CHAPTER 1
INTRODUCTION

1.1 Introduction

The search for a good signal -to- noise ratio (SNR) estimation technique is motivated by the fact that various algorithms require knowledge of the SNR for optimal performance if the SNR is not constant. The performance of diverse systems may be improved if knowledge of the SNR is available .Past engineering practice has often used estimation of the total signal plus noise power instead of estimation of the SNR, since it is much easier to measure total power than the ratio of signal power to noise power. However, decreasing hardware costs and increasing demands for pushing system performance to the achievable limits make an investigation of SNR estimation techniques timely.

There are several methods of optical signal to noise ratio estimation. One of the common method is second and fourth order moment calculation method. In this research, we attempt to improve the current method for higher order QAM. Practical investigation shows that second and fourth order method is appropriate for lower order QAM for the purpose of OSNR monitoring. But for higher order QAM when the SNR is varying to a higher value it cannot estimate it properly. To solve this problem an attempt is taken in this literature.

The estimation result of second and fourth order method shows good result for QPSK and 4-QAM. Instead of taking all the signals from the constellation diagram, only taking certain number of signal from the constellation diagram of 16-QAM, 32-QAM, 64-QAM, 128-QAM and 256-QAM, we can solve the problem.

The estimator under consideration derive the SNR from the baseband, sampled, data-bearing received signal. The data may be known or unknown to the receiver. Those technique which derive the SNR estimates solely from the unknown, information-bearing portion of the received signal are known as “in-service” SNR estimators and are of particular interest since they do not impinge upon the through out of the channel.

1.2 Related Works

In this section our aim is to take an over view of the different literature abstract in this field.

A quite number of OSNR monitoring technique is developed for satisfactory OSNR monitoring. A deep neural networks (DNN) based OSNR monitoring technique is developed by Takahitu Tanimura and Jens Munseen.

They demonstrate a use of deep neural networks (DNN) for OSNR monitoring with minimum prior knowledge. By using 5-layers DNN trained with 400,000 samples, the DNN successfully estimates OSNR in a 16-GB DP-QPSK system.

The study is performed using principal component analysis-based pattern recognition on asynchronous delay-tap plots and it yields accurate results in the simultaneous monitoring of linear impairments. Another recent work facing the limited scalability, which are based on the prior knowledge of a determined set of signals, where a deep neural network (DNN), trained with raw data asynchronously sampled by a coherent receiver is proposed for OSNR monitoring. Results show that OSNR is accurately estimated.

Md. Saifuddin Faruk,Yojiro Mori and Kazuro Kikuchi proposed a novel method of in –band estimation of optical signal-to-noise ratio (OSNR) using a digital coherent receiver, where OSNR is determined from second and fourth order statistical moments of equalized signals in any modulation format. Their proposed method is especially important in recently-developed Nyquist wavelength-division multiplexed (WDM) systems and / or reconfigurable optical-add/ drop-multiplexed (ROADM) networks, because in these systems and networks, we cannot apply the conventional OSNR estimation methods best on optical-spectrum measurement of the in band signal and the out of band noise .Effectiveness of the proposed method is validated with computer simulations of nyquist-WDM systems and ROADM networks using 25-Gbaud quadrature phase shift keying (QPSK) and 16-QAM formats.

The performance of several signal-to-noise ratio (SNR) estimation techniques reported in a literature by David R. Pauluzzi and Norman C. Beaulieu, are compared to identify the “best” estimator. The SNR estimators are investigated by the computer simulation of baseband signals in real additive white Gaussian noise (AWGN) and baseband 8-PSK signals in complex AWGN. The mean square error is used as a measure of performance. In addition to comparing the relative performances, the absolute levels of performance are also established; the simulation performances are compared to a published Cramer-Rao bound (CRB) for real AWGN and a CRB for complex AWGN that is derived there. Some known estimator structures are modified to perform better on the channel of interest. Estimator structures for both real and complex channels are examined.

As optical fiber communication has become very popular nowadays, OSNR monitoring has become a must at the receiver side. A vast scope of development is available in this field.

1.3 Objectives

a) To investigate the performance of conventional second and fourth order moment method.
b) To develop an algorithm to improve the performance of conventional second and fourth order method.

CHAPTER 2

BACKGROUND THEORY

2.1 Introduction

The optical fiber communication is the communication in which signal is transmitted or received through the fiber where the communicating frequency are converted into light in optical form by optical source i.e. LED, LASER with the velocity of light propagates through the fiber.

2.2 Historical background of optical fiber communication

1880- Alexander Graham Bell repeated the x-on of Speech using a Light beam.

1954- Harold Hopkins and Narinder Singh Kapany showed that rolled fiber glass allowed light to be transmitted. Initially it was considered that the light can traverse in only straight medium.

1960- With inventor of the study LASER an intense coherent light source operating at just one wave length mode available by T.H. Maimon.

1963- B. Urdles of several hundred glass fibers were used for small scale illumination. The attenuation of this fiber is greater than 100dB/km.

So their use as X-on medium for optical communication was not considered.

1966- C.K.Kad & Hockman postulated the use of glass fibers as optical communication wave guides. The cause of high attenuation is intrinsic & extrinsic loss. The glass fiber attenuation had to be reduced in less 20 dB/km.

1970-works at the coring glass works produced a fiber with the required attenuation. After improves attenuation. Now the attenuation is 0.1 dB/km.

2.3 Basic block diagram of optical fiber

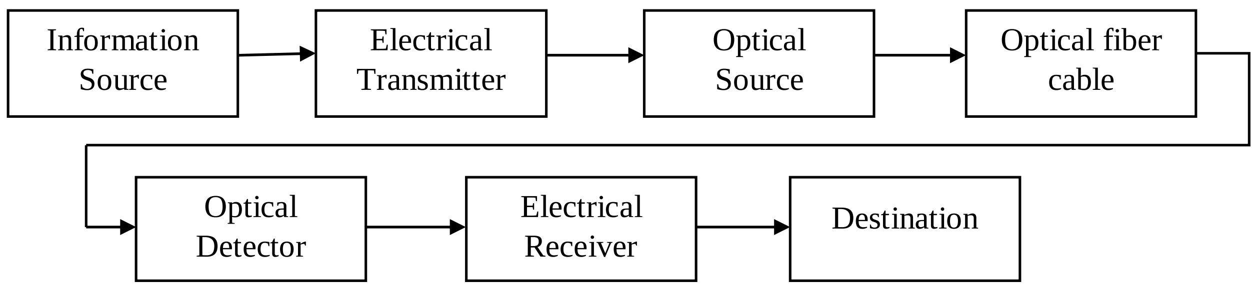


Fig.2.1. Basic block diagram of optical fiber communication.

Fig.2.1 shows basic block diagram of optical fiber communication. In this case the information source provides an electrical signal to a transmitter comprising an electrical stage which drives an optical source to give modulation of the light wave carrier. The optical source which provides the electrical–optical conversion may be either a semiconductor laser or light-emitting diode (LED). The transmission medium consists of an optical fiber cable and the receiver consists of an optical detector which drives a further electrical stage and hence provides demodulation of the optical carrier. Photodiodes (p–n, p–i–n or avalanche) and, in some instances, phototransistors and photoconductors are utilized for the detection of the optical signal and the optical–electrical conversion. Thus there is a requirement for electrical interfacing at either end of the optical link and at present the signal processing is usually performed electrically. The optical carrier may be modulated using either an analog or digital information signal. In the system shown in Figure 2.1 analog modulation involves the variation of the light emitted from the optical source in a continuous manner. With digital modulation, however, discrete changes in the light intensity are obtained (i.e. on–off pulses). Although often simpler to implement, analog modulation with an optical fiber communication system is less efficient, requiring a far higher signal-to-noise ratio at the receiver than digital modulation. Also, the linearity needed for analog modulation is not always provided by semiconductor optical sources, especially at high modulation frequencies. For these reasons, analog optical fiber communication links are generally limited to shorter distances and lower bandwidth operation than digital links.

