Design and Performance Study of MMDWDM Systems

Devendra Kr, Tripathi, Pallavi Singh, N.K. Shukla and H.K. Dixit

Department of Electronics & Communication, J.K. Institute of Applied Physics & Technology, University of Allahabad, Allahabad, U.P, India

Abstract - The rising need for bandwidth created innumerable efforts from academic and industry group towards development of most efficient optical communication networks. In order to compete it numerous investigators have designed their own novel schemes. In this view the paper presents multiple modulation dense wavelength division multiplexed transmission designed links each with a total capacity of 640Gbps and with channel to channel to spacing of 100Ghz, employing multiple modulation schemes such as non return to zero rectangular, non return to zero raised cosine, return to zero rectangular, non return to zero raised cosine, return to zero soliton, return to zero Super Gaussian. The optical transmission performance characteristics like bit error rate, Q parameter at the output have been investigated by simulating different systems for a fixed transmission length of 260kilometers. Results show that transmission performance of DWDM system with non return to zero raised cosine scheme has been better with quality factor ranging from 16 to 23dB and bit error rate ranging from $10^{-11}$ to $10^{-40}$ for detected channels at selected transmission reach (260KM) and other schemes with good performance were RZ Super Guassian DWDM and RZ Soliton DWDM systems for the same transmission reach. The transmission parameter jitter have been also investigated for each system which depict that jitter effect is more severe for return to zero systems as compared to non return to zero DWDM systems. From the performance analysis for different optical links involving different modulation schemes it can be articulated that novel modulation scheme generally improves the transmission performance and must for modern optical communication systems operating at high bit rate and longer reach.

Key words: Time division multiplexing (TDM), code division multiplexing (CDM), fiber optic communication (FOC), orthogonal frequency division multiplexing (OFDM)

1. Introduction

Communication is the basic need of people since primordial days. People adopted numerous ways of information sharing altogether. Together with development of human civilization from time to time several eras of communication have been surpassed. The present era is of telecommunication revolution and fiber-optic transmission is one of the most trustworthy schemes which have got concentration due to development of fiber optic communication supporting devices. Now a day’s fiber optic communication (FOC) is most customary and employed over worldwide for national, intercontinental information and data transportation purposes. However with innovation of the World Wide Web there is swift increase in multimedia services and the information traffic have grown up exponentially. Thus it immediately provokes requirement for additional capacity data networks[1]. For that several capacity enhancing schemes have been devised involving deployment of multichannel systems such as time division multiplexing(TDM), code division multiplexing(CDM), frequency division multiplexing(FDM), sub carrier multiplexing(SCM), orthogonal frequency division multiplexing(OFDM) and wavelength division multiplexing(WDM). WDM is the method which employs multiple optical carriers at different wavelengths that were modulated by means of independent electrical bit streams and after that
transmitted over the same fiber with capability of exploiting the huge bandwidth obtainable by optical fibers.

Introduction of WDM has created revolution in light wave system designing community. WDM devices were simpler to put into operation as all components in WDM devices were required to function only at electronic speed. As a consequence numerous WDM devices were devised, accessible in the marketplace since past time and at present, still in growing stage. Although significant works were around 1980’s with narrowly spaced channels and a channel spacing of less than 0.1nm were illustrated by 1990 with multichannel systems and throughout the decade of 1990s WDM systems grown up swiftly[1-12]. The novel designed 10Gb/s binary NRZ systems with electronic-signal-processing show that up to 1.6bits/sec/Hz of spectral efficiency were obtainable, an improved efficiency[13]. For two channel WDM system at bit rate 10Gb/s study exhibited that spectral characteristics were highly dependent on channel spacing and dispersion coefficient and cross phase modulation dependent on the optical powers of the injected signals in a very large range of system parameter [14]. Study for 340Gb/s capacity link, illustrated by transmitting seventeen channels and each channel operating at 20Gb/s over 150km successfully[15]. Novel designed three WDM systems transmission performance were investigated for dispersion values, show that system were affected by dispersion and non-linear effects. Presently the long-haul communication systems employ multiple carrier wavelengths and higher data rates which created higher channel capacity. As spectral efficiency is one of the most important parameter for optical systems, have to be achieved in the investigations. Due to high data rates the limitation imposed by dispersion and nonlinearities in the optical communication system has been of great concern as parameters such as quality factor (Q), Jitter, BER and optical modulation selected limits the overall efficiency of the system. The performance study with chirped RZ and NRZ formats showed, improved transmission performance [16-17]. Further study with non-return to zero (NRZ) and RZ modulation format show that with increased data rates RZ modulation formats present benefits over NRZ since higher robustness against distortions [18-20].

