Integrated DWDM and MIMO-OFDM System for 4G High Capacity Mobile Communication

Shikha Nema seeshikhanema@yahoo.co.in
Department of Electronics and Communication Engineering,
MANIT(Deemed University)
Bhopal -462051,India

Dr Aditya Goel adityagoel2@rediffmail.com
Department of Electronics and Communication Engineering,
MANIT(Deemed University)
Bhopal -462051,India

Dr R P Singh prof_rpsingh@rediffmail.com
Department of Electronics and Communication Engineering,
MANIT(Deemed University)
Bhopal -462051,India

Abstract

Dense wavelength-division multiplexing (DWDM) technique is a very promising data transmission technology for utilizing the capacity of the fiber. By DWDM, multiple signals (video, audio, data etc) staggered in wavelength domain can be multiplexed and transmitted down the same fiber. The Multiple-input multiple-output (MIMO) wireless technology in combination with orthogonal frequency division multiplexing (MIMO-OFDM) is an attractive air-interface solution for next-generation wireless local area networks (WLANs) and fourth generation mobile communication system. This paper provides an overview of the modified integrated DWDM MIMO-OFDM technology and focuses on DWDM transmitter design with adequate dispersion compensation for high data rate of 10Gbps, MIMO-OFDM system design and receiver design.The performance analysis in terms of bit error rate for Integrated system has also been carried out.Here a 64 channel DWDM system is simulated for transmission of baseband NRZ signal over fiber. Each of the transmission is at the bit rate of 10 Gbps leading to high data rate transmission of 640 Gbps. The resultant Bit Error Rate (BER) is in the range 10^{-12} for DWDM system which is given as input to MIMO-OFDM system. The system performance is analyzed in terms of BER with Signal to Noise Ratio(SNR) for Rayleigh and AWGN channels and desirable BER of 10^{-4} [3] is achieved at SNR of 10dB .

Keywords: DWDM system , 0.5nm channel spacing ,MIMO-OFDM system, Space Time Coding

1 Introduction

Tremendous consumer interest in multimedia applications requires high data rates in mobile communication system. With the advent of 4G mobile communication systems, many broadband wireless applications can be supported like Video Conferencing, Wireless Scada [1] and HDTV. High capacity and variable bit rate information transmission with high bandwidth efficiency are the key requirements that the modern transceivers have to meet in order to provide a variety of new high quality services to be delivered to the customers.

For achieving high capacity transmission, Optical fiber network plays an important role. **B**ROAD-BAND millimeter-wave fiber-radio access system will meet demands for "*wireless first/last hop*" to the customers, which can support broad-band and portable services [2].It will also resolve the scarcity of available microwave-band. For millimeter-wave fiber-radio systems, the only feasible option to connect between the central control office (CO) and the micro- or pico-cellular antenna base stations (BSs) would be an optical generation and transport technique of millimeter-wave RF signals over optical fiber links. In the micro- or pico-cellular fiber-radio access system, more than 1000 BSs are likely to be located under the coverage of a single CO; therefore, it would be desirable to accommodate a large number of BSs [3], and the promise for support will be wavelength division multiplexed (WDM) technology. Recently, there has been rapid progress in WDM transmission technologies. Dense WDM (DWDM) shows promise to increase the transmission capacity of trunk lines within the spectral regions limited by the gain bandwidths of optical fiber amplifiers.

The key challenge faced by future mobile communication system[16] is to provide high-data-rate wireless access at high quality of service (QoS). Combined with the facts that spectrum is a scarce resource and propagation conditions are hostile due to fading (caused by destructive addition of multipath components) and interference from other users, this requirement calls for means to radically increase spectral efficiency and to improve link reliability. Multiple-input multiple-output (MIMO) wireless technology [4] seems to meet these demands by offering increased spectral efficiency through spatial multiplexing gain, and improved link reliability due to antenna diversity gain. Even though there are still a large number of open research problems in the area of MIMO wireless, both from a theoretical perspective and a hardware implementation perspective, the technology has reached a stage where it can be considered ready for use in practical systems.

In this paper simulation is performed for 64 channel DWDM system integrated with MIMO-OFDM technology.The simulation is carried out using powerful software tools **Optisystem** and MATLAB Section 2 describes the DWDM transmitter module which describes the channel properties of optical fiber with dispersion compensated fiber. Section 3 deals with MIMO-OFDM system design. Numerical results and analysis are provided in Section 4.Finally, Section 5 concludes the paper.

2 Design of 64 channel DWDM System

2.1 Transmitter Module

The transmitter module shown in Fig1 is divided into three parts .First part consists of sixty four NRZ Transmitters. For the generation of 10Gbps NRZ signal, a Pseudorandom bit sequence generator is used whose output in turn is given to a pulse generator to generate NRZ pulses. These Pulses are used to directly modulate externally Modulated LASER which operates at 1566nm wavelength and all subsequent sources are located at the wavelength difference of 0.5 nm . The Mech-Zehnder Modulator which is an intensity modulator based on an interferometric principle is used [8] .It consists of two 3 dB couplers which are connected by two waveguides of equal length .By means of an electro-optic effect ,an externally modulated applied voltage can be used to vary the refractive indices in the waveguide branches. The different paths can lead to constructive and destructive interference at the output depending on the applied voltage. Then the output intensity can be modulated according to the voltage. The model implements a continuous wave (CW)

