

## Research on Mixed Data Rate and Format Transmission in WDM Networks

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### Abstrak

Untuk memenuhi permintaan lalu lintas data yang terus tumbuh di aplikasi telekomunikasi, jumlah panjang gelombang jaringan serat optis tulang punggung jaringan telekomunikasi dinaikkan. Pertumbuhan layanan internet yang eksponensial, kapasitas transmisi menjadi tantangan luar biasa bagi jaringan. Sekarang, system transmisi 10 Gb/s digunakan dalam aplikasi komersial. Dalam waktu yang sama, efek nonlinear seperti FWM, SRS, XPM, SPM dan dispersi juga meningkat saat jumlah panjang gelombang yang melewati system transmisi bertambah. Untuk analisis format modulasi efisien bagi DWDM dan system transmisi long-haul, kita akan memakai beraneka modulasi sistem DWDM. Kecepatan data maksimal format modulasi NRZ-OOK adalah 10gb/s, sedangkan untuk RZ-OOK adalah sebesar 50 Gb/s. Karena modulasi Z-OOK menggunakan lebar pita dua kali bila dibandingkan dengan modulasi NRZ-OOK. Format modulasi sebagai dinaiktarafan dari OOK menjadi PSK, pengaruh sinyal OOK terhadap sinyal PSL hasil penaiktarafan harus ikut dipertimbangkan apabila menggunakan konversi panjang gelombang multikanal. Modulasi PSK juga ikut dianalisa.

**Kata kunci:** komunikasi serat optis, DWDM, NRZ-OOK, spektrum, nonlinearitas

### Abstract

To meet the growing data traffic demands in the telecommunication applications, the number of wavelengths is to be increased in a fiber-optic backbone of the telecommunication network. The exponential growth of internet services, transmission capacity is a tremendous challenge to networks. Nowadays, 10 Gb/s transmission systems are being used for commercial applications. At the same time, the non-linear effects such as FWM, SRS, XPM, SPM, and Dispersion are also increased, when the number of wavelengths passing through the single fiber is increased. The analysis of efficient modulation formats for DWDM system and long-haul transmission system, we go for various modulations for DWDM system. The maximum data rate for NRZ-OOK modulation format is 10 Gb/s. For RZ-OOK the maximum rate is 50 Gb/s. Since RZ-OOK modulation uses twice the band width when compared to NRZ-OOK modulation. The modulation format is partially upgraded from OOK to PSK, the influence of OOK signals on the updated PSK signals must be considered when using multi-channel wavelength conversion. The PSK modulation is also analyzed.

**Keywords:** optical fiber communication, DWDM, NRZ-OOK, RZ-OOK, spectrum, nonlinearities

### 1. Introduction

Communication system transmits information from one place to another, whether separated by a few kilometers or by transoceanic distances. Information is often carried by an electromagnetic carrier wave whose frequency can vary from a few Megahertz to several hundred Terahertz. Optical communication systems use high carrier frequencies (100THz) in the visible or near-infrared region of the electromagnetic spectrum. Fiber optic communication systems are a light wave system that employs optical fiber for information transmission since 1980 [1]. Before nineteenth century, all communication systems were operated at a very low information rate and involved only optical or acoustic means such as signal lamp or horns. In the ensuing years, an increasing large proportion of the electromagnetic message from one place to another.

In contrast to electrical communication, transmission of information in an optical format is not only carried out by frequency modulation of the carrier, but also by the variation of

intensity of the optical carrier [2]. After the viability of transmitting light over fiber had been established, the next step in the development of fiber optics was to find a light source that would be sufficiently powerful and monochromatic narrow. The light-emitting diode (LED) and the laser diode proved capable of meeting these requirements [3].

Lasers went through several generations since its invention in the 1960s, culminating with the semiconductor lasers that are most widely used in fiber optics today. Light frequencies are of the order of  $10^{14}$  Hz.