Study in eight channel WDM at 10Gb/s with NRZ/RZ/ Duo-binary signal formats for distances (5Km to 100Km) for Quality factor(Q) and Jitter show that NRZ is good modulation format in the intensity modulated direct detection fiber-optical communication systems. As NRZ pulses are with narrow optical spectrum and reduced spectrum width improves the dispersion tolerance however inter symbol interference (ISI) is present. While a part of the bit slot is occupied with RZ pulse and a broad spectrum as RZ pulse shape allows an enhanced robustness to fiber non-linear effects as well as to the cause of polarization mode dispersion[21-22]. Later on study with non binary encode technique such as multilevel intensity or phase modulation systems ultimate spectral efficiency showed for various modulation formats (NRZ/RZ/RZ-SuperGaussian) at data rates 10/15/20/25Gb/s and impact of EDFA power were investigated showed that smaller width, 3rd to 5th order super Gaussian pulse, full width at half maximum (FWHM) 10ps to 60ps, with raised cosine filter, post and symmetric scheme showed better transmission performance. With single channel 100Gb/s transmission investigation with ASK/PSK/RZ-DQPSK, exhibited BER of 10^-10 without FEC at 1920km of transmission [23-25].

Later study for three WDM systems (RZ/NRZ/CSRZ/Duo binary) of four channel and two channel systems for the effect of different dispersion values, effect of FWM investigated showed that CSRZ signal is far less sensitive to fiber nonlinear effects, RZ system has reduced dispersion tolerance, NRZ system has improved dispersion tolerance and good transmission performance although it has the effect of inter-symbol interference between the pulses this modulation format is not suitable when high bit rates, showed that BER got improved with duo binary modulation format and by increasing core effective area which will offer a significant performance benefit in digital systems[26-28]. Further significant performance improvement shown with CSRZ format, in contrast to the conventional NRZ/RZ formats, over 120km with pre/ post/symmetrical
dispersion compensation schemes for various input signal powers. Better performance also shown with post compensation scheme in terms of Q value, eye opening over 120km of transmission, for 32-channel DWDM system investigated the Kerr effect of nonlinearity over 120km, illustrated that for 80GHz and above channel spacing the power loss becomes constant and does not depend on the number of channels so for optimal BER and power penalty with 80 GHz channel spacing have to be used. FWM effect also diminished while maintaining bandwidth efficiency with unequal channel spacing using channel allocation method based on the optimal Golomb ruler (Exhaust and Search algorithm)[29-31]. Study with 2.5 Gbit/s HDWDM transmission system based on the quasi-rectangular optical filter technique, illustrated that channel interval be greater than 25 GHz and for the 10Gbit/s HDWDM system not less than 37.5 GHz. Implementation of OADM with DWDM transmission, for the dispersion value of 1.5 ps/nm/km, EDFA power of 4dBm and lower value of attenuation factor illustrated optimum performance over three hundred km transmission reach[32-33].

Lots of study has been performed in past but still some unearthed work has to come in front of swiftly varying communication world and investigations on this approach were always going on to achieve higher spectral efficiency which pertains higher data rates per channel and deployment of high-order modulation formats in the multiplexed links. So in this view novel designed MMDWDM (multiple modulations DWDM) links with every thirty two channel DWDM links were designed with fixed optical modulation and each channel operates at 20Gb/s data rate, to investigate for the selected transmission reach.