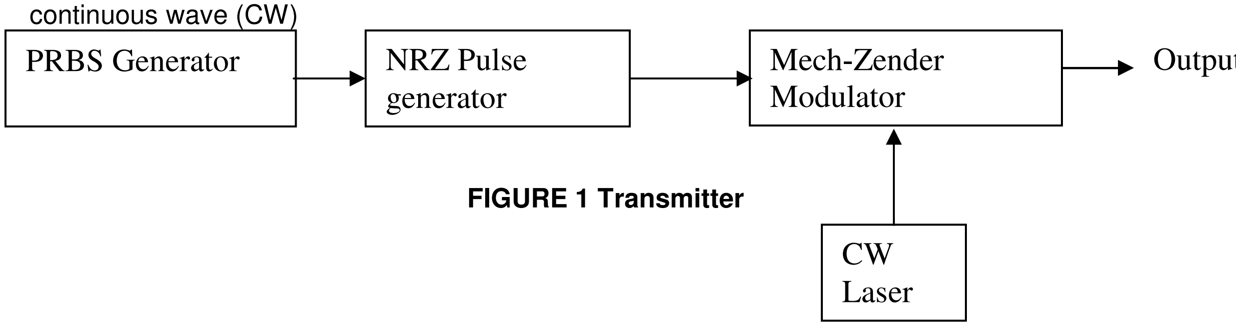

FIGURE 1 Transmitter

laser with phasor noise with overshoot and undershoot value of 30%. The output is provided to sixty four channel DWDM multiplexer operating at wavelength of 1566nm with channel spacing of 0.5 nm with line-width of 0.1 MHz.

2.2 Fiber Link Design

The output from the 64 channel DWDM Multiplexer is given to Single Mode fiber (SMF) of lengths 60 Km ,120Km and 240Km with Post dispersion compensated fiber of 10 Km, 20Km and 30Km respectively.[5]
The value of dispersion is different for different wavelengths so the exact value of dispersion at each wavelength for SMF and DCF is computed by using the formula :

D= WS (1-(w/W)^4)/4 (1)

where:
D= Required value of Dispersion
S= Dispersion Constant
w= Reference Wavelength of the Fiber.
W= Wavelength at which Dispersion has to be calculated
Here the value of 'w' lies between 1295 to 1322 nm while the value of 'S' lies below 0.095 ps/((nm)^2*km).

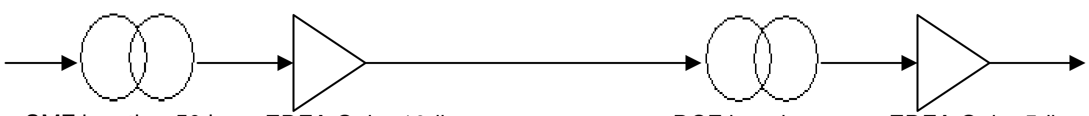

FIGURE 2 Fiber Design

Fig 2 shows the fiber link design of 60 Km with 50km of SMF and 10km of DCF.Polarization mode Dispersion (PMD) and deterministic birefringence with differential group delay of 0.2ps/Km are used to simulate the fiber. Two EDFA amplifiers are used with respective gains of 10db and 5 db to overcome the effect of attenuation.[5]

2.3 Receiver Design

Firstly the output from fiber is given to 64 channel DWDM demultiplexer. The output from each channel is fed to Fiber Bragg Grating which is a periodic or aperiodic perturbation of the effective refractive index in the core of an optical fiber. Typically, the perturbation is approximately periodic over a certain length of e.g. a few millimeters or centimeters, and the period is of the order of hundreds of nanometers, or much longer for *long-period fiber gratings* . The fiber core has a periodically varying refractive index over some length. The typical dimensions are 125 μm cladding diameter and 8 μm core diameter; periods of the refractive index gratings vary in the range of hundreds of nanometers or (for long-period gratings) hundreds of micrometers.[6,7]

The refractive index perturbation leads to the reflection of light (propagating along the fiber) in a narrow range of wavelengths, for which a *Bragg condition* is satisfied (Bragg mirrors):

$$\frac{2\pi}{\Lambda} = 2 \cdot \frac{2\pi n_{eff}}{\lambda} \quad \Rightarrow \quad \lambda = 2 n_{eff} \Lambda \qquad (2)$$

where Λ is the grating period, λ is the vacuum wavelength, and n_{eff} is the effective refractive index of light in the fiber. Essentially, the condition means that the wave number of the grating matches the difference of the (opposite) wave vectors of the incident and reflected waves. In that case, the complex amplitudes corresponding to reflected field contributions from different parts of the grating are all in phase so that they can add up constructively; this is a kind of phase matching. Even a weak index modulation (with an amplitude of e.g. 10^{-4}) is sufficient for achieving nearly total reflection, if the grating is sufficiently long (e.g. a few millimeters).

It is shown that the dispersion of the neighboring transmitted channel may be determined uniquely by using FBG which is IIR filter. When considering dispersion effects on neighboring channels ,dispersion may dictate channel spacing .[7] Light at other wavelengths, not satisfying the Bragg condition, is nearly not affected by the Bragg grating, except for some side lobes which frequently occur in the reflection spectrum (but can be suppressed by apodization of the grating).As a result of it, desired BER value of 10^{-12} can be obtained with small channel spacing of 0.5nm.

The receiver design shown in Fig3 consists of FBG whose output is fed into PIN photodetector having -3db gain with dark current of 10nA and responisivety of 1A/W which performs optical to electrical conversion. The electrical signal is fed into fourth order Low Pass Bessel filter having bandwidth of 7.5Ghz and depth of 100db.It is followed by 3R regenerator which consists of data recovery component and a NRZ pulse generator .The first output of Regenerator is the bit sequence, the second one is the modulated NRZ signal and the last output is reference input signal. These three signals can be connected directly to BER analyzer.