The first generation of light wave systems operated near 0.8 (micrometer) and used GaAs semiconductor laser. They are operated at a bit rate of 45 Mb/s and allowed repeater spacing of up to 10 km. The repeater spacing of the second-generation light wave systems was limited by the fiber losses at the operating wavelength of 1.3  $\mu$ m (typically 0.5 dB/km). Losses of silica fibers become minimum near 1.55 $\mu$ m. The dispersion problem can be overcome either by using dispersion-shifted fibers designed to have minimum dispersion near 1.55 micrometer or by limiting the laser spectrum to a single longitudinal mode [4]. The third generation repeaters spacing can be increased by making use of a homodyne or heterodyne detection scheme because its use improves receiver sensitivity. The fourth generation of light wave systems makes use of optical amplification for increasing the repeater spacing and of Wavelength-Division Multiplexing (WDM) for increasing the bit rate. The WDM technique started a revolution in doubling the system capacity every 6 months and led to light wave systems operating at a bit rate of 10 Tb/s by 2001. In most WDM systems, fiber losses are compensated periodically using erbium-doped fiber amplifiers spaced 60-80 km apart. The current emphasis of WDM light wave systems is on increasing the system capacity by transmitting more and more channels through the WDM technique.

For a long time, non-return-to-zero (NRZ) has been the dominant modulation format in intensity modulation direct detection (IMDD) fiber optical communication systems. The major reasons for using NRZ in the early days of fiber optical communication were a relatively low electrical bandwidth for the transmitters and receivers compared to return-to-zero (RZ) [5]. In general, NRZ modulated optical signal has the most compact spectrum compared to that with other modulation formats. However, this does not mean that NRZ optical signal has superior resistance to residual chromatic dispersion in an amplified fiber system. In addition, NRZ modulated optical signal has been found to be less resistive to fiber nonlinearities [6].

RZ modulation has become a popular solution for 10Gbit/s systems because it has a higher peak power, a higher signal-to-noise ratio (SNR), and lower bit error rate (BER) than NRZ encoding. Despite these advantages, conventional RZ signal is not well suited for the use in dense wavelength division multiplexing (DWDM) systems due to its broad spectral width [7].

By encoding multiple bits per symbol, non-binary modulation techniques can accomplish significant spectral efficiency. Spectral narrowing alone can also reduce the effect of chromatic dispersion. Encoding multiple bits per symbol also gives rise to longer symbol duration that can in turn increase robustness to fiber propagation impairments. Duobinary (Duo) is a three level code which substantially reduces the bandwidth occupancy of a signal compared to coding with NRZ or RZ [8].

Mixed WDM systems have several problems to be overcome. These problems include wavelength dispersion, dispersion slope, polarization-mode dispersion, and nonlinear effects of the transmission line. Other critical issues are the linear and nonlinear crosstalk from adjacent channels and the cost increase of the mixed WDM signal control. Therefore, the complete understanding of multiform signals mixed transmission is compulsory for future WDM networks.

## 2. Measurement Technique and System Model

Our research is based on the evaluation such system parameter as the bit error rate (BER) using powerful techniques which are incorporated in OptSim 4.7 simulation software. In the present work, we show spectrum and eye diagrams for various simulation setups, since they are a fast way how to approximately evaluate a system performance; respectively, an eye has to be opened wide enough and spectrum diagrams should be regular without negative multipeak structure for good system performance. An eye diagram shows the patterns of the electrical signal after detection. The eye height is an indicator of noise, whereas the signal width at the centre of an eye diagram represents a measure of

timing jitter. The use of simulation software allows for preliminary results, though precise enough to be considered as true [9-11].

The accepted method of calculation is based on the solving a complex set of differential equations, taking into account optical and electrical noise as well as linear and nonlinear effects. We used model where signals are propagating as time domain samples over a selectable bandwidth (in our case, a bandwidth that contains all channels). The Time Domain Split Step (TDSS) method was employed to simulate linear and nonlinear behaviour for both optical and electrical components. The Split Step method is used in all commercial simulation tools to perform the integration of the fiber propagation equation (1):

$$\frac{\partial A(t, z)}{\partial z} = \{L + N\}A(t, z) \quad (1)$$

Here  $A(t, z)$  is the optical field,  $L$  is the linear operator that stands for dispersion and other linear effects, and  $N$  is the operator that is responsible for all nonlinear effects. The idea is to calculate the equation over small spans of fiber  $\Delta z$  by including either a linear or a nonlinear operator. For instance, on the first span  $\Delta z$  only linear effects are considered, on the second-only nonlinear, on the third-again only linear ones, and so on. Two ways of calculation are possible: Frequency Domain Split Step (FDSS) and the above mentioned Time Domain Split Step (TDSS) methods. These methods differ in how linear operator  $L$  is calculated: FDSS does it in a frequency domain, whereas TDSS - in the time domain by calculating the convolution product in sampled time. The first method is easy to fulfill, but it may produce severe errors during computation. In our simulation we have employed the second method, TDSS, which, despite its complexity, ensures an effective and time - efficient solution.