2. Theoretical Presentment

For long haul transmission, modulation is the fundamental necessitate of any communication system and previously for the optical links different types of optical modulation schemes were studied to fulfill the rising need for higher data rates and to cut in links cost. Since past decades on off keying (OOK) in either RZ or NRZ were one of the alternatives for physical layer level of optical communication [34]. Advanced optical modulation formats is one of key component to the design of present optical communication networks having special focus on metro, core and access networks. Thus to modulate a signal the component electrical drivers were used which performs the simulations. It converts the logical input signal, a binary sequence of zeros and ones into an electrical signal. Several mapping laws were available, ranging from simple ones, such as NRZ, NRZ raised cosine and RZ rectangular shaped, RZ raised cosine, RZ Super Gaussian and RZ soliton shaped pulses, a brief of each one is presented below.

NRZ Rectangular- With NRZ rectangular driver, an electrical output signal assumes one of the two electrical levels depending upon the transmitted bits. For “0” and “1” fed into the driver, the output signal is at the high level and low level during the entire bit time respectively and switching in between the levels, can be instantaneous for field set(time slope) to zero or else the needed time slope.

NRZ Raised Cosine- Here the NRZ raised cosine driver is simulated and switching between the two levels is not instantaneous but it follows a raised cosine shape with a given roll-off, while driver were joined to a linear optical modulator, can shape either the optical amplitude or the optical power.

Return to Zero (RZ) Rectangular- This component simulates the RZ rectangular driver. It has an output signal that can assume two electrical levels. When a “1” is transmitted, the output signal is at the High Level for a time equal to the product of the duty cycle by the bit time. Then it goes down to the Low Level for the remaining time. When a “0” is transmitted, the output is constant at the low level for the entire bit time. Switching between the two levels is instantaneous...
with resulting square edges. The parameters duty cycle is the ratio between the time at High Level for the first part of the bit, when a “1” is transmitted, and the bit time.

**Return to Zero (RZ) Raised Cosine** - The return to zero raised cosine driver simulates the RZ raised cosine driver the switching between the two levels were not instantaneous. It follows a raised cosine shape with a selected roll-off generates raised cosine waveform. The raised cosine waveform, when the driver is connected to a linear optical modulator, can shape either the optical amplitude or the optical power. Let for a centered pulse peak in which relative time origin in the center of a bit the electrical output when “1” is transmitted it is with expression shown below:

\[ V = (A_h - A_l)f(T) + A_l \]

For raised cosine pulse chosen in power

\[ V = (A_h - A_l)f^2(T) + A_l \]

Now for amplitude chosen raised cosine pulse \( A_h \) is the high level, \( A_l \) is the low level and \( f(t) \) is standard raised cosine function.

\[ f(T) = \left( \frac{1}{2} \right) \left[ 1 - \sin \left( \frac{\pi |T| - T_L}{\alpha T_L} \right) \right] \]

\[ f(T) = \begin{cases} 0, & |T| > \frac{T_L (1 + \alpha)}{2} \\ \frac{1}{2} \left[ 1 - \sin \left( \frac{\pi |T| - T_L}{\alpha T_L} \right) \right], & \frac{T_L (1 - \alpha)}{2} \leq |T| \leq \frac{T_L (1 + \alpha)}{2} \\ 1, & |T| < \frac{T_L (1 - \alpha)}{2} \end{cases} \]

Where \( T = \frac{T_b}{1+\alpha} \) the parameter \( \alpha \) is the roll-off factor and \( T_b \) is the bit time.