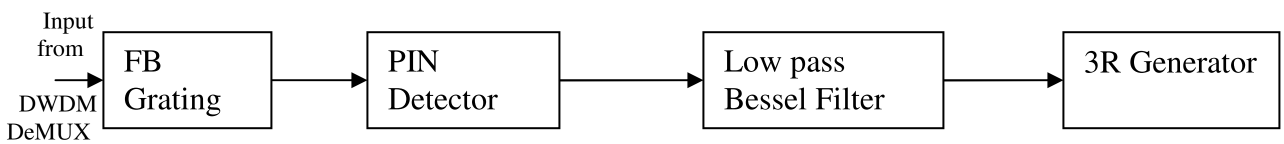

FIGURE 3 Receiver Design

Thus additional connections between transmitter and receiver stage are avoided. The output of BER analyzer gives the eye-diagram which gives the BER performance and Q factor for the system. The *MATLAB* code deals with the wireless part of this project. The output of the *OPTIWAVE* is a binary signal which is fed as an input to the *MATLAB* code for MIMO-OFDM system.[8]

3 MIMO-OFDM System

Traditionally, multiple antennas (at one side of the wireless link) have been used to perform interference cancellation and to realize diversity and array gain through coherent combining. The use of multiple antennas at both sides of the link offers an additional fundamental gain — spatial multiplexing gain, which results in increased spectral efficiency. A brief review of the techniques in a MIMO system is given in the following.

Spatial multiplexing yields a linear (in the minimum of the number of transmit and receive antennas) capacity increase, compared to systems, with a single antenna at one or both side of the link, at no additional power or bandwidth expenditure [3, 9]. The corresponding gain is available if the propagation channel exhibits rich scattering and can be realized by the simultaneous transmission of independent data streams in the same frequency band. The receiver exploits differences in the spatial signatures induced by the MIMO channel onto the multiplexed data streams to separate the different signals, thereby realizing a capacity gain.

Diversity leads to improved link reliability by rendering the channel “less fading” and by increasing the robustness to co-channel interference. Diversity gain is obtained by transmitting the data signal over multiple (ideally) independently fading dimensions in time, frequency, and space and by performing proper combining in the receiver. Spatial (i.e., antenna) diversity is particularly attractive when compared to time or frequency diversity, as it does not incur an expenditure in transmission time or bandwidth, respectively. Space-time coding [2] realizes spatial diversity gain in systems with multiple transmit antennas without requiring channel knowledge at the transmitter. **Array gain** can be realized both at the transmitter and the receiver. It requires channel knowledge for coherent combining and results in an increase in average receive signal-to-noise ratio (SNR) and hence improved coverage.

3.1 Space time Coding

Diversity combining technique is implemented in the system by using space-time block codes. To get the idea of Space-Time Block Codes, it is comfortable to investigate the scheme for two transmit antennas. The information data is mapped to either PSK or QAM symbols and is divided in blocks of two symbols. To explain the functionality, two consecutive time steps of such a block are observed. (Fig-4)[10]
In the first time step the signals X_1 and X_2 are transmitted simultaneously from the first and the second antenna. In the next time step, the signals $-X_2^*$ and X_1^* are transmitted, so that we achieve the given code word matrix, which consists of orthogonal columns.

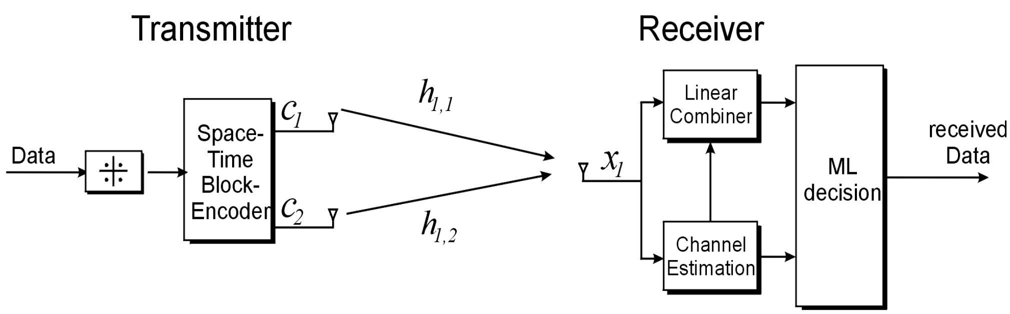

FIGURE 4 Space time block Coding

The received signals is described in the two timeslots by the given formula, which can be simplified by conjugating the term for describing the second received signal.

$$y[k] = h_0x_0[k]+h_1x_1[k]+n[k] \quad (3)$$

Three terms are received depending only on the fading gains, the transmitted signal and the noise. [2] The bandwidth efficiency challenge requires novel solutions in both the network and physical layers. The latter could include powerful coding and modulation methods, transmission adaptation techniques, and antenna configurations. MIMO communications based on multiple transmit and receive antenna is a very promising technique to increase bandwidth efficiency, and is seen as a potential key solution for fading channels with rich enough scattering MIMO technology will predominantly be used in broadband systems that exhibit frequency-selective fading and, therefore, intersymbol interference(ISI). OFDM modulation turns the frequency-selective channel into a set of parallel flat fading channels and is, hence, an attractive way of coping with ISI. Fig 5 and 6 depicts the schematic of a MIMO-OFDM system. The basic principle that underlies OFDM is the insertion of a guard interval, called cyclic prefix (CP), which is a copy of the last part of the OFDM symbol, and has to be long enough to accommodate the delay spread of the channel.
The use of the CP turns the action of the channel on the transmitted signal from a linear convolution into a cyclic convolution, so that the resulting overall transfer function can be diagonalized through the use of an IFFT at the transmitter and an FFT at the receiver .Consequently, the overall frequency-selective channel is converted into a set of parallel flat fading channels, which drastically simplifies the equalization task. However, as the CP carries redundant information, it incurs a loss in spectral efficiency, which is usually kept at a maximum of 25 percent.[4,11]