2.4 Advantage of optical fiber communication

(a) Enormous potential bandwidth
(b) Small size and weight
(c) Electrical isolation
(d) Immunity to interference and crosstalk
(e) Signal security
(f) Low transmission loss
(g) Ruggedness and flexibility
(h) System reliability and ease of maintenance
(i) Potential low cost

2.5 Construction of optical fiber

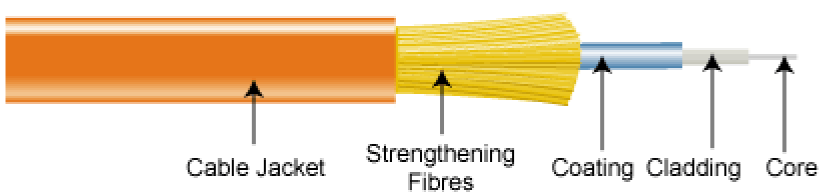


Fig.2.2 Basic construction of optical fiber

Core

This is the physical medium that transports optical data signals from an attached light source to a receiving device. The core is a single continuous strand of glass or plastic that's measured in microns (µ) by the size of its outer diameter. The larger the core, the more light the cable can carry.

All fiber optic cable is sized according to its core's outer diameter. The three multimode sizes most commonly available are 50, 62.5, and 100 microns. Single-mode cores are generally less than 9 microns.

Cladding

This is the thin layer that surrounds the fibre core and serves as a boundary that contains the light waves and causes the refraction, enabling data to travel throughout the length of the fibre segment.

Coating

This is a layer of plastic that surrounds the core and cladding to reinforce and protect the fibre core. Coatings are measured in microns and can range from 250 to 900 microns.

Strengthening fiber

These components help protect the core against crushing forces and excessive tension during installation. The materials can range from Kevlar® to wire strands to gel-filled sleeves.

Cable jacket

This is the outer layer of any cable. Most fibre optic cables have an orange jacket, although some types can have black or yellow jackets.

2.6 Ray Transmission Theory

The propagation of light within an optical fiber utilizing the ray theory model it is necessary to take account of the refractive index of the dielectric medium. The refractive index of a medium is defined as the ratio of the velocity of light in a vacuum to the velocity of light in the medium. A ray of light travels more slowly in an optically dense medium than in one that is less dense, and the refractive index gives a measure of this effect. When a ray is incident on the interface between two dielectrics of differing refractive indices. It may be observed that the ray approaching the interface is propagating in a dielectric of refractive index n1 and is at an angle φ 1 to the normal at the surface of the interface. If the dielectric on the other side of the interface has a refractive index n2 which is less than n1, then the refraction is such that the ray path in this lower index medium is at an angle φ 2 to the normal, where φ 2 is greater than φ 1. The angles of incidence φ 1 and refraction φ 2 are related to each other and to the refractive indices of the dielectrics by Snell's law of refraction which states that**:**

$n_1 \sin \varphi_1 = n_2 \sin \varphi_2$

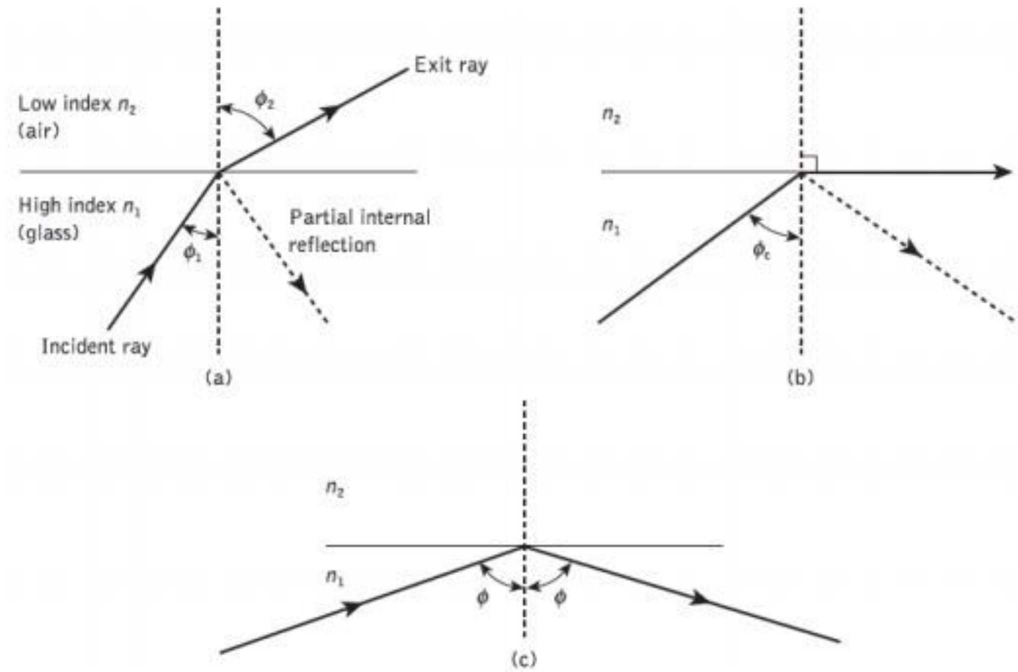


Fig.2.3 Light ray incident on a high to low refractive index interface (e.g glass air): (a) refraction; (b) the limiting case of refraction showing the critical ray at and angle Φ_c (c) total internal reflection where $\Phi > \Phi_c$.

2.7 Some Important Terms in Optical Fiber Communication

2.7.1 Acceptance Angle

The maximum angle to the axis at which light may enter the fiber in order to be propagated is called acceptance angle.

Any rays which are incident into the fiber core at an angle greater than Φa will be transmitted to core-cladding interface at an angle less than Φ_c,and will be totally internally reflected.

In fig. the incident ray B at an angle then Φ_a is refracted into the cladding & loss by radiation