**Return to Zero (RZ) Super-Gaussian** - The return to zero (RZ) Super Gaussian driver and for “0” is transmitted the output signal is at the high level and when “1” is transmitted it generates a pulse with Super Gaussian shape during the entire bit time respectively. Now let for a centered pulse peak in which relative time origin in the center of a bit the electrical output when "1" is transmitted it is with expression shown below:

\[ V(t) = (A_h - A_l)e^{-\frac{1}{2} \left( \frac{t - T_0}{T_0} \right)^{2m}} + A_l \]

Where \( m \) is the Super Gaussian order, \( A_l \) and \( A_h \) were the low and high level amplitudes and \( T_0 \) is related to the \( T_{FWHM} \) (full width half maximum time) through this function:

\[ T_0 = \frac{T_{FWHM}}{\sqrt{2m}} \]

**Return to Zero (RZ) Soliton** - It generates a soliton shaped pulse for a “1” is transmitted when employed with return to zero soliton driver and when a “0” is transmitted the output signal is set to the low level for the entire bit time. Now for a peak centered pulse let us assume that a time origin in the center of bit time, then for a transmitted bit “1” the electrical output signal have the expression:
Where $A_l$ and $A_h$ were the low and high level amplitudes and $T_0$ is related to the $T_{\text{FWHM}}$ (full width half maximum time) through this function:

$$T_0 = \frac{T_{\text{FWHM}}}{\ln 3 + 2\sqrt{2}}$$

3. The Simulink Design Presentment

The figure1 shows design of the proposed topology implemented for the simulation and figure 2 shows design used for each single transmitter employed with their respective modulation schemes. Based on these transmitter designs total of six DWDM transmission links have been proposed. Each of the proposed transmission link is having with thirty two channel DWDM optical system, where each channel operated at 20Gb/s. The employed optical modulation of each DWDM link were different such as NRZ rectangular, NRZ raised cosine, RZ rectangular, RZ raised cosine, RZ super Guassian and RZ soliton optical modulations. In each of the DWDM transmission link transmitter consists of CW laser array, data modulators and the optical multiplexer. The used emission frequency range is 193.79 to 195.102THz with the channel to channel frequency spacing of 100GHz, centre frequency were 193.45 THz. After the optical modulation thirty two channels signals were multiplexed and resulting signal is passed through single mode fiber repeater loop along with pre and post amplification, in which semiconductor optical amplifiers were used at 200mA, Amplifier length of 300nm and while active layer width as 2.5nm. Thereafter signal were optically demultiplexed and demuxed optical signal passed through their respective optical filters which were tuned to particular channels frequency (with -3dB frequency is 25 GHz) thereafter passed through PIN diode detector. In this for all MMDWDM links at the receiving end out of thirty two channels only randomly selected five channels operating at frequencies 191.9Thz,192.6Thz,193.4Thz,194.2Thz,195Thz were used for the detection. Resulting detected electrical signal is passed through Bessel electrical filter (with -3dB frequency is 20 GHz) thereafter to a measuring instrument such as eye diagram, BER, Q value, eye opening etc.

![Figure1: General Topology used for DWDM (640Gbps) system](image-url)
4. Results and Discussion

The multiple modulation DWDM optical transmission links each with total transmission capacity of 640Gbps have been designed and their transmission performances were successfully investigated for transmission reach of more than 250 kilometers. In each of the MMDWDM designed system every single channel operates at 20Gbps data rate and individual systems were designed with employed modulation formats as NRZ rectangular, NRZ cosine, RZ-rectangular, RZ super-Gaussian, RZ cosine and RZ-soliton. The transmission performances were examined in terms of quality factor (Q) which represents the signal-to-noise ratio at the receiver decision circuit in voltage or current unit and jitter values which is an estimate of the input signal. Jitter value is estimated as the standard deviation of the position of the maximum of the received signal termed to the bit frame. The simulated results were illustrated for the quality factor transmission reach and jitter vs. transmission reach in the numerous resulting plots. The figure 3 depicts input optical spectrum for respective MMDWDM (32chx20Gbps) systems at transmitting end.