### 2.1. NRZ-On- Off Keying (NRZ-OOK) Modulation

In the case of ASK (Intensity Modulation) format, the amplitude 'As' is modulated while keeping ' $\omega_0$ ' and ' $\varphi_s$ ' constant. For binary digital modulation, 'As' takes one of the two fixed values during each bit period, depending on whether '1' or '0' bit is being transmitted. The ASK format is then also called as on-off keying (OOK) and is identical with the modulation scheme commonly used for non-coherent (IM/DD) digital light wave systems [12]. The electric field associated with an optical signal can be written as (2).

$$E_s(t) = A_s(t) \cos[\omega_0 t + \varphi_s(t)] \quad (2)$$

where,

$A_s$  is amplitude,  $\omega_0$  carrier frequency,  $\varphi_s$  is phase

The implementation of ASK for coherent systems differs from the case of the direct-detection systems. The optical bit stream for direct-detection systems can be generated by modulating a light-emitting diode (LED) or a semiconductor laser directly, external modulation is necessary for coherent communication systems. The amplitude 'As' is changed by modulating the current applied to a semiconductor laser. The situation is entirely different in the case of For the coherent systems, the phase detector response depends upon the phase of the received signal. The implementation of ASK format for coherent systems requires the phase ' $\varphi_s$ ' to remain nearly constant. All external modulators have some insertion losses, a power penalty occurs whenever an external modulator is used; it can be reduced to below 1 dB for monolithically integrated modulators [13].



The transmitter block consists of 3 multiplexed channels, each of them consisting of a data source, a driver, a laser and external modulator. The data source produces a bit stream that presents the information to be transmitted via fiber optical link. Then we need a driver, which forms different code pulses from incoming bits. The pulses are then modulated with continuous wave (CW) laser radiation to obtain optical pulses.

Reference wavelength  $\lambda = 1550$  nm. At the fiber end the channels are demultiplexed, so that each channel could be analyzed separately. After that, each channel is optically filtered, converted to electrical one and then electrically filtered. To evaluate the system performance several measurements have been taken. We were interesting in observing the optical spectrum at the beginning and at the end of optical link, as well as eye diagrams and BERs quantity.

The idea is to compare the different mixed WDM system performance when using distinctive modulation formats simultaneously.

### 3. Results and Discussions

The aim of this section is to verify systems simulation with the integrated OptSim package and to numerically evaluate and compare the performance of mixed-NRZ, RZ and Duo-modulation formats in WDM systems with typical system parameters.

The eye pattern is a powerful, yet simple time- domain tool for assessing the data capability of an optical digital transmission system. The eye pattern measurements are made in the time domain and in real time showing the effects of waveform distortions immediately on an oscilloscope. Much system performance information can be deduced from the eye-pattern display. Information regarding the signal amplitude distortion, timing jitter and system rise time can be derived simply by observing certain features of the pattern. The eye-pattern obtained during simulations will be analyzed to obtain and to compare various system performance characteristics.

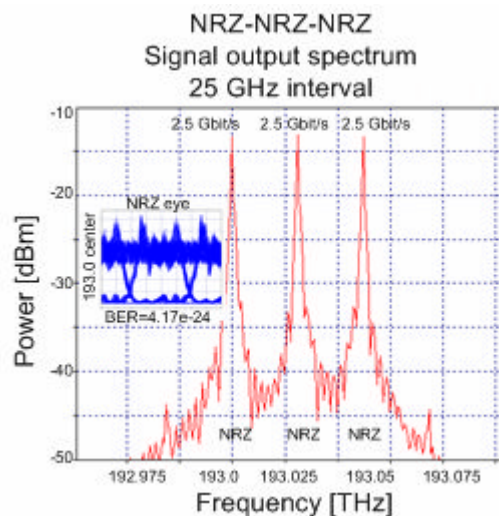


Figure 3. NRZ-NRZ-NRZ output optical signal spectrum and output eye pattern of a 3-channel WDM system, after 80 km of SSMF

Figure 3 depicts output optical signal spectrum and electrical signal eye pattern for NRZ format 2.5 Gb/s WDM system where 25 GHz channel interval is presented. That solution indicates that for 50 GHz ITU-T standard channel spacing can be two times reduced and the BER value still sufficient for good system performance. For 10 Gb/s WDM system 25 GHz channel interval is not suitable mainly of signal distortion. Figure 4 shows an optimal channel spacing for 10 Gb/s NRZ format WDM system.

