and each of the subcarriers would be represented by a perfect sinc function in the frequency domain.

C OFDM Transmitter and Receiver

Symbols at the output of the IFFT block are then serialized and converted into an analogue signal before transmitting them to the channel. In a similar way, the subcarriers forming the received signal r(t) are demodulated by an FFT operation after being analogue to digital (A/D) converted and parallelized to form the FFT block inputs, as shown in Figure3.

III PROPOSED OPTICAL OFDM SYSTEM

The block diagram of proposed Optical OFDM system with non-linearity is shown in Figure4. Here a direct optical-IQ modulator [1] is used, which allows any optical amplitude and phase to be transmitted along the same link. This modulator produces a single-sideband optical spectrum with a totally suppressed carrier. In-phase and quadrature components of a locally generated carrier are mixed with the optical signal at the receiver to obtain in phase and quadrature electrical signal components [12]. These are digitized by analog-to-digital converters for processing in a standard OFDM receiver. The fiber enters into the non linear medium once the power inside the fiber becomes high, so the losses and refractive index of the fiber becomes dependant of the transmitted signal. Hence correspondingly nonlinearity in the fiber increases. But present system of communication needs a very high bit rate for transmission. So we require more power to transmit the information into the fiber. Correspondingly the power level required for driving the bit rate increases .This increases the power level feeding into the fiber. Hence the fiber enters into the nonlinear medium. As a result there is a greater impact in the reduction of the systems performance .So our proposed model uses Hermitian Symmetry to overcome the nonlinearities in the fiber. The nonlinearity can be eradicated by maintaining the power level in the fiber. In our proposed model the ofdm carriers consist of large number of closely packed channels. Itconsists of lower and higher subcarriers. Hence we take the advantages of these sub carriers. In ofdm the lower subcarriers is a complex conjugate of the upper sub carriers. Hence before transmission into the fiber the subcarriers are added together making the imaginary part of the ofdm subcarriers to be nullified, yielding only the real part. Thus in normal transmission both the real and imaginary part gets transmitted. The ofdm can decode the original information from the received signal with a single pulse shaping signals. By taking this into an advantage, byapplying Hermitian Symmetry the real part alone is transmitted. Thus one can transmit a very high bit rate at normal power eliminating the additional powers required fir transmission. This prevents the nonlinearity in the fiber also introduction of Hermitian Symmetry adds the advantage of excluding RF up converter and RF down converter in the transmitter and receiver process [13]. Also in the VPI during transmission the real and imaginary part across the ofdm coder part is treated to reduce nonlinearity. The imaginary part is removed making only the real part suitable for transmission. Also in the modulator section the laser source and the information is modulated using Mach-Zhender modulator. In normal ofdm transmission we use Double Side Band (DSB) for transmission .In this modulator the transmission is done through Single Side Band – Suppressed Carrier (SSB-SC), this reduces the bandwidth consumption making the ofdm more bandwidth efficient and it eradicates the chromatic Dispersion (CD) caused due to duplicate side bands in ofdm systems. The power level required for transmission in fiber is reduced by implementation of Hermitian Symmetry. This also makes the ofdm system as a more power efficient sytem. This system also provides more power, bandwidth and cost efficient.

Figure2 shows a schematic for an OFDM transmitter where subcarriers are modulated in the digital domain by means of an IFFT. The transformed