In general, OFDM has tighter synchronization requirements than single-carrier (SC) modulation and direct-sequence spread spectrum (DSSS), is more susceptible to phase noise, and suffers from a larger peak-to-average power ratio.[10,11]

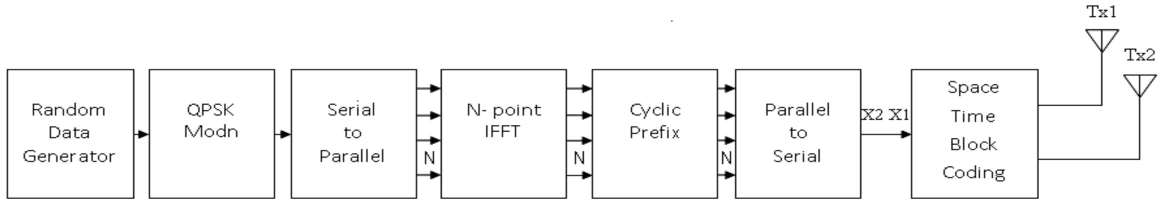

FIGURE 5 MIMO-OFDM Transmitter

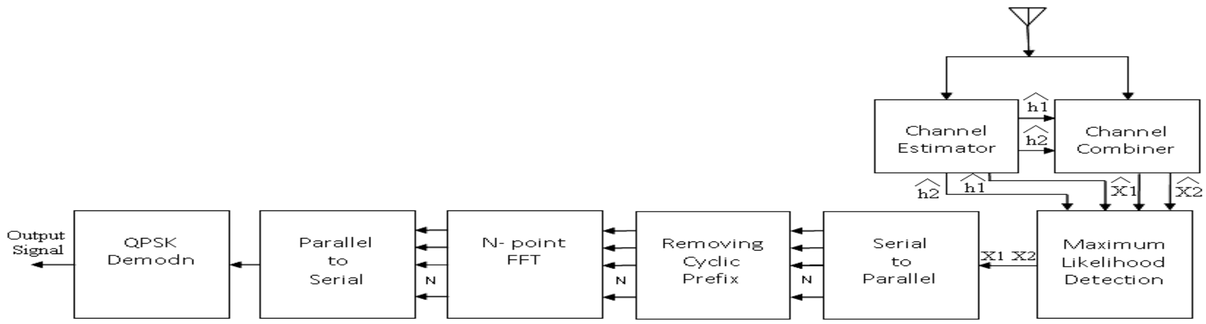

FIGURE 6 MIMO-OFDM Receiver

In MIMO-OFDM transmitter the binary signal is first converted into 4-ary signal so that the signal can be QPSK modulated. This modulated signal has to be converted into time domain. For this purpose the signal is first passed through a serial to parallel conversion block which takes 32 symbols at a time and converts them into parallel stream of data. Then this parallel data is used for taking IFFT which converts the signal into time domain.

In an *OFDM* signal the frequencies are orthogonal to each other. But still during transmission some amount of noise would be added to the signal due to multipath propagation. In order to reduce this Cyclic Prefix is used. Cyclic prefix are often used in conjunction with modulation in order to retain sinusoids properties in multipath channels. It is well known that sinusoidal signals are Eigen functions of linear and time-invariant systems. Therefore, if the channel is assumed to be linear and time-invariant then a sinusoid of infinite duration would be an Eigen function. However, in practice, this cannot be achieved, as real signals are always time-limited. So, to mimic the infinite behavior, prefixing the end of the symbol to the beginning makes the *linear convolution* of the channel appear as though it were *circular convolution*, and thus, preserve this property in the part of the symbol after the cyclic prefix.[12] After prefixing the signal is transmitted using Space Time Coding *(Almounti Scheme*) [2].Here *spatial diversity* is used where a signal is passed through 2 antennas and both of them follow different path and the best path is chosen by the receiver resulting in 2:1 *MIMO OFDM system*. The same is the case when 4 antennas are used (4:1). [2]

The signal when passed through a channel is acted upon by noise. Two different channels are considered according to the type of noise that is added. The first one is *Rayleigh channel* where noise is in complex form and both the real and the imaginary part are *Gaussian* variables. The second is an ideal case i.e. *AWGN channel* which has a constant power spectral density.[13] The performances for these channels are seen by plotting graphs of *BER* VS *SNR*. After the signal is received Cyclic Prefix is removed. Then the signal is QPSK demodulated and converted from decimal to binary to obtain the original information.