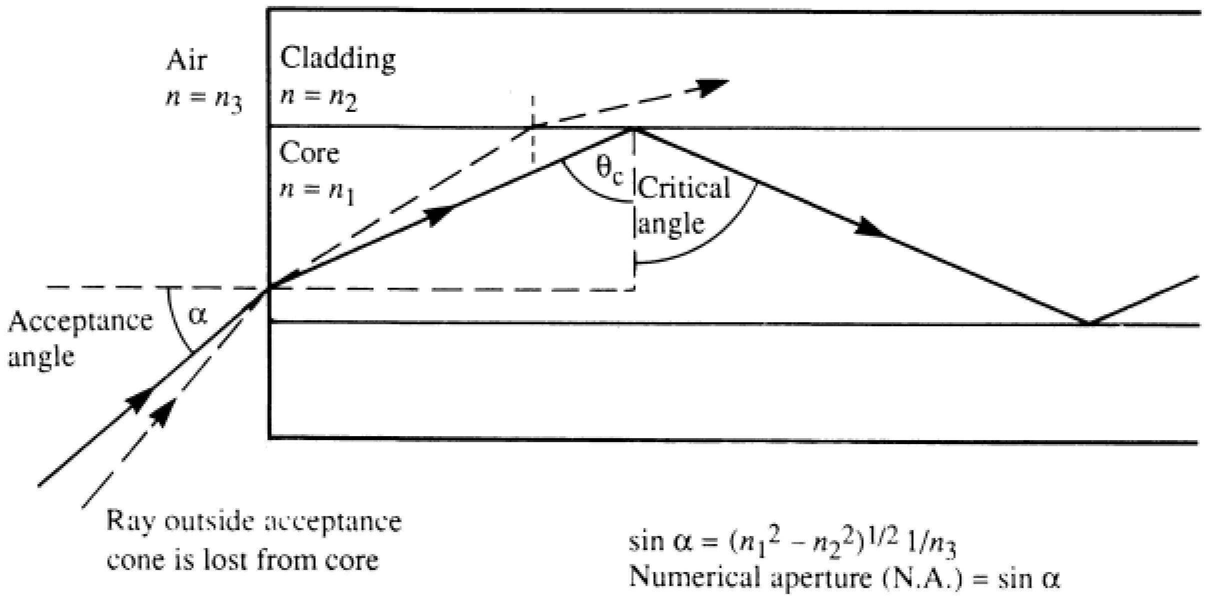


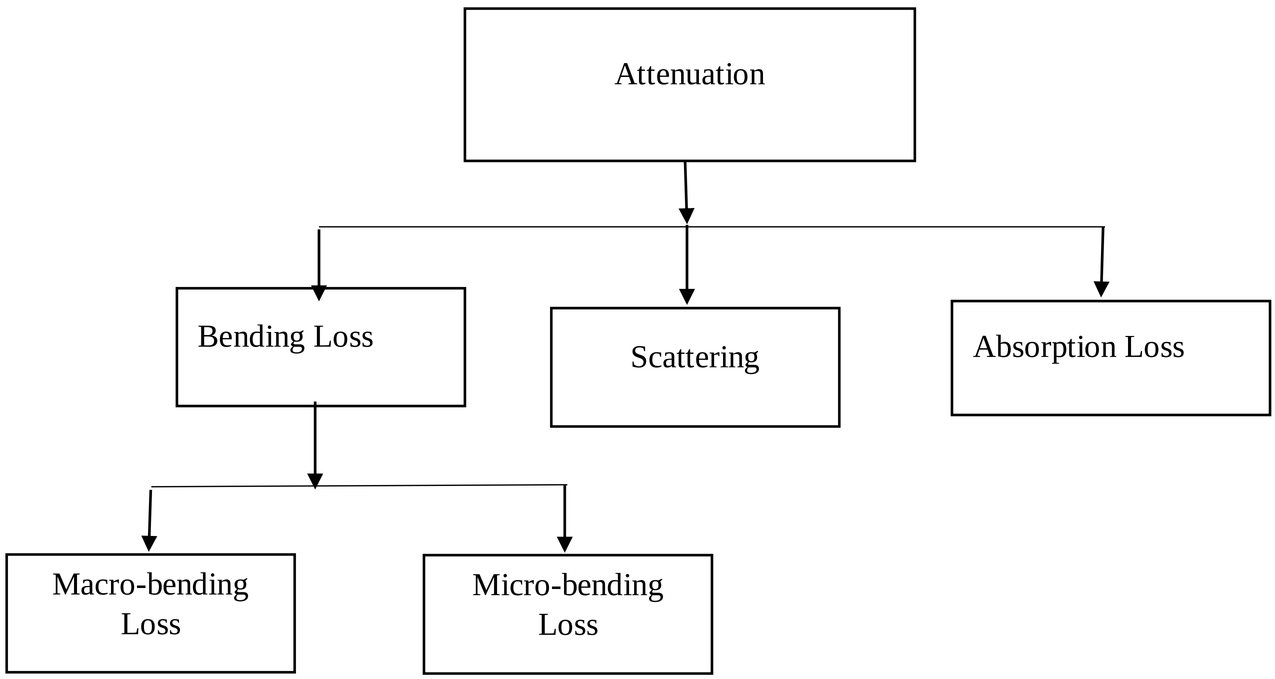
Fig.2.4 Launching light into an optical fiber.

2.7.2 Numerical aperture

In optics, the numerical aperture (NA) of an optical system is a dimensionless number that characterizes the range of angles over which the system can accept or emit light. By incorporating index of refraction in its definition, NA has the property that it is constant for a beam as it goes from one material to another, provided there is no refractive power at the interface. The exact definition of the term varies slightly between different areas of optics. Numerical aperture is commonly used in microscopy to describe the acceptance cone of an objective (and hence its light-gathering ability and resolution), and in fiber optics, in which it describes the range of angles within which light that is incident on the fiber will be transmitted along it.

2.8 Attenuation

Every transmission line introduce some loss of signal power which is known is attenuation. Attenuation is the decrease in light power during light propagation along an optical fiber. Attenuation or Loss caused by violation of the condition of total internal reflection when launching light into a fiber. But practically speaking, fiber optic communications technology never considers this loss as a component of total attenuation because, without total internal reflection optical fiber simply does not work as a communication conduit. Attenuation can be categorized into three types-



2.8.1 **Bending loss**

There are two types of bending loss occurring in the optical fiber which fails to achieve total internal reflection.

a. **Macro-bending loss:** Macro-bending happens when the fiber is bend into a large radius of curvature relative to the fiber diameter (large bends).These bends becomes a great source of power loss when the radius of curvature is less than several centimeters. At the bending point the incidence angle is smaller than critical angle for which some portion of the light ray is refracted. The result is failure to achieve total internal reflection in the bend fiber. Hence the power of the light arriving at its destination will be less than the power of the light emitted into the fiber from a light source. The propagation of light of a straight fiber and a bend fiber is shown in the figure.

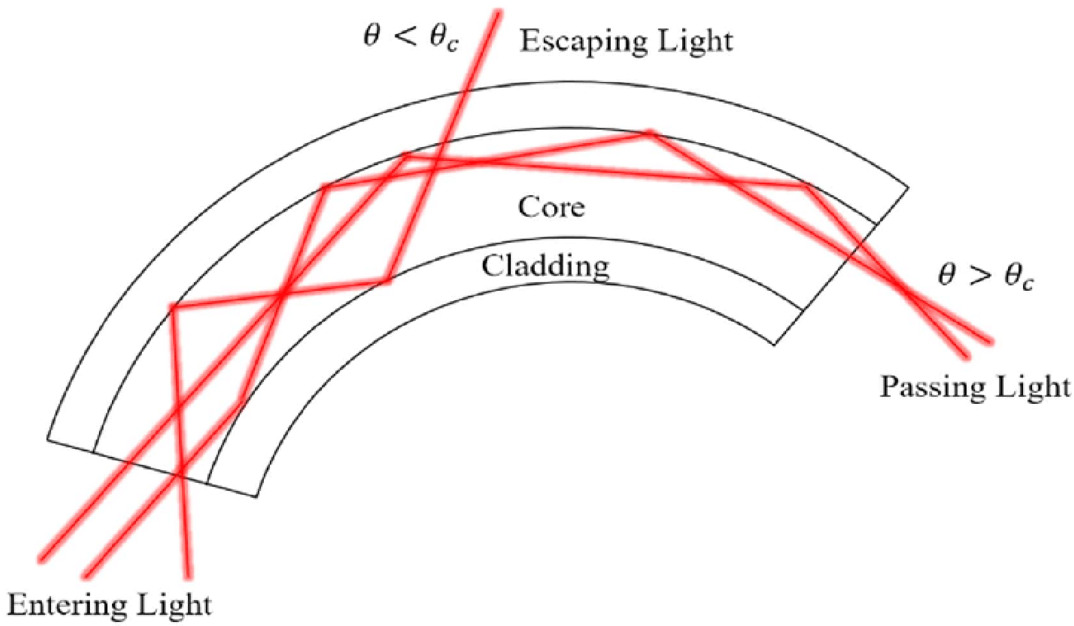


Fig.2.5. Macro-bending loss in optical fiber.

b. Micro-bending Loss:

Micro-bending losses are caused by small imperfections in the fiber core. It is caused by manufacturing process. When the light beam meets these imperfections, changes its direction. The light beam which travel initially at the critical propagation angle, at this point it will be reflected and will change the angle of propagation. The result is that the condition of total internal reflection is not attained and portion of the beam will be refracted. As a result some portion of light lost in the fiber during propagation shown in figure.

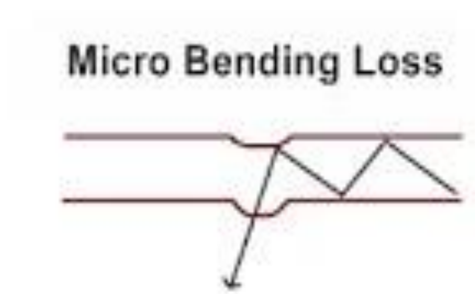


Fig.2.6. Macro-bending loss in optical fiber.

2.8.2 Scattering loss

The propagation of a light is based on total internal reflection of light wave. Rough and irregular surfaces can cause light ray to be reflected in random direction. Scattering losses occurs when a wave interacts with a particle in a way that removes in the directional propagating wave and transfers it to other directions. The light is note absorb, just send in another direction. There are two main types of scattering.

- Linear Scattering.
- Nonlinear Scattering.

For linear scattering, the amount of light power that is transferred from a wave is proportional to the power in the wave. It is characterized by heavy no change in frequency in the scattered wave. On the other hand, nonlinear scattering is accompanied by a frequency shift of the scatter light. Nonlinear scattering is caused by high values of electric field within the fiber (modest to high amount of optical power). Nonlinear scattering cause significant power to be scattered in the forward, backward, or sideways directions.

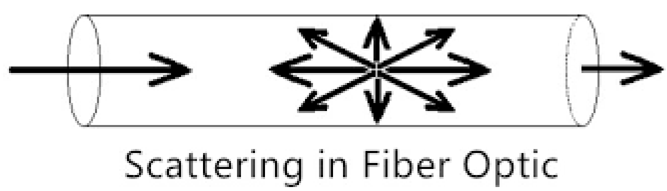


Fig.2.7. Scattering loss

2.8.3 Absorption loss

If an incoming photon has such a frequency that its energy (E_p=hf) is equal to the energy gap (ΔE) of the material, this photon will be absorbed by the material. ΔE is the energy difference between the two energy levels. Light travels down an optical fiber and encounter a material whose energy level gap is exactly equal to the energy of this photons. Obviously, this impact we lead to light absorption, resulting in a loss of light power. This is the basic mechanism of the third major reason for attenuation in optical fibers. Material absorption is a loss mechanism related to the material composition and the fabrication process for the fiber, which result in the dissipation of some of the transmitted optical power as heat in the wave guide. The absorption of the light may be intrinsic or extrinsic.