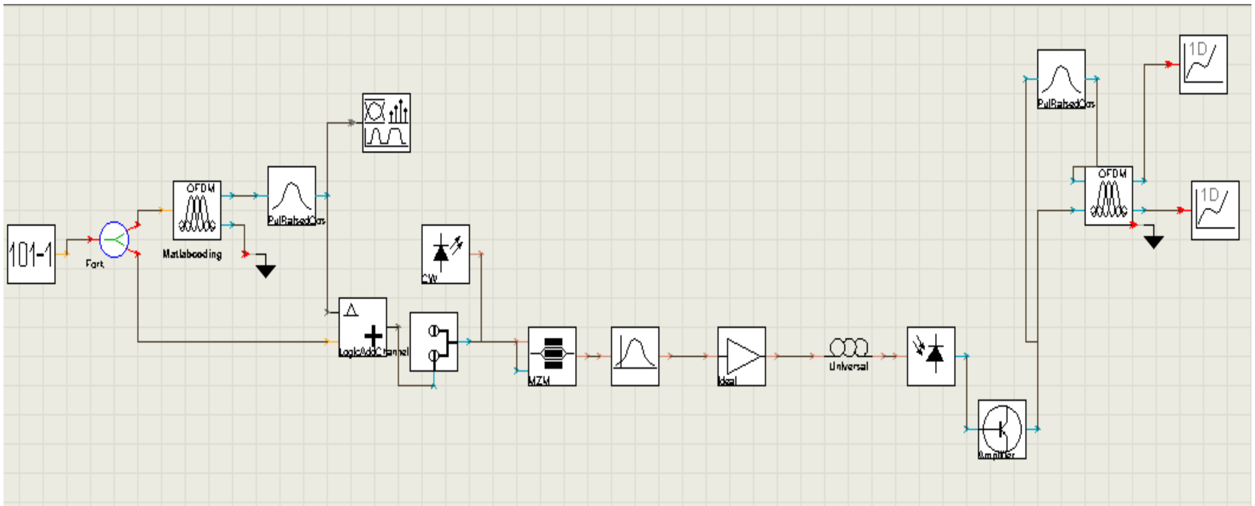

Figure4. Block Diagram of Proposed Optical OFDM System with Hermitian Symmetry.

IV SIMULATION AND RESULT

The data rate is 25Gbps and the block length is 2048 bits, giving 1024 OFDM carrier in an optical bandwidth of 7.5 GHz with 4-Quadrature Amplitude Modulation (QAM). The 1000–km link comprises 25 uncompensated 40-km spans. The fiber has a loss of 0.2 dB/km, a non-linearity coefficient, n_2, of $2.5*10^{-20}$ m^2/W and an effective cross section of $5.281*10^{-11} m^2$. VPI Transmission Maker V7.01 is used for simulation with an optical bandwidth of 100 GHz and an electrical bandwidth of 50 GHz. Once the VPI simulation is executed, the VPI Photonic Analyzer tool will display the received optical spectrum, the received constellation diagram and the Bit Error Rate (BER) plot. The received optical spectrum, shown in Figure5 is plotted just after the fiber link, before the signal is detected by the photodiode. This will also be the frequency for the optical carrier signal, which is separated by a 5 GHz gap from both the suppressed sideband and the optical OFDM signal centered at 7.5 GHz from the optical carrier.

Figure6 and Figure7 shows the constellation for the electrical signals with and without non-linearity pre- compensation. Dispersion compensation is enabled in both the cases. When considered in frequency domain, the fiber non-linearity acting on the instantaneous phase of the superposition of all subcarriers cause intermodulation between subcarriers known as Four-Wave Mixing (FWM) [14]. This intermodulation perturbs the amplitude and phase of each subcarrier, spreading the points of the constellation. The Bit Error Rate (BER) is estimated from the electrical quality measured from the constellation using