4 Results and Discussion:

Bit error rate is calculated for NRZ system at three different distance of 60km , 120km and 240 km,at the wavelength of 1566nm Fig 7 shows the Q factor for NRZ signal at wavelength of 1566nm. It shows that Q factor of 8 is achieved at half the bit period .It is shown experimentally in [14] that Q factor of 7 to 8 is achieved at the data rate of 5 Gbps for a single channel system employing pre/post Dispersion compensation scheme with channel spacing of 1nm .Here the same performance is achieved with more stringent parameters i.e. data rate of 10Gbps for the channel spacing of 0.5nm. Fig 8 shows the bit error rate performance for the same system at 1566nm. It shows that BER of 10^{-16} is achieved at half the bit period

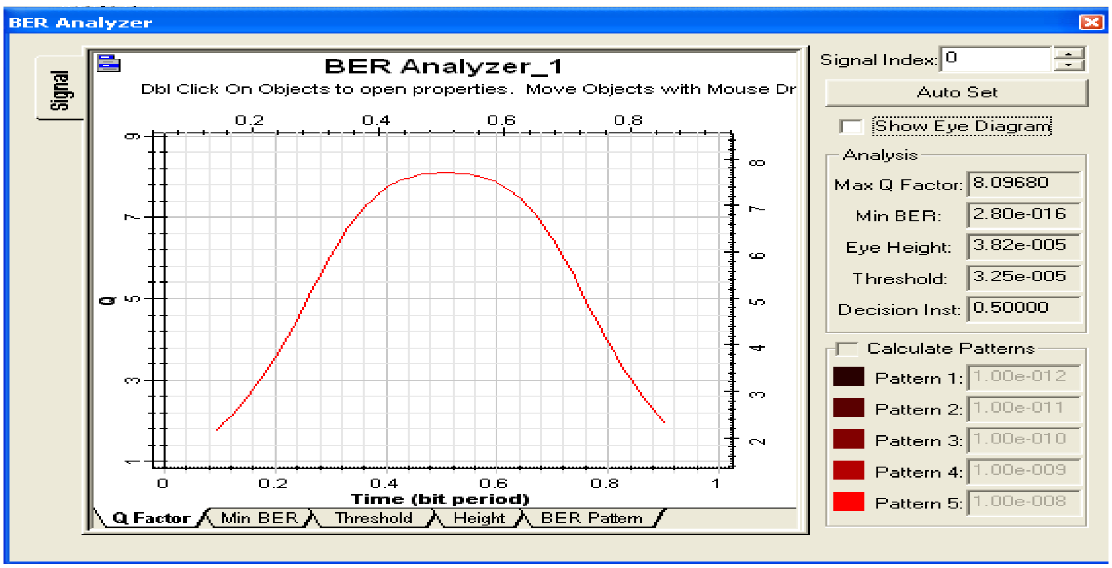

FIGURE 7 Q factor v/s bit period for NRZ signal at 1566nm

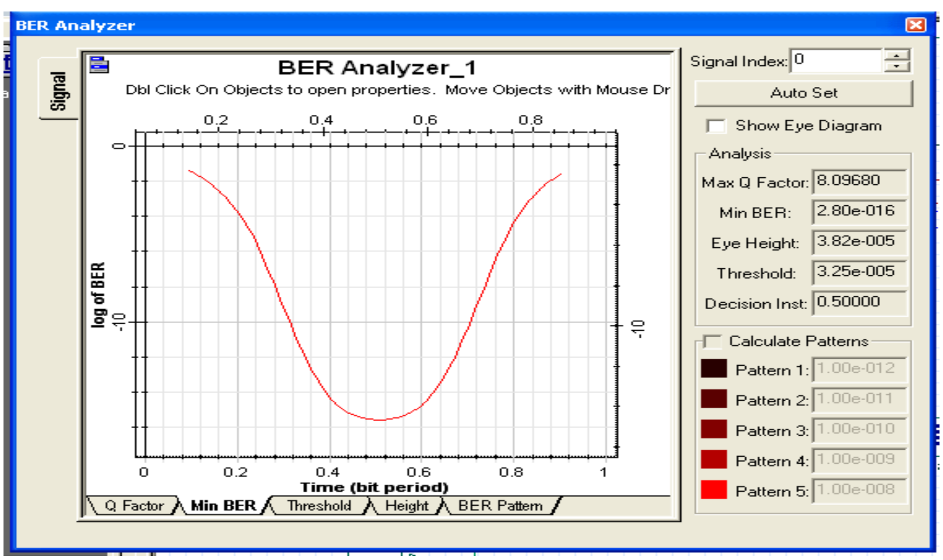

FIGURE 8: Log of BER v/s bit period for NRZ signal at 1566nm

Fig 9 shows the eye diagram with minimum BER value which is in the range of 10^{-16}.The eye opening shows that the signal is free of intersymbol Interference and can be detected at the centre of the bit period.