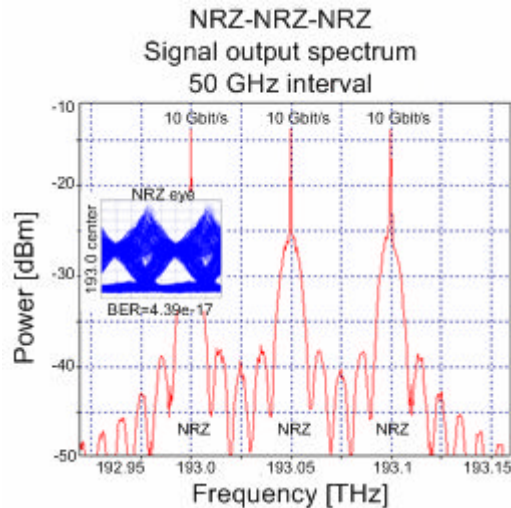


Figure 4. NRZ-NRZ-NRZ output optical signal spectrum and output electrical eye pattern of a 3-channel WDM system, after 80 km of SSMF

For the next generation WDM systems the mixed signal formats transmission will be necessary. Figure 5 presents output optical signal spectrum and electrical signal eye patterns for NRZ-RZ-NRZ mixed formats.

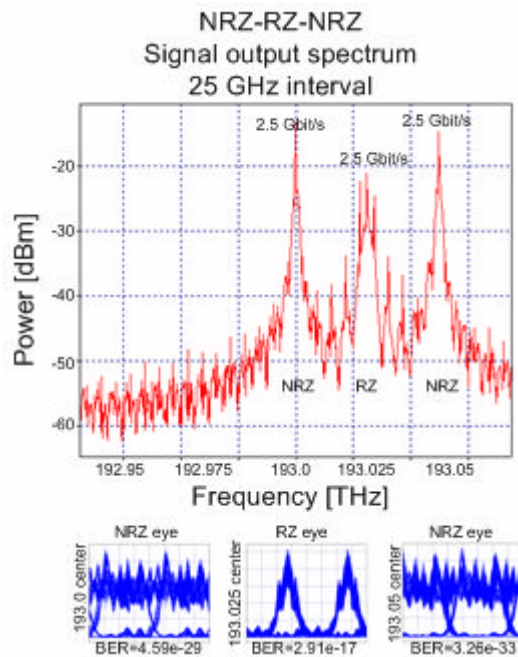


Figure 5. NRZ-RZ-NRZ output optical signal spectrum and output electrical eye patterns of a 3 channel mixed WDM system, after 80 km of SSMF

This example shows that optimal channel spacing for mixed NRZ-RZ-NRZ 2.5 Gb/s systems should be more than 25 GHz. For mixed data rates in the same system an optimal channel interval should be more than 50 GHz, and only in that case the maximum transmission distance stay unchanged Figure 6.

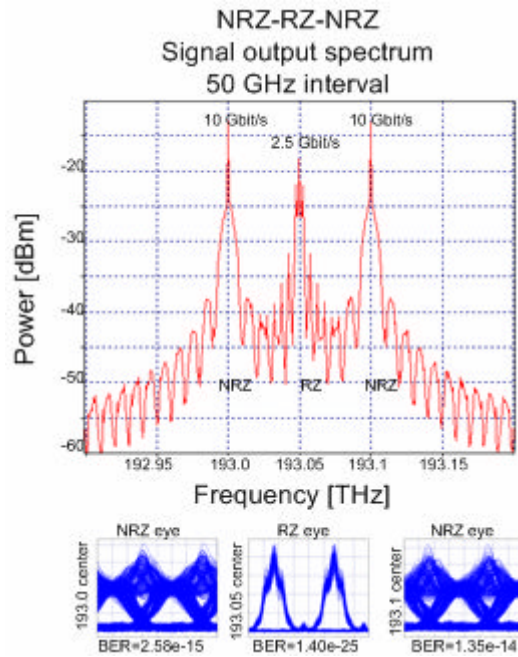


Figure 6. NRZ-RZ-NRZ output optical signal spectrum and output electrical eye patterns of a 3-channel mixed WDM system, after 80 km of SSMF

Figure 7 depicts output optical signal spectrum and electrical signal eye patterns for NRZ-Duo-NRZ mixed formats where the most perspective Duobinary modulation format is presented.