$$BER = 0.5\, erfc\left(\frac{q}{1.414}\right) \qquad (5)$$

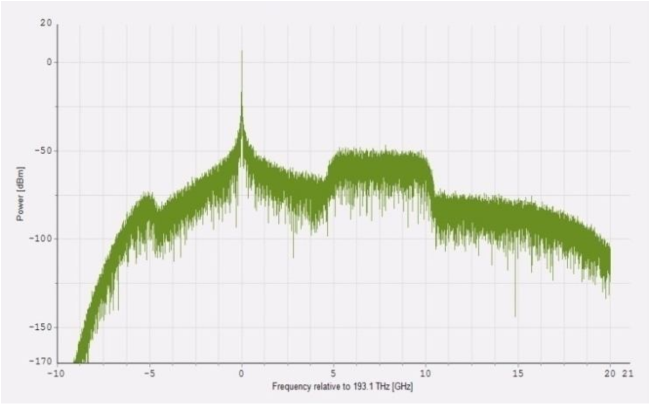

Figure5. Received Optical Spectrum before Photo detection

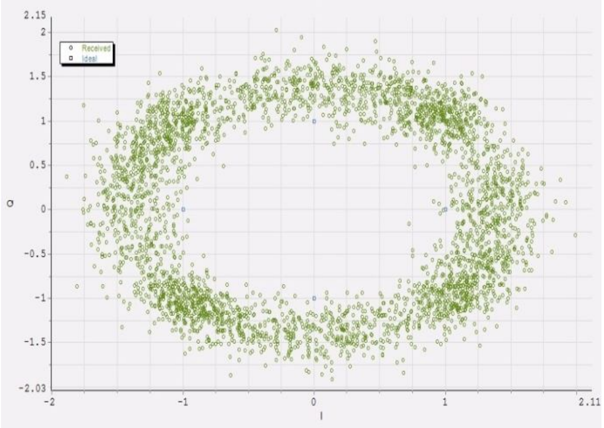

Figure6. Constellation diagram without Hermitian Symmetry

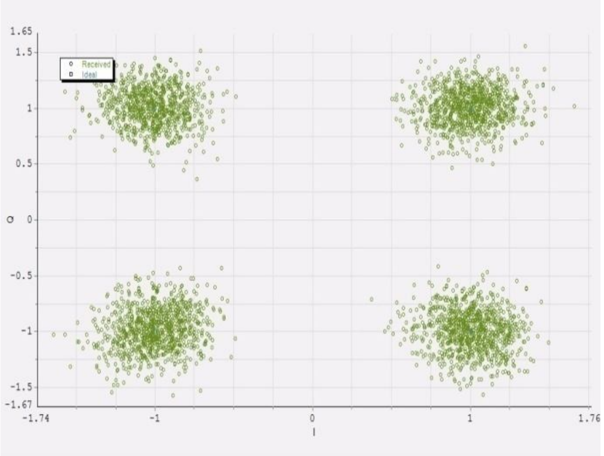

Figure7. Constellation diagram with Hermitian Symmetry

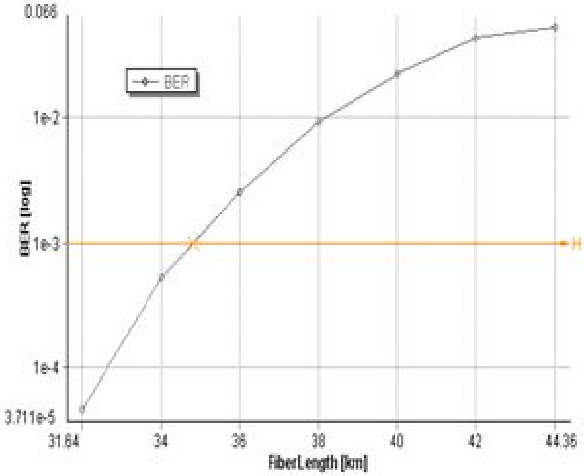

Figure8. Bit Error Rate (BER) Vs Fiber Length without Hermitian Symmetry

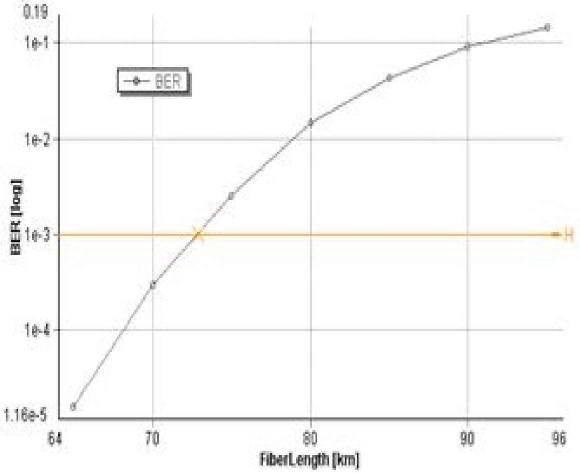

Figure9. Bit Error Rate (BER) Vs Fiber Length with Hermitian Symmetry

Figure8 plots the BER Vs Fiber Length without Hermitian Symmetry, and Figure9 plots the BER Vs Fiber Length with Hermitian Symmetry, from Figure 8 and Figure9 we can infer the maximum distance the information can be transmitted at BER of 1e^{-3}is 30-35kms without Hermitian Symmetry, with applying Hermitian Symmetry the same BER can be achieved till 70-80kms.From this we can see that there is a significant improvement in the BER performance of the system.

V.CONCLUSION & FUTURE WORK

A simple modification to coherent optical OFDM has been proposed that mitigates the effects of non-linearity in the transmission path, particularly for low- dispersion fiber. This requires a simple computation. With compensation, the non-linear limits for near-zero and reduced dispersion fiber are increased to above that for standard single-mode fibers (provided large-core areas are used for each type of fiber). A single tuning parameter is used, so the little knowledge is required for the actual fiber plant, to achieve a reasonable benefit. The results presented are for a single optical channel, rather than a WDM OFDM system. However, as the dominant effect of fiber non-linearity is the interaction between the closely spaced subcarriers (approximately 10 MHZ), rather than the widely spaced WDM channels (10 GHz spacing), this method is likely to also give significant improvements in OFDM WDM system.

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