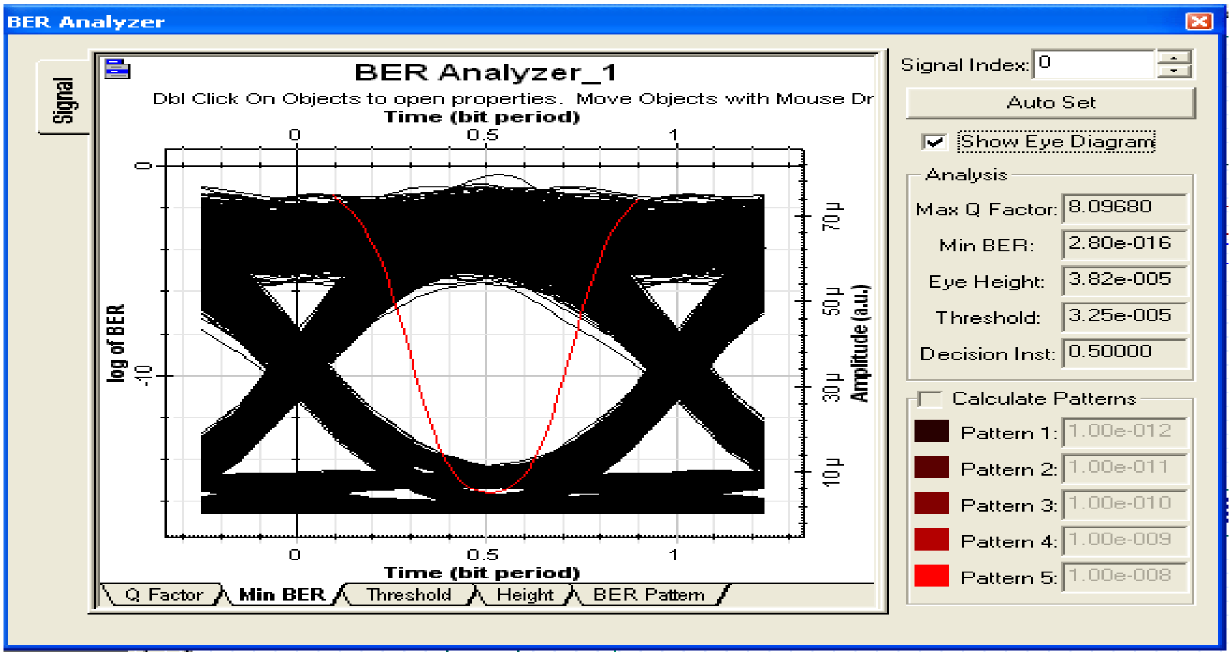

FIGURE 9: Eyediagram for NRZ at wavelength 1566nm at 60 KM

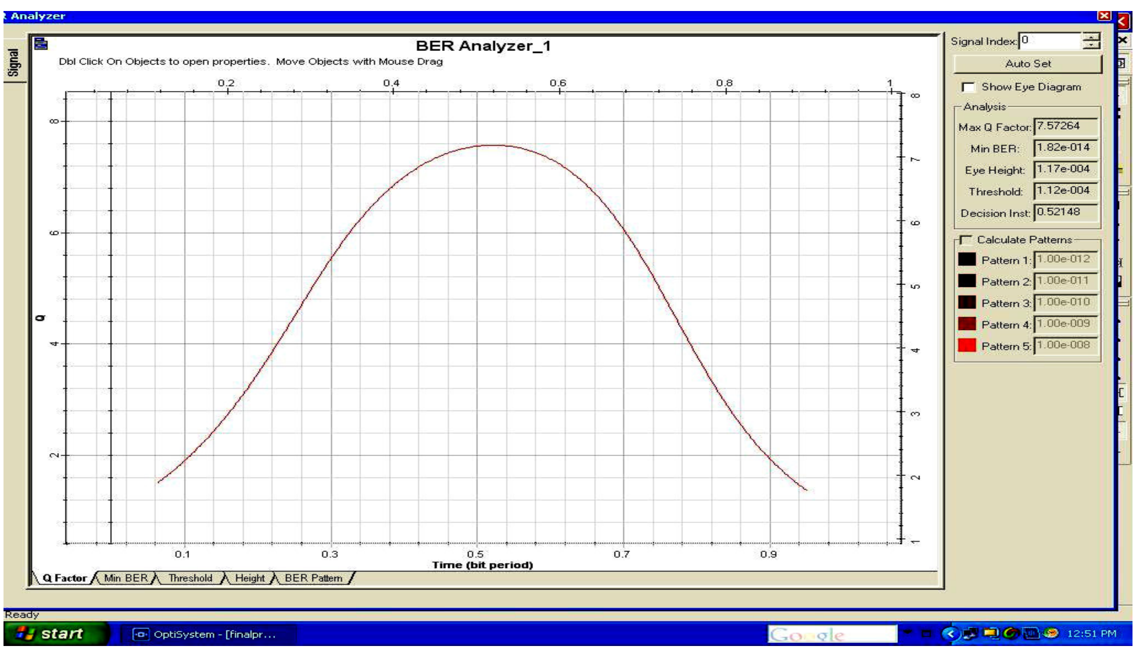

FIGURE 10 Q factor v/s Bit period for NRZ system at bandwidth of 1566nm at the distance of 120 KM.

FIGURE 11 Q factor v/s Bit period for NRZ system at bandwidth of 1566nm at the distance of 240KM

Second NRZ Output is taken at the distance of 120 and 240Km whose Q factor plots are shown in Fig 10 and 11.Q Factor of 7.5 and BER value of 10^{-14} is achieved for 120KM while maximum Q factor of 7 is achieved in the system with min BER of 10^{-11} for 240KM. Hence it can be concluded that as the distance increases, Q factor decreases .Improvement in Q factor can be achieved by increasing the transmit power of CW laser source.[14,15]

The received signal is then converted into a binary form and then modulated again so that it can be used as an input to the transmitters of the MIMO-OFDM system. After passing through desired channel model, the receiver then receives the signal and the signal is then checked for BER again at different values of Signal to Noise Ratio. The BER was found to be within acceptable limits. The BER v/s SNR curves for the systems with 2 transmit antennas and 4 transmit tested with the Rayleigh and AWGN channels are shown in fig12 to fig 15.