- Intrinsic absorption caused by the interaction with one or more of the major components of the glass.
- Extrinsic absorption caused by impurities within the glass

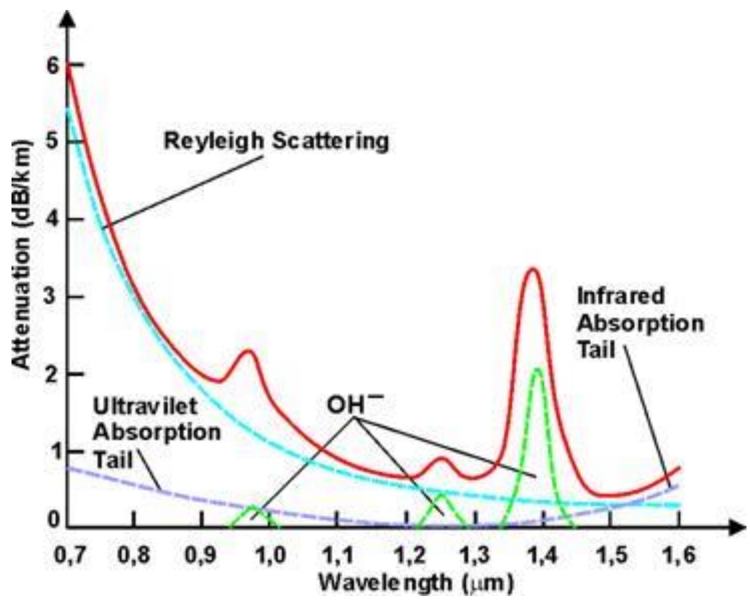


Fig.2.8 Wavelength verses attenuation curve.

2.9 Sources of power penalty

The sensitivity of the optical receiver in a realistic light wave system is affected by several physical phenomena which, in combination with fiber dispersion, degrade the SNR at the decision circuit. Among the phenomena that degrade the receiver sensitivity are modal noise, dispersion broadening and inter symbol interference, mode-partition noise, frequency chirp, and reflection feedback. In this section we discuss how the system performance is affected by fiber dispersion by considering the extent of power penalty resulting from these phenomena.

2.9.1 Modal noise

Modal noise is associated with multimode fibers. Interference among various propagating modes in a multimode fiber creates a speckle pattern at the photo detector. The non-uniform intensity distribution associated with the speckle pattern is harmless in itself, as the receiver performance is governed by the total power integrated over the detector area. However, if the speckle pattern fluctuates with time, it will lead to fluctuations in the received power that would degrade the SNR. Such fluctuations are referred to as modal noise. They invariably occur in multimode fiber links because of mechanical disturbances such as vibrations and micro-bends. In addition, splices and connectors act as spatial filters. Any temporal changes in spatial filtering translate into speckle fluctuations and enhancement of the modal noise. Most light wave systems that use multimode fibers also use LEDs to avoid the modal-noise problem. Modal noise becomes a serious problem when semiconductor lasers are used in combination with multimode fibers.

2.9.2 Dispersive pulse broadening

The use of single-mode fibers for light wave systems nearly avoids the problem of intermodal dispersion and the associated modal noise. Dispersion-induced pulse broadening can also decrease the receiver sensitivity. In this subsection we discuss the power penalty associated with such a decrease in receiver sensitivity. Dispersion-induced pulse broadening affects the receiver performance in two ways. First, a part of the pulse energy spreads beyond the allocated bit slot and leads to inter-symbol interference (ISI). In practice, the system is designed to minimize the effect of ISI. Second, the pulse energy within the bit slot is reduced when the optical pulse broadens. Such a decrease in the pulse energy reduces the SNR at the decision circuit. Since the SNR should remain constant to maintain the system performance, the receiver requires more average power. This is the origin of dispersion induced power penalty δd. An exact calculation of δd is difficult, as it depends on many details, such as the extent of pulse shaping at the receiver. The optical pulse remains Gaussian. If we define the power penalty δd as the increase (in dB) in the received power that would compensate the peak-power reduction, δd is given by $\delta d = 10 \log10 fb$, where fb is the pulse broadening factor.

2.9.3 Polarization

As bit rates increase to meet expanding demand, systems have become increasingly sensitive to polarization-related impairments. These include polarization mode dispersion (PMD) in optical fibers, polarization-dependent loss (PDL) in passive optical components, polarization-dependent modulation (PDM) in electro-optic modulators, and polarization dependent gain (PDG) in optical amplifiers. These impairments result from imperfections in the optical fibers. If the fibers were perfect, the state of polarization (SOP) of the signal would remain constant, and the polarization-related impairments could easily be eliminated. However, the SOP of light propagating in the standard communication fiber varies along the fiber because of the random birefringence induced by thermal stress, mechanical stress and irregularities of the fiber core. Generally, at the output end of the fiber, the light is elliptically polarized with varying degrees of ellipticity, and with the major elliptical axis at an arbitrary angle relative to some reference orientation. Worst of all, the induced birefringence changes with temperature, pressure, stress and other environmental variations, making polarization-related impairments unpredictable. Because polarization-induced penalties are time dependent, mitigation of the polarization-related impairments must be dynamic and adaptive to random variations.

2.9.4 Phase noise

Temperature fluctuations create constantly changing phase noise in optical fibers. This is generally an issue important to interferometry fiber optics sensors, but not optical communication. However as before, phase noise can be converted to amplitude noise under the right conditions, such as poor component design, damaged connectors, fiber or splice.

2.9.5 Acoustic noise

It is possible to have mechanical or acoustic vibrations generate noise-like effects through various transduction effects. For example, undersea cables experience sea-noise due to the hydrostatic pressures encountered. Other sources of this type of noise would be air gaps in fiber connectors or damaged fiber that can cause micro-phonic effects to occur. This type of noise can be neglected in properly designed systems.

2.9.6 Quantum noise

Laser quantum (shot) noise, which is a component of RIN, arises from the quantum nature of the injected carriers and emitted photons of the laser diode. For frequencies <100 MHz, these components are below –60dB. In an incoherent emitter such as a LED, or a laser operating below the threshold, the laser quantum noise arises from spontaneous emission only. In the normal operating mode of a laser, there is the spontaneous emission, plus another term that is the spontaneous emission beating with the lasing optical field.

2.9.7 Reflection feedback and noise

In most fiber-optic communication systems, some light is invariably reflected back because of refractive-index discontinuities occurring at splices, connectors, and fiber ends. The effects of such unintentional feedback have been studied extensively because they can degrade the performance of light wave systems considerably. Even a relatively small amount of optical feedback affects the operation of semiconductor lasers and can lead to excess noise in the transmitter output. Even when an isolator is used between the transmitter and the fiber, multiple reflections between splices and connectors can generate additional intensity noise and degrade receiver performance. This subsection is devoted to the effect of reflection-induced noise on receiver sensitivity.

2.9.8 Amplifier noise

If optical amplifiers are used in the system, they have additive and multiplicative noise components that must be taken into consideration. This is beyond the scope of this report but is important in long-haul transmission.

All amplifiers degrade the signal-to-noise ratio (SNR) of the amplified signal because of spontaneous emission that adds noise to the signal during its amplification. The SNR degradation is quantified through a parameter Fn, called the amplifier noise figure in analogy with the electronic amplifiers and defined as

$$F_n = (SNR)_{in} / (SNR)_{out} \tag{1}$$

Where SNR refers to the electric power generated when the optical signal is converted into an electric current. In general, Fn depends on several detector parameters that govern thermal noise associated with the detector. A simple expression for Fn can be obtained by considering an ideal detector whose performance is limited by shot noise only.

2.9.9 Noise Contribution from Photo detector

The source of noise contribution of a photo detector may be classified into intrinsic and extrinsic: intrinsic noise arises from fundamental physical effects, and extrinsic-source noise comes from the surrounding environment. All detectors are square-law detectors.

2.9.10 Quantum Shot Noise

Shot noise or Poisson noise is a type of noise which can be modeled by a Poisson Method. In electronics shot noise originates from the discrete nature of electric charge. Shot noise also occurs in photon counting in optical devices, where shot noise is associated with the particle nature of light.