Figure 3: Optical spectrum at input with (32chx20Gbps) MMDWDM (a) soliton (b) NRZ rect (c) NRZ raised cosine (d) RZ raised cosine (e) RZ Super Gaussian (f) RZ rectangular modulation DWDM systems.
Figure 4. Quality factor (Q) vs. transmission distance performance with DWDM nrz-rectangular (640Gbps) modulation system

The simulated results as exhibited in figure 4 for the quality factor (Q) vs. transmission length with NRZ-rectangular (640Gbps) modulation DWDM system. It is noticed that quality factor, which is the performance measuring parameter, is high (Q>6dB) for all of the randomly detected channels but with increase in transmission distance Q factor is diminishing.

Figure 5. Quality factor (Q) vs. transmission distance performance with DWDM NRZ-raisedcosine (640Gbps) modulation system

Figure 5 shows transmission performance for the quality factor (Q) vs. transmission length employing NRZ-raisedcosine (640Gbps) modulation DWDM system, it is noticed that quality factor (Q) ranging from 16 to 23dB. It have achieved highest quality factor value in the range of 23dB for the randomly detected channels with increase in transmission distance.
Figure 6: Quality factor (Q) vs. transmission distance performance with DWDM RZ-rectangular (640Gbps) modulation system.

Figure 6 illustrates results for the quality factor (Q) vs. transmission length employing RZ-rectangular (640Gbps) modulation with DWDM system. It is perceived that quality factor is severely degraded (lowest Q=6dB) the randomly detected channels with increase in transmission distance.

Figure 7: Quality factor (Q) vs. transmission distance performance with DWDM RZ-raised cosine (640Gbps) modulation system.

The simulation result as shown in figure 7 for the quality factor (Q) vs. transmission length employing RZ-raised cosine (640Gbps) modulation DWDM system. It is noticed that overall quality factor is satisfactory (12 to 22dB) for all of the randomly detected channels with increase in transmission distance.
Figure 8: Quality factor (Q) vs. transmission distance performance with DWDM RZsoliton (640 Gbps) modulation system

The results as shown in figure 8 for quality factor (Q) vs. transmission length employing RZsoliton (640 Gbps) modulation DWDM system, it is noticed that quality factor is high and satisfactory ranging from 13 to 18 dB for all of the randomly detected channels with increase in transmission distance. Thus high quality factor has been achieved with soliton pulse modulation system so transmission performance is excellent.

Figure 9: Quality factor (Q) vs. transmission distance performance with DWDM RZSuperGuassian (640 Gbps) modulation system

Figure 9 illustrates the simulated results for the quality factor (Q) vs. transmission length with RZSuperguassian (640 Gbps) modulation DWDM system. It is observed that quality factor is good ranging from 14 to 26 dB, achieved for all of the randomly detected channels with increase in transmission distance its performance is very much satisfactory.
Figure 10: Jitter vs. transmission distance performance of DWDM RZSuperGuassian (640Gbps) modulation

Figure 11: Jitter vs. transmission distance performance of DWDM RZ-soliton (640Gbps) modulation

Figure 12: Jitter vs. transmission distance performance of DWDM RZraisedcosine (640Gbps) modulation

Figure 13: Jitter vs. transmission distance performance of DWDM RZraisedCosine (640Gbps) modulation
The simulated results were exhibited for the jitter vs. transmission length in the figure10 to figure13 with numerous DWDM (640Gbps) links with different return to zero (RZ) modulation schemes. It is noticed that jitter is growing for all the channels with increase in transmission distance for all the received channels.