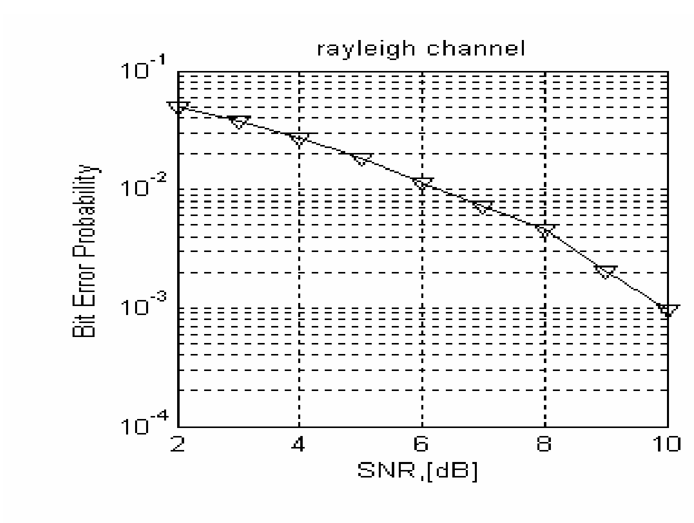

FIGURE 12 BERv/s SNR plot for rayleigh channel with 2 :1 MIMO OFDM system

From fig 12 and 13 , it can be seen that BER value of 10^{-3} is achieved at 10 db of SNR and AWGN channel performance is better as compared to Rayleigh Channel for two transmit antenna and one receive antenna MIMO-OFDM system.

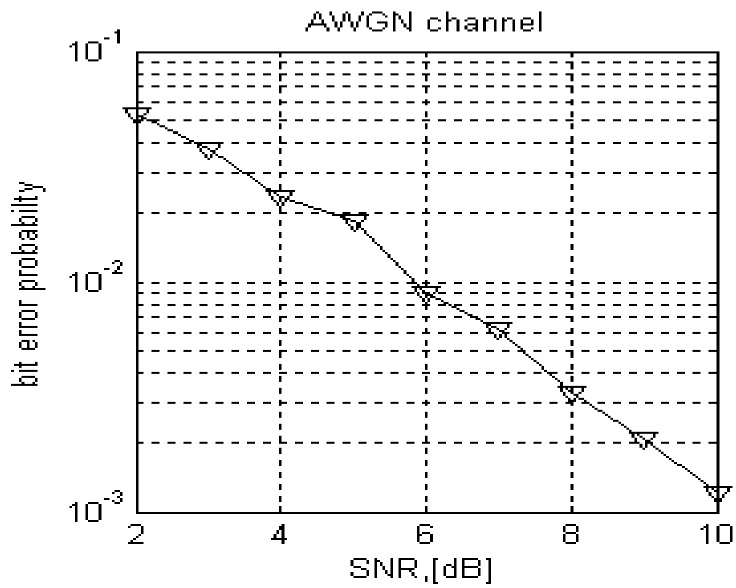

FIGURE 13 BERv/s SNR plot for AWGN channel with 2 :1 MIMO OFDM system

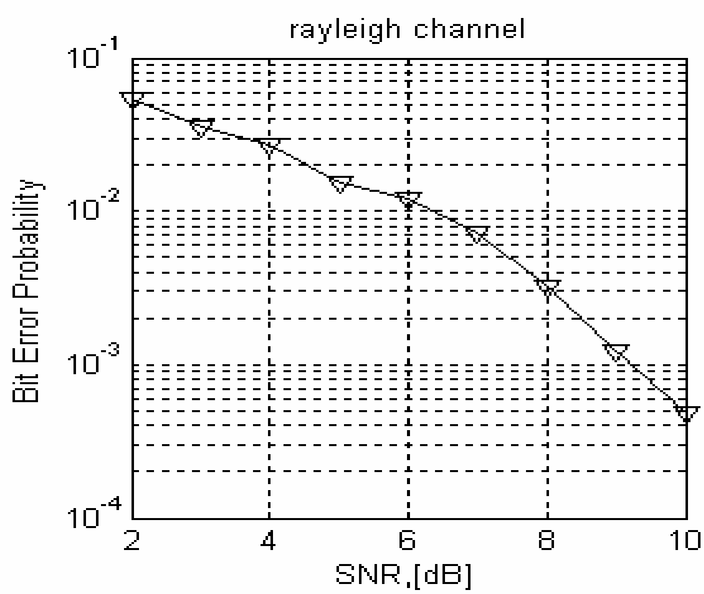

FIGURE 14 BERv/s SNR plot for rayleigh channel with 4 :1 MIMO OFDM system

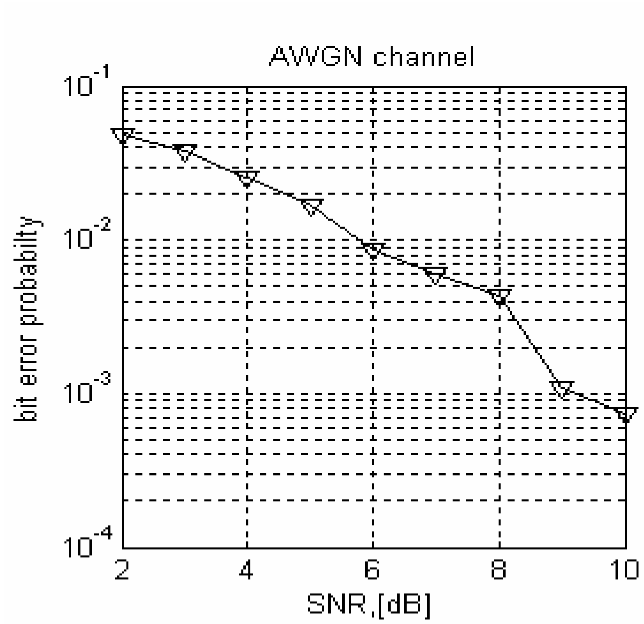

FIGURE 15 BER v/s SNR plot for AWGN channel with 4 :1 MIMO OFDM system

From Fig 14 and Fig 15 it can be seen that BER performance of $10^{-3.5}$ is achieved at SNR of 10dbs with four transmit and one receive antenna which is better as compared to two transmit and one receive antenna .