2.9.11 1/f Noise

This phenomenon is evident in many physical systems, including lasers and electronics, but its origin is not well understood. This is the dominant noise at very low frequencies. Again, AC-coupled electronics eliminates the contribution from our calculations also.1/f noise is a signal or process with a frequency spectrum such that the power spectral density (energy or power per frequency interval) is inversely proportional to the frequency of the signal.

2.9.12 Thermal Noise

Thermal noise for the photodiode itself is usually neglected, because the parasitic shunt resistance with a reverse-biased PN junction is very large, inducing little noise. Thermal noise of the subsequent amplification stages, particularly the first stage of amplification or Tran’s impedance amplifier, can be important for low light levels.

2.10 Quadrature amplitude modulation (QAM)

Quadrature Amplitude Modulation (QAM) is a complicated name for a simple technique. In the simplest of terms, Quadrature amplitude modulation is the combination of amplitude modulation and phase shift keying. More technically, quadrature amplitude modulation is a system of modulation in which data is transferred by modulating the amplitude of two separate carrier waves, mostly sinusoidal, which are out of phase by 90 degrees (sine and cosine). Due to their phase difference, they are called quadrature carriers.

Unmodulated signals exhibit only two positions enabling a transfer of either a 0 or 1. In quadrature amplitude modulation, it is possible to transfer more bits per position as there are multiple points of transfer. In quadrature amplitude modulation, a signal obtained by summing the amplitude and phase modulation of a carrier signal (a modulated sine and cosine wave or quadrature waves) is used for the data transfer. As the number of transfer points remains high, it is possible to convey more bits per every position change.

The possible states of a particular configuration can be best denoted using a constellation diagram. In a constellation diagram, constellation points are arranged in a square grid with equal horizontal and vertical spacing (other configurations are possible as well). In digital communication, as data is binary, it follows that the number of points in the grid usually will be a function of the power of 2 (2, 4, 8, etc). As the quadrature amplitude modulation is usually square, some of these may be missing or atypical. The most common ones are 16-QAM, 64-QAM, 128-QAM and 256-QAM.

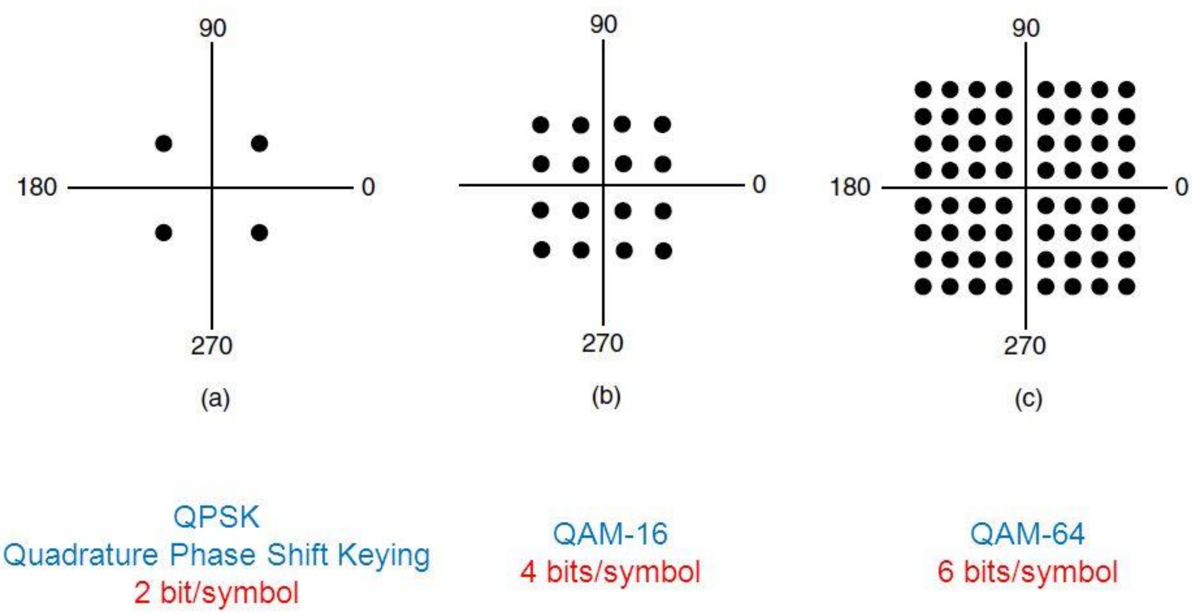
Even if it's possible to transfer more bits per symbol with higher order constellations, theoretically, an inherent technical problem may exist. In order to maintain the mean energy of a higher order constellation at the same level, it is imperative that the constellation points remain close to each other. However, such a configuration brings with it additional chances of noise and additional corruption. In practical application, higher order QAM delivers more data, but delivers it less reliably (that is, with a higher bit error rate) than the lower order QAM.

Incidentally, rectangular quadrature amplitude modulations are preferred to non-rectangular quadrature amplitude modulations as the former is easier to modulate and demodulate.

64-QAM and 256-QAM are often used in cable modem and digital cable television applications. In fact, 64-QAM and 256-QAM are the mandated modulation directives for digital cable television, as laid down by SCTE in the standard ANSI/SCTE 07 2000. In the UK, 16-QAM and 64-QAM are also presently used in digital terrestrial television.

Phase modulation and phase shift keying can be regarded as special cases of quadrature amplitude modulation where the amplitude of the modulating signal is constant and the phase only changing. The same theory can further be extended to frequency shift keying and frequency modulation. Both are special cases of phase modulation.

Constellation diagram of different quadrature amplitude modulation is shown below



2.11 Coherent detection

Coherent detection originates from radio communications, where a local carrier mixes with the received RF signal to generate a product term. As a result, the received RF signal can be demodulated or frequency translated.

A block diagram of coherent detection is shown in Figure 2.7.1. In this circuit, the received signal $m(t)\cos(\omega_{sc}t)$ has an information-carrying amplitude $m(t)$ and an RF carrier at frequency ω_{sc}, whereas the local oscillator has a single frequency at ω_{loc}. The RF signal multiplies with the local oscillator in the RF mixer, generating the sum and the difference frequencies between the signal and the local oscillator. The process can be described by the following equation:

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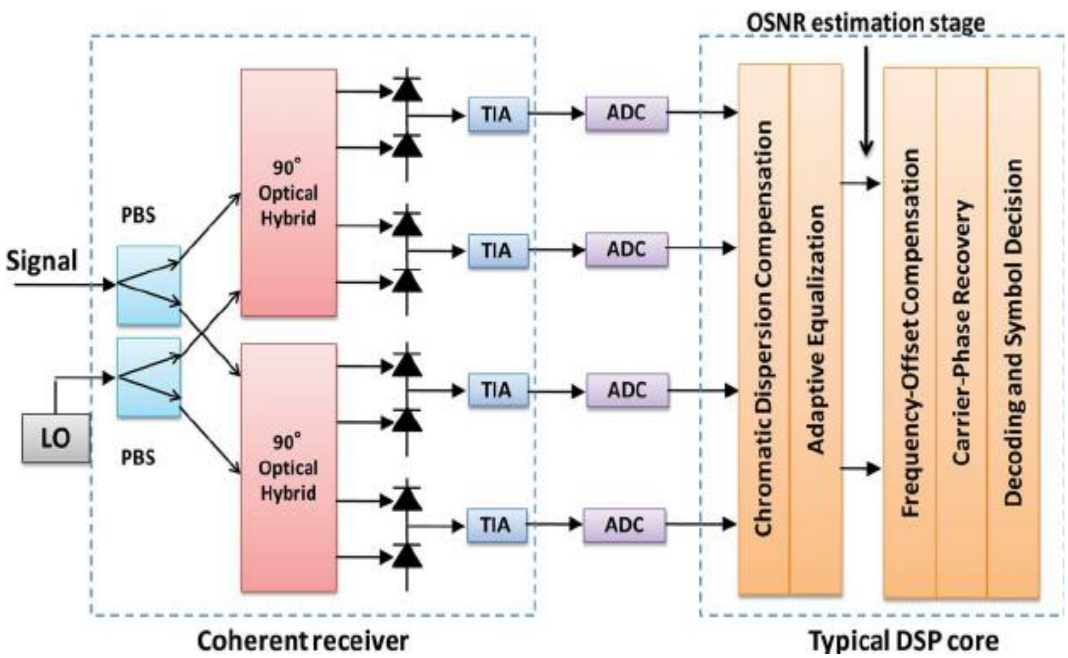

Fig.2.9 Coherent detection.