**Figure14: Jitter vs. transmission distance performance of DWDM with NRZ-rectangular (640Gbps) modulation system**

![Figure14](image1)

**Figure15: Jitter vs. transmission distance performance of DWDM with NRZ-raised cosine (640Gbps) modulation system**

![Figure15](image2)

Results as shown in figure14 and figure15 for jitter vs. transmission length with DWDM (640Gbps) with non return to zero modulation schemes it is noticed that jitter is constant for all the channels but few received channels show a high jitter value with increase in transmission distance.
For good optical transmission performance quality factor (Q) must be higher and bit error rate must be low, for satisfactory transmission performance of an optical transmission link it requires Q > 6dB for the BER of 10^{-9}. This BER provide an upper limit for the signal because some degradation arises on the receiving end. From the comprehensive performance analysis of MMDWDM transmission links, it is noticed that MMDWDM link with NRZ raised cosine pattern has shown better transmission performance in terms of quality factor, bit error rate (figure16) which were in the range of 10^{-11} to 10^{-40} for all received channels at selected transmission reach of 260 kilometers, followed by other schemes as Rz superguassian and RZSoliton transmission links. While for the same transmission reach (260km) RZrectangular scheme has shown poor transmission performance as compared to other schemes employed. An additional optical transmission parameter of observation is jitter, on observing jitter performance of various transmission links it is noticed that jitter show low impact on DWDM systems with NRZ type of modulations but it is more dominant for the DWDM transmission links with RZ format.

5. Conclusion

The article illustrates comprehensive performance study of the multiple modulation DWDM systems each with aggregate capacity of 640Gbps. The systems were employed with different type of modulation schemes such as NRZrectangular, NRZraisedcosine, RZ-rectangular, RZ Super Guassian, RZ cosine and RZ soliton schemes and each system were investigated on the basis of optical transmission parameters such as quality factor, jitter and bit error rate. After successful transmission the performance were compared for the fixed transmission reach of 260 kilometers, it exhibited that DWDM link with non return to zero raised cosine scheme has shown better transmission performance followed by Rz superguassian and RZ Soliton in contrast to other schemes employed. Comparing jitter performance for all transmission links, it is observed that jitter effect is more dominant for the DWDM systems with RZ type formats in contrast DWDM transmission links using NRZ format. Consequently from the study it can be inferred that a novel advanced optical modulation scheme is always must to compete with swiftly changing spectrum need, highly efficient system were to design and for that NRZ-Raised cosine (leading scheme), RZ superguassian and RZ Soliton pattern are the other frontier schemes, will be an aid to design of the advanced optical communication systems.
Acknowledgement

Thanks to J.K.Institute Allahabad (University of Allahabad) for providing the software OptSim(R-Soft) optical communication system.

REFERENCES


Authors:

D. K. Tripathi received his BSc from A.U and B. Tech and M. Tech degree in Electronics and Telecommunication engineering from the Department of Electronic & Communication, University of Allahabad. Presently he is pursuing his Ph.D. degree in Electronics Engineering. His area of interest includes Wireless communication technology and fiber optics communication. He is life member of ISTE.

Pallavi Singh received B.Tech and M.Tech degrees in electronics and Telecommunication engineering from Department of Electronics & Communication University of Allahabad, in 1999 and 2002, respectively, where she is currently pursuing her Ph.D. degree in electronic engineering. Her current research interests include wavelength converter and all-optical logic gates using SOA-based Mach-Zehnder interferometer.

Dr N.K. Shukla is associate Professor in J.K.Institute of Applied Physics and Technology, University of Allahabad (India). He started teaching in the department as lecturer, having teaching experience of more than 18 Years. His main research area is fiber optics communication and Holography. He has supervised many PhD candidates. He has published a lot of papers in National, International journals and in National and International conferences. He is a member of many academic bodies of other University and institution, and life member and fellow in organizations like ISTE, IETE etc.

Prof. (Dr) H.K. Dixit is former head of department of J.K. Institute of Applied Physics and Technology, University of Allahabad (India). He started teaching in the department as lecturer in March 1975 and teaching experience of more than 38 Years. His main research area is fiber optics communication and Holography. He has supervised a number of PhD candidates. He has published a lot of papers in National, International journals and in National and International conferences. He is a member of a number of RDC, and academic bodies of other University and Institution, and life member and fellow in organizations like ISTE, IETE etc.