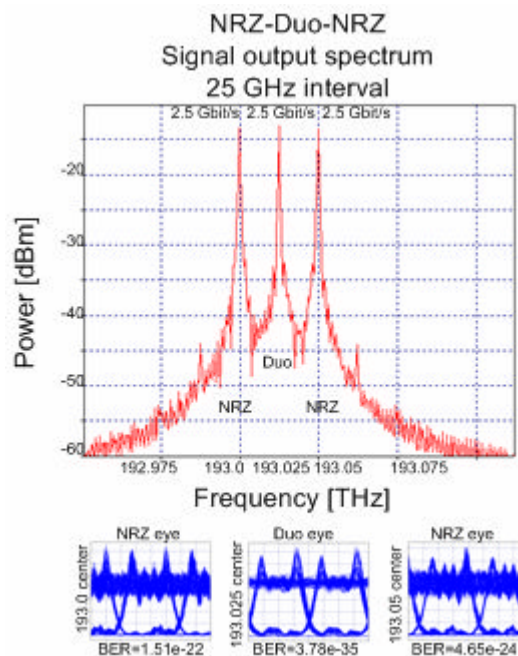


Figure 7. NRZ-Duo-NRZ output optical signal spectrum and output electrical eye patterns of a 3-channel mixed WDM system, after 80 km of SSMF



Non-binary modulation technique can perform significant spectral efficiency. In our case NRZ-Duo-NRZ mixed transmission shows great signals quality on output and to increase the bit rate of each channel up to 10 Gb/s system characteristics remains settled Figure 8.

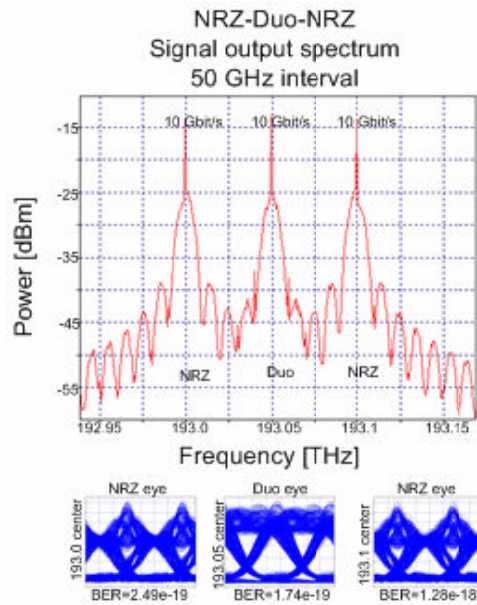


Figure 8. NRZ-Duo-NRZ output optical signal spectrum and output electrical eye patterns of a 3-channel mixed WDM system, after 80 km of SSMF

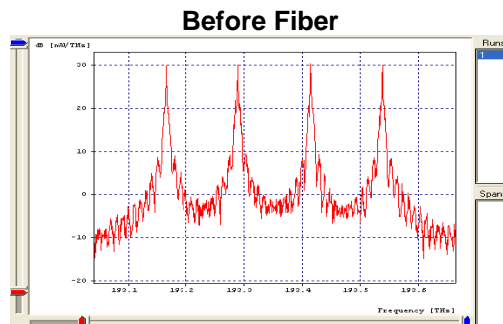


Figure 9. OSA Multiplexer Output with Bit rate of (10 Gb/s)

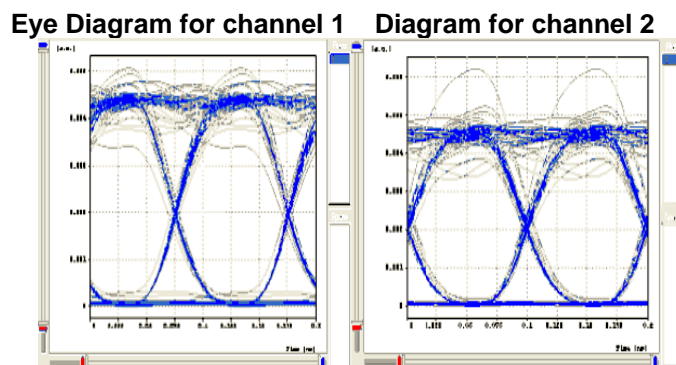


Figure 10. Rx\_end Eye Diagram with bit rate of (10 Gb/s)