2.12 Digital signal processing (DSP)

The performance of high-capacity optical communication systems can be significantly degraded by fiber attenuation, chromatic dispersion (CD), polarization mode dispersion (PMD), laser phase noise (PN) and Kerr nonlinearities. Using coherent detection, the powerful compensation of transmission impairments can be implemented in electrical domain. With the full information of the received signals, the chromatic dispersion, the polarization mode dispersion, the carrier phase noise and the fiber Kerr nonlinearities can be equalized and mitigated using digital signal processing (DSP).

Coherent optical detection re-attracted the research interests until 2005, since the advanced modulation formats i.e. m-level phase shift keying (m-PSK) and m-level quadrature amplitude modulation (m-QAM) can be applied. In addition, coherent optical detection allows the electrical mitigation of system impairments. With the two main merits, the reborn coherent detections brought us the enormous potential for higher transmission speed and spectral efficiency in current optical fiber communication systems.

With an additional local oscillator (LO) source, the sensitivity of coherent receiver reached the limitation of the shot-noise. Furthermore, compared to the traditional intensity modulation direct detection system, the multi-level modulation formats can be applied using the phase modulations, which can include more information bits in one transmitted symbols than before.

Meanwhile, since the coherent demodulation is linear and all information of the received signals can be detected, signal processing approaches i.e. tight spectral filtering, CD equalization, PMD compensation, laser PN estimation, and fiber nonlinearity compensation can be implemented in electrical domain.

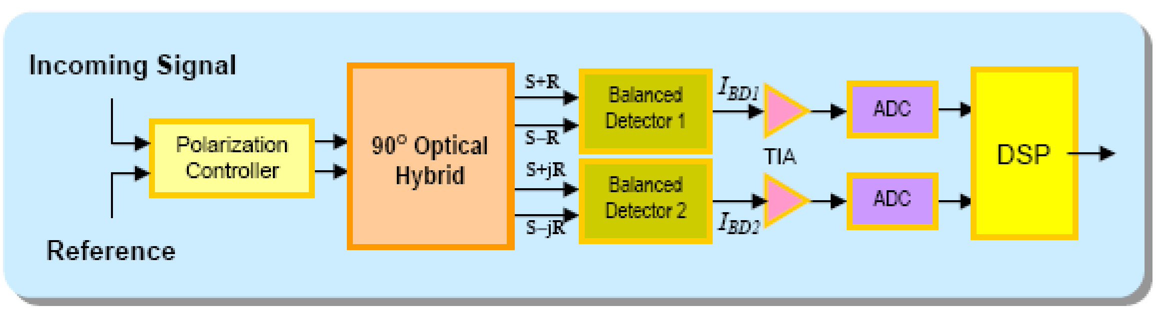

Fig.2.10. Schematic of coherent optical communication system with digital signal processing.

The typical block diagram of the coherent optical transmission system is shown in Figure 1. The transmitted optical signal is combined coherently with the continuous wave from the narrow-line width LO laser, so that the detected optical intensity in the photodiode (PD) ends can be increased and the phase information of the optical signal can be obtained. The use of LO laser is to increase the receiver sensitivity of the detection of optical signals, and the performance of coherent transmission can even behave close to the Shannon limit.

The development of the coherent transmission systems has stopped for more than 10 years due to the invention of Erbium-doped fiber amplifiers (EDFAs). The coherent transmission techniques attracted the interests of investigation again around 2005, when a new stage of the coherent light wave systems comes out b combining the digital signal processing techniques. This type of coherent light wave system is called as digital coherent communication system. In the digital coherent transmission systems, the electrical signals output from the photodiodes are sampled and transformed into the discrete signals using high speed analogue-to-digital convertors (ADCs), which can be further processed by the DSP algorithms.

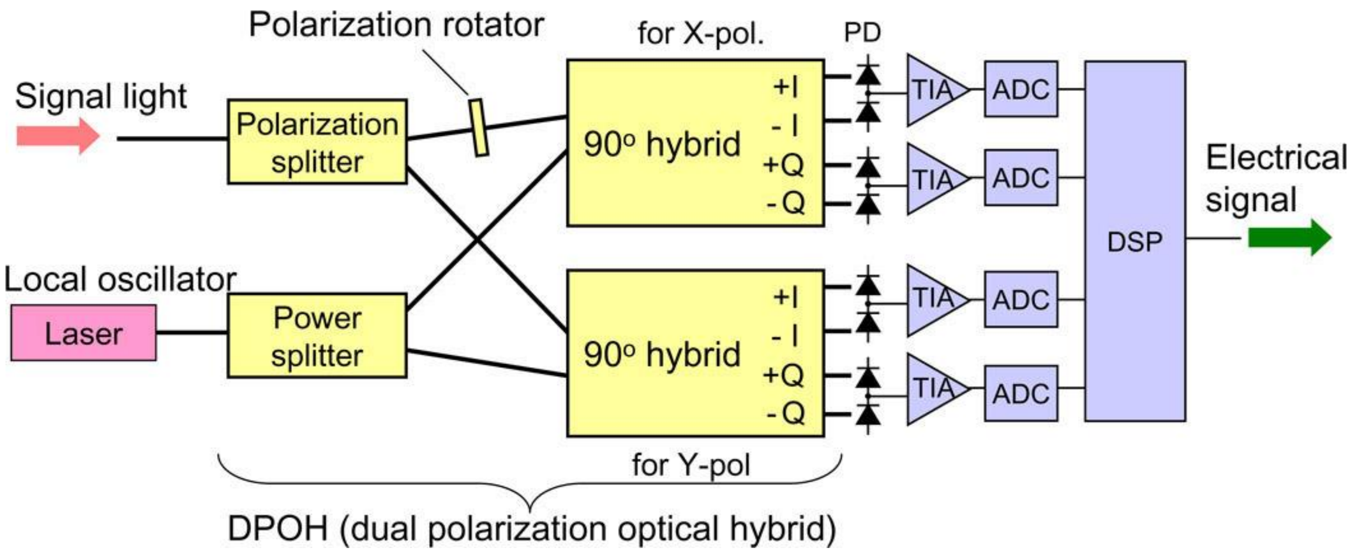

Fig.2.11. Block diagram of DSP in digital coherent receiver.

The phase locking and the polarization adjustment were the main obstacles in the traditional coherent light wave systems, while they can be solved by the carrier phase estimation and the polarization equalization respectively in the digital coherent optical transmission systems. Besides, the chromatic dispersion and the nonlinear effects can also be mitigated by using the digital signal processing techniques. The typical structure of the DSP compensating modules in the digital coherent receiver is shown in Figure 2.11s

2.13 Optical signal-to-noise-ratio

Optical signals have a carrier frequency that is much higher than the modulation frequency (about 200 THz and more). This way the noise covers a bandwidth that is much wider than the signal itself. The resulting signal influence relies mainly on the filtering of the noise. To describe the signal quality without taking the receiver into account, the optical SNR (OSNR) is used. The OSNR is the ratio between the signal power and the noise power in a given bandwidth. Most commonly a reference bandwidth of 0.1 nm is used. This bandwidth is independent of the modulation format, the frequency and the receiver. For instance an OSNR of 20 dB/0.1 nm could be given, even the signal of 40 GBit DPSK would not fit in this bandwidth. OSNR is measured with an optical spectrum analyzer.

2.14 Importance of optical signal to noise ratio monitoring

In long haul optical transmission systems and networks, erbium-doped fiber amplifiers (EDFAs) compensate for loss of optical fibers for transmission and photonic-node components ; then the optical signal is contaminated by amplified-spontaneous-emission (ASE) noise accompanied with optical gain. The quality of the optical signal is generally assed by means of optical-signal-to-noise ratio (OSNR) which is defined as the ratio of the signal power and the ASE noise power in a reference bandwidth. OSNR is one of the key parameters for optical performance monitoring which enables fault management of optical transmission systems and networks including diagnosis and localization.

Importance of OSNR monitoring for submarine cable is given bellow-

a) Minimize Submarine Network Downtime
   Each 100G or higher (100G+) coherent submarine cable features a minimum OSNR value that must be met at the receiver to ensure error-free transmission. Regularly measuring OSNR can help service providers and system vendors assess how much OSNR margin (headroom) is available to proactively address any performance issues before a network outage actually occurs.
b) Reduce Troubleshooting Time
   Network failures can occur for a number of reasons and OSNR testing allows for quickly pinpointing and addressing any defective ROADM or repeat

c) Assess the Upgrade Potential to Rates higher than 100GB

In systems designed for transmission longer than approximately 100 km, amplification is needed to compensate for the power losses in the fiber. It is obvious that this is an important topic, since many submarine and long-haul systems have a length of several thousands of kilometers. Today, in advanced WDM systems, amplification is exclusively achieved with optical amplifiers. An optical amplifier boosts the signal power in the optical domain, i.e. without needing to convert to electrical signals. This greatly reduces complexity for WDM systems. The amplifiers however give rise to noise that will degrade the signal and the bit-error-rate (BER). Therefore, the optical signal-to-noise-ratio (OSNR) is an important signal performance metric. An important class of optical amplifiers is the erbium doped fiber amplifiers (EDFA). The EDFA is a lumped amplifier, based on stimulated emission in a gain medium, much like a laser. One of the energy transitions in erbium ions matches the standard wavelength used in long-haul fiber-optic links, 1550 nm. The amplification is achieved by exciting the erbium ions to the higher energy state of the transition. An incoming photon can then stimulate a transition from the higher to the lower state, which give rise to the emission of another photon. This photon will be an exact copy of the incoming photon, with the same wavelength, phase, propagation direction and polarization. Apart from the stimulated emission, spontaneous electron transitions from the higher to the lower energy states also occur. The photons emitted in such a process will have random direction, polarization, phase and wavelength, within the gain band of the amplifier. The spontaneously emitted photons will then be amplified in the following amplifiers of the system, reaching the receiver as amplified spontaneous emission (ASE). The OSNR is defined as the ratio of the whole signal power and the noise power.

$$\mathrm{OSNR} = (P_{signal,x} + P_{signal,y}) / (P_{noise,x} + P_{noise,y}) \quad (1)$$

where the noise power is measured within a specified bandwidth, usually 0.1µm. Optical signal-to-noise ratio (OSNR) is used to quantify the degree of optical noise interference on optical signals. It is the ratio of service signal power to noise power within a valid bandwidth. When the signal is amplified by the optical amplifier (OA), like EDFA, its optical signal to noise ratio (OSNR) is reduced, and this is the primary reason to have limited number of OAs in a network.

The OSNR values that matter the most are at the receiver, because a low OSNR value means that the receiver will probably not detect or recover the signal. The OSNR limit is one of the key parameters that determine how far a wavelength can travel prior to regeneration.

OSNR serves as a benchmark indicator for the assessment of performance of optical transmission systems. DWDM networks need to operate above their OSNR limit to ensure error – free operation. There exists a direct relationship between OSNR and bit error rate (BER), where BER is the ultimate value to measure the quality of a transmission.

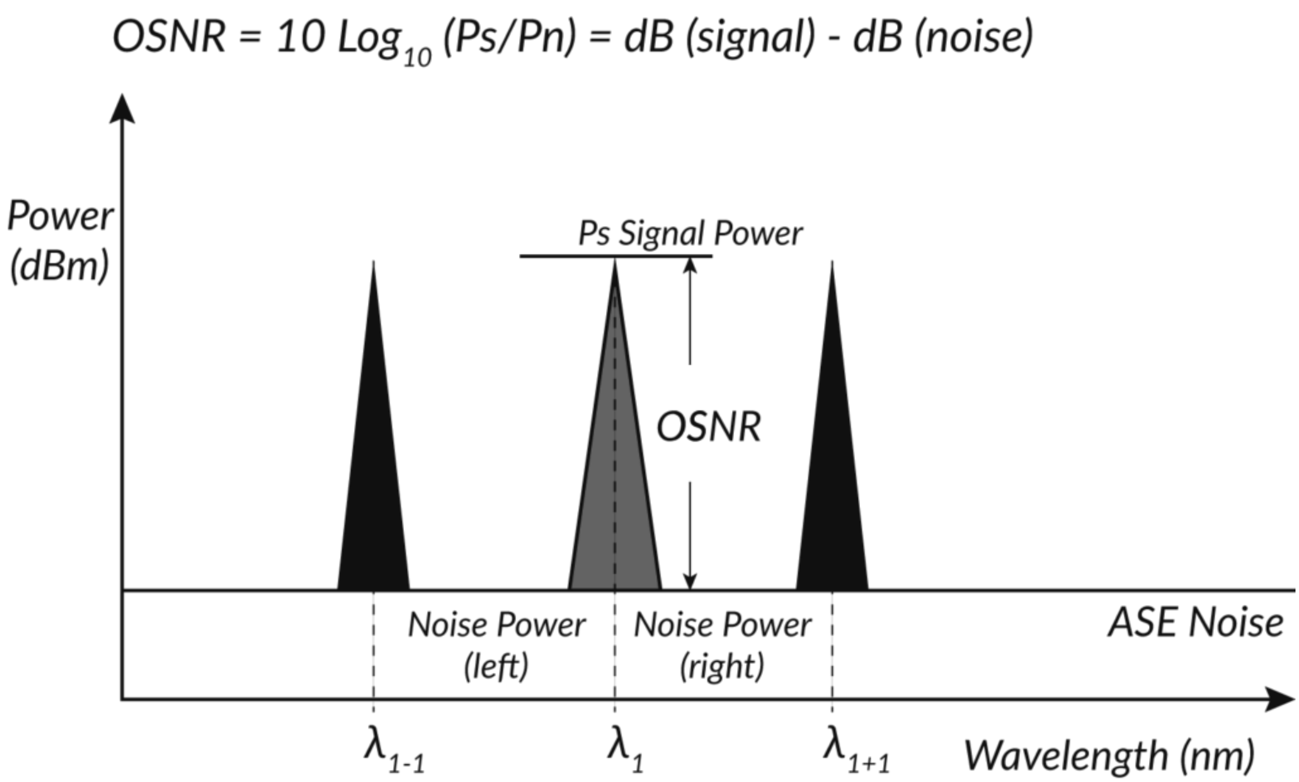

Fig.2.12. Graphical representation of wavelength (nm) verses power (dBm)

CHAPTER 3

PROPOSED OSNR MONITORING TECHNIQUE

3.1 Introduction

The quality of the optical signal is generally assed by means of optical signal to noise ratio (OSNR) which is defined as the ratio of optical signal power to the ASE noise power in a reference bandwidth. OSNR is one of the key parameter which enables fault management of optical transmission system and networks. The OSNR limits is one of the key parameters that determine how far a wavelength can travel prior to regeneration. There are several methods of OSNR monitoring such as

a) Split-Symbol Moments Estimator (SSME)
b) Maximum-likelihood (ML) Estimator for SNR.
c) Squared signal to noise variance estimator (SNV).
d) Second and fourth order moments (M_2M_4) estimator.
e) Signal to variance ratio estimator.

Among them Second and fourth order moments method is of our interest. Advantages of second and fourth order moments methods are:

a) The performance of such OSNR estimation is inherently insensitive to the phase noise of transmitter LASERs and local oscillators, since it involves only the measurement of second and fourth order moments only.
b) It is not affected by linear fiber transmission impairments such as chromatic dispersion (CD) and polarization mode dispersion (PMD), because OSNR estimation is done after adaptive equalization.

3.2 Conventional Second and Fourth Order Moments (M_2 M_4)Method

Coherent optical receiver employing phase and polarization diversities and typical DSP stages for data recovery in polarization-division multiplexed transmission systems .For OSNR monitoring, we use the signal at the adaptive equalizer output. The digital filters used in the equalizer can compensate for a large amount of linear fiber transmission impairments without any notable penalty and the signal at this stage is mainly contaminated by ASE noise. Therefore, the output of the adaptive equalizer is the earliest stage of the DSP chain where the OSNR estimation is done. In addition, DSP stages for frequency-offset compensation and carrier-phase estimation can be placed after the OSNR estimation stage. The output signal from the adaptive filter can be approximated as

$$Yn \approx \sqrt{C} a_n e^{j\theta_n} + \sqrt{N} W_n \tag{1}$$

Where a_n is the M-PSK or M-QAM symbol amplitude, C the signal-power scale factor, N the noise-power scale factor, W_n the ASE noise, θ_n the phase noise stemming from phase fluctuation of a transmitter laser and a local oscillator, and n the number of samples,

The second order moment M_2 of Y_n can be expressed as

$$\begin{aligned} M_2 &= E\{y_n y_n^*\} \\ &= CE\{a_n e^{j\theta_n} a_n^* e^{-j\theta_n}\} + \sqrt{CN} E\{a_n e^{j\theta_n} W_n\} + NE\{w_n w_n^*\} \\ &= CE\{|a_n|^2\} + \sqrt{CN}\left(E\{a_n e^{j\theta_n} W_n^*\} + E\{a_n^* e^{-j\theta_n} W_n\}\right) + NE\{|W_n|^2\} \end{aligned} \tag{2}$$

Where E {-} represents the ensemble average and the superscript $(-)^*$ denotes the complex conjugate. Since the signal and the noise obey a mutually-independent complex-valued stochastic process, we have

$$E\{a_n e^{j\theta_n} W_n^*\} = 0 \tag{3}$$

$$\mathrm{E}\{ a_n^* e^{-j\theta_n} W_n\} = 0 \tag{4}$$

We also assume that the signal a_n and the noise W_n are normalized to have an equal variance given by,

$$\{E\{|a_n|^2\} = E\{|W_n|^2\} = v \tag{5}$$

Thus, we can rewrite Eq. (2) as

$$M_2 = v(C + N) \tag{6}$$

And the signal to noise ratio (CNR) is expressed as

$$SNR = \frac{C}{N} \tag{7}$$

On the other hand, the fourth-order moment M_4 of y_n can be written as

$$M_4 = E\{(y_n y_n^*)^2\}$$

$$= \mathrm{C}^2 \mathrm{E}\{(a_n a_n^*)^2\} + 2C\sqrt{CN}\left(E + E\left\{a_n a_n^* a_n^* e^{-j\theta_n} W_n\right\}\right) + \mathrm{CN}\left(\mathrm{E}\left\{\left(a_n e^{j\theta_n} W_n^*\right)^2\right\} + 4E\{a_n a_n^* W_n W_n^*\} + E\left\{\left(a_n * e^{-j\theta_n} W_n\right)^2\right\}\right) + 2C\sqrt{CN}(\mathrm{E}\{W_n W_n^* a_n e^{j\theta_n} W_n^*\} + \mathrm{E}\{W_n W_n^* a_n e^{-j\theta_n} W_n^*\}) + N^2 E\{(W_n W_n^*)^2\} \tag{8}$$

In Eq. (8), since

$$\mathrm{E}\{\{a_n\} = E\{a_n^*\} = E\{W_n\} = E\{W_n^*\} = 0 \tag{9}$$

$$E\left\{a_n a_n^* a_n e^{j\theta_n} W_n^*\right\} = 0 \tag{10}$$

$$\mathrm{E}\{W_n W_n^* a_n e^{j\theta_n} W_n^*\} = 0 \tag{11}$$

$$E\left\{a_n a_n^* a_n^* e^{-j\theta_n} W_n\right\} = 0 \tag{12}$$

$$\mathrm{E}\{W_n W_n^* a_n^* e^{-j\theta_n} W_n\} = 0 \tag{13}$$

Also note that the real part $a_{nl}$and the imaginary part a_{nQ} of a_n are uncorrelated in M=ary PSK and M-ary QAM signals when M≥4. Then we find that

$$E\{\left(a_n e^{j\theta_n} W_n^*\right)^2\} = E\{a_n^2\}.E\left\{\left(e^{j\theta_n} W_n^*\right)^2\right\} = 0 \tag{14}$$

Because

$$\mathrm{E}\{(a_n^2\} = E\left\{a_{nl}^2 - a_{nQ}^2 + 2j a_{nl} a_{nQ}\right\} = 0 \tag{15}$$

Similarly, we have

$$E\left\{\left(a_n e^{-j\theta_n} W_n^*\right)^2\right\} = E\left\{\left(W_n e^{-j\theta_n}\right)^2\right\}.E\{(a_n^*)^2\} = 0 \tag{16}$$

In addition it is evident that

$$\mathrm{E}\{(a_n a_n^*)^2\} = E\{|a_n|^4\} \tag{17}$$

$$\mathrm{E}\{(w_n w_n^*)^2\} = E\{|w_n|^4\} \tag{18}$$

$$E\{a_n a_n^* w_n w_n^*\} = E\{|a_n|^2 |w_n|^2\} \tag{19}$$

Taking all of these equations into consideration, we can simplify Eq. (8) as

$$M_4 = C^2 E\{|a_n|^4\} + 4CNE\{|a_n|^2|w_n|^2\} + N^2 E\{|w_n|^4\}$$

$$= k_a v^2 C^2 + 4v^2 CN + k_w v^2 N^2 \tag{20}$$

Where

$$\mathrm{k_a} = \frac{E\{|a_n|^4\}}{E\{|a_n|^2\}^2} \tag{21}$$

$$k_w = \frac{E\{|w_n|^4\}}{E\{|w_n|^2\}^2} \tag{22}$$

Are kurtoses of the signal and the noise respectively, The Gaussian distribution of ASE noise yields $k_w = 2$.

Solving Equations (6) and (20), we obtain

$$C = \frac{1}{v}\sqrt{\frac{2M_2^2 - M_4}{2 - k_a}} \tag{23}$$

$$N = \frac{1}{v}\left\{M_2 - \sqrt{\frac{2M_2^2 - M_4}{2 - k_a}}\right\} \tag{24}$$

Therefore, determining M_2 and $M_4$from exponential results and using Eqs. (7), (23) and (24), we can estimate CNR as

$$\mathrm{SNR} = \frac{\sqrt{2M_2^2 - M_4}}{M_2\sqrt{2 - k_a} - \sqrt{2M_2^2 - M_4}} \tag{25}$$

In a practical system, we can calculate second- and fourth-order moments from a received data block of L symbols as

$$M_2 \approx \frac{1}{L}\sum_{n=0}^{L-1}|y_n|^2 \tag{26}$$

$$\mathrm{M}_4 \approx \frac{1}{L}\sum_{n=0}^{L-1}|y_n|^4 \tag{27}$$

Respectively, As shown in Eqs. (26) and (27), measuring second- and fourth order moments does not include any effect of the phase noise and thus the proposed scheme operates phase insensitively.

Equation (25) is a generalized equation to calculate CNR of any arbitrary modulation format. The value of k_a is dependent on the modulation format; for example, in the case of QPSK, we have $k_a = 1$ since, $a_n \in \{1, -1, j, -j\}$.

Then CNR is expressed as

$$\mathrm{SNR}_{QPSK} = \frac{\sqrt{2M_2^2 - M_4}}{M_2 - \sqrt{2M_2^2 - M_4}} \tag{28}$$

On the other hand, for the 16-QAM signal, since $a_n \in \{\pm 1 \pm i, \pm 1 \pm 3i, \pm 3 \pm i, \pm 3 \pm 3i\}$, $k_a = 1.32$

Then, SNR is given as

$$\mathrm{SNR}_{16-QAM} = \frac{\sqrt{2M_2^2 - M_4}}{M_2\sqrt{0.68} - \sqrt{2M_2^2 - M_4}} \tag{29}$$

3.3 Problems of Conventional Method

Conventional second and fourth order moments method can estimate OSNR with low error for 4-QAM signal for all value of SNR.

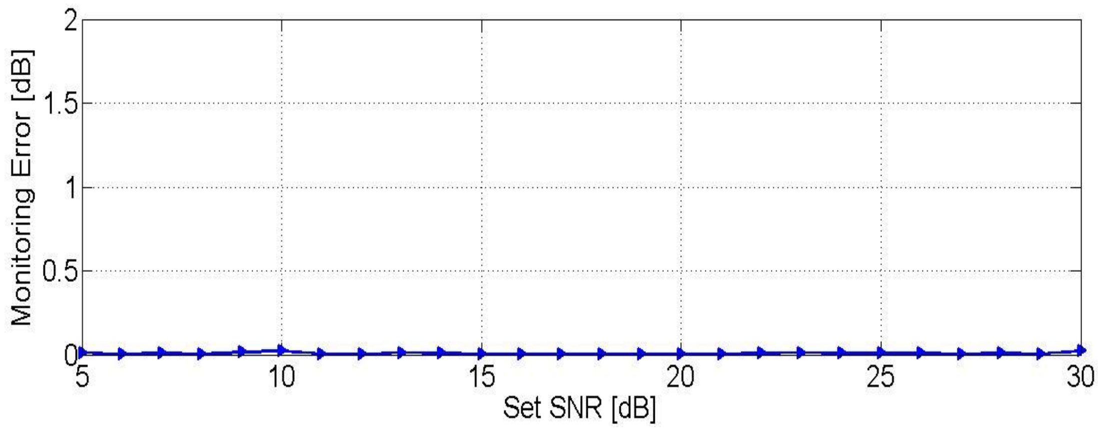

Fig.3.1Set SNR verses Monitoring Error curve for 4-QAM

Estimation of OSNR by M_2M_4 method for high OSNR provides large error for higher order QAM, if the OSNR increases to a higher value. A graph of varying OSNR and estimated error is shown below.