We have designed 64 channel DWDM system with data rate of 10Gbps and 0.5nm Channel spacing. BER and Q factor are observed for various fiber spans of 60km, 120km and 240km.It is obvious from Fig 9 and Fig 11 that for the fiber span of 60km BER achieved is 10^{-16} which is increased to 10^{-11} for the fiber span of 240km which is within the acceptable range.[14] For MIMO-OFDM system, analysis is performed for Rayleigh and AWGN Channel. Rayleigh Channel will provide a typical multipath environment in urban area for mobile communication while AWGN channel will provide additive white Gaussian noise. The simulation is performed for two transmit and one receive antenna and four transmit and one receive anteena. For both these cases, and under the different channel conditions it can be seen from fig 12-15 that BER of $10^{-3.5}$ is obtained for SNR of 10db. Hence it is obvious that for an integrated DWDM-MIMO-OFDM system an average BER of 10^{-12} is achieved for DWDM optical system and 10^{-4} is achieved with MIMO-OFDM system which is within the acceptable range for optical and wireless system respectively.[4,14]

5 Conclusion

Error Free DWDM transmission over 300 Km of Single mode fiber is simulated with 64 channel EML system with 0.5 nm channel spacing. Performance analysis for NRZ transmission is done. Minimum BER achieved with NRZ is 10^{-16} for 60 KM which is 10^{-11} for 240 KM of fiber length. This binary output is given to MIMO-OFDM system designed in MATLAB .Two MIMO=OFDM system is designed with two transmit antenna and one receive antenna and four transmit antenna and one receive antenna. Results which are plotted for various channels are shown above. These results are tabulated in Table1.It can be inferred that the system with four transmit antennas gives better performance than two transmit antennas. This BER performance is achieved at the higher data rate of 10Gbps . The system performance can be further improved by in incorporating Error correction technique in the system

Table1

Sr.NO	MIMO System	SNR	Rayeleigh Channel	AWGN Channel
1	4:1	10	10-3.5	10-3.1
2	2:1	10	10-3	10-3

References

1. Aditya Goel and Ravi Shankar Mishra "Remote Data Acquisition using Wireless SCADA System", International Journal of Engineering, Volume 3 (1),pp.58-65, 2009
2. S.Almouti, " A simple transmit diversity technique for wireless communication" IEEE journal on select areas in communications, Oct 1998
3. Foschini, "Layered space time Architecture for wireless communication", Bell labs Tech Journal Vol 1,1996
4. Markku Juntti, Mikko Vehkapera, Jouko Leinonen, Zexian Li,and Djordje Tujkovic "MIMO MC-CDMA communications for future cellular systems", IEEE Communication Magazine, Feb 2005.

5 D.Wake, L.Noe1, D.G.Moodie, D.D.Marcenac, L.D.Westbrook and D.Nesset "A 60 GHz 120 Mbps QPSK fiber-radio transmission experiment incorporating an electroabsorption modulator transceiver for a full duplex optical data path"*IEEE 1997 MTT-S Digest*

6 Volkan Kaman, Xuezhe Zheng, , Shifu Yuan, Jim Klingshirn, Chandrasekhar Pusarla, Roger Helkey, Olivier Jerphagnon, and John E. Bowers, "A 32 10 Gb/s DWDM Metropolitan Network Demonstration Using Wavelength-Selective Photonic Cross-Connects and Narrow-Band EDFAs" *IEEE Photonics Technology letters,* volume 17(9) *september 2005*

7 G. Lenz, B. J. Eggleton, C. R. Giles, C. K. Madsen, and R. E. Slusher," Dispersive Properties of Optical Filters for WDM Systems" IEEE journal of quantum electronics, volume 34(8) August 1998 pp1390-1402

8 Aditya Goel, R K Sethi " Integrated Optical wireless network for next generation Wireless Systems" , Signal Processing – An International Journal Volume 3 (1), pp.1-13, 2009

9 V Tarokh, Hamid Jafarkhani and A Robert Calderbank , "Space time Block Coding for wireless Communications :Performance Results" IEEE Journal on Selected Area in Communications, volume 17(3) March 1999

10 A. J. Paulraj, R. U. Nabar, and D. A. Gore, Introduction to Space-Time Wireless Communications, Cambridge, UK: Cambridge Univ. Press, 2003.

12 Rane Manzoor, Regina Gani, Varun Jeoti, Nidal kamal, Muhammad Asif , " Dwpt based FFT and its application to SNR estimation in OFDM systems" Signal Processing– An International Journal Volume 3 (2) , 2009

13 T. Rappaport "Wireless Communication" 2nd edition ,Prentice Hall Publication December 2001

14 Fariborz Mousavi Madani and Kazuro Kikuchi," Design Theory of Long-Distance WDM Dispersion-Managed Transmission System" ,Journal of lightwave technology, volume 17(8) pp1326-1335 , August 1999

15 Zhang Dechao, Li Xiaolin, Zhang Xiaoru, Wang Ziyu, Xu Anshi Chen Zhangyuan, Li Hongbin, Li Zhengbin, "43 Gb/s DWDM Optical Transmission System Using NRZ Format and Electro-absorption Modulation" *IEEE 2006*

16. Aditya Goel and A. Sharma,"Performance Analysis of Mobile Ad-hoc Network using AODV protocol", International Journal of Computer Science and Security, Vol. 3(5),2009