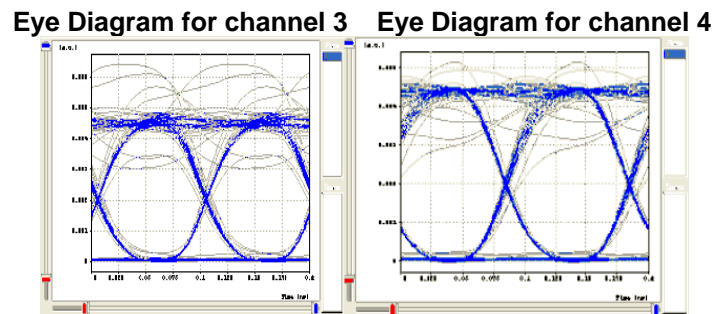


Figure 11. Rx\_end Eye Diagram with Bit rate of (10 Gb/s)

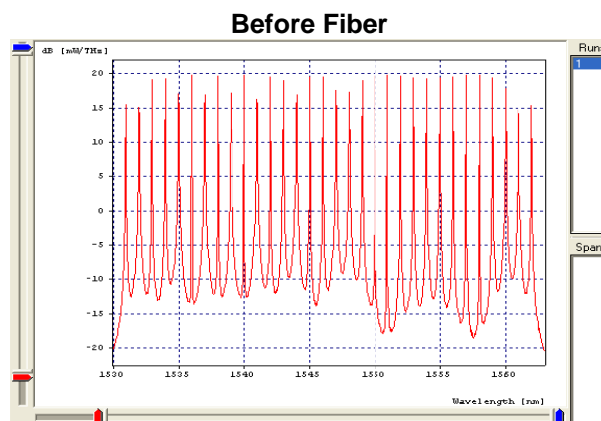


Figure 12. OSA output with Bit rate of (10 Gb/s)

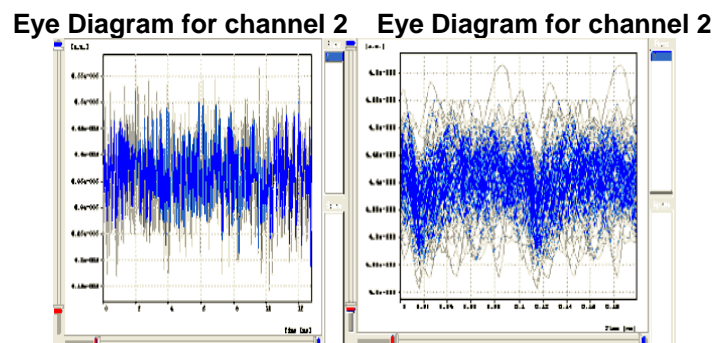


Figure 13. Rx\_end Eye Diagram with Bit rate of (100 Gb/s)

From Figure 8 to 13, it is noted that when data rate is high then the output spectrum after the fiber will be corrupted by the factor of SBS "ON" condition and SRS "ON" condition and Raman effect will "ON" condition. Then the Eye diagram at the Transmitting end and Receiving end can be shown in the Figure 9 and Figure 10. The eye diagram at the Transmitting end will have clear Eye opening and the Receiving end the Eye diagram will be corrupted when high data rate is encountered into the fiber. When Eye opening is clear it refers to low Bit Error Rate. Multiplexer output with four wave length will be shown in the Figure 8. In De-multiplexer output the individual wavelength can be shown in the Figure 12 and Figure 13.

#### 4. Conclusion

In this report we have investigated the performance of mixed 2.5 Gb/s and 10 Gb/s optical systems with simultaneous propagation of various modulation formats. For mixed WDM systems with 25 GHz channel spacing, nonlinear crosstalk originated from cross phase modulation and four-wave mixing is the major source of system performance degradation.

Dispersion limited distances for conventional NRZ external modulated systems at 10 Gb/s is about 80 km, for the mixed 10 Gb/s NRZ-RZ-NRZ system these distances is two times shorter. Traditional 10 Gb/s NRZ and 10 Gb/s mixed NRZ- Duo-NRZ WDM systems have similar transmission properties and equally efficient for 80 km, and efficient channel interval should be more than 50 GHz. Compared together all investigated modulation formats, it can be seen that all of them can be used for future mixed traffic transmission in WDM networks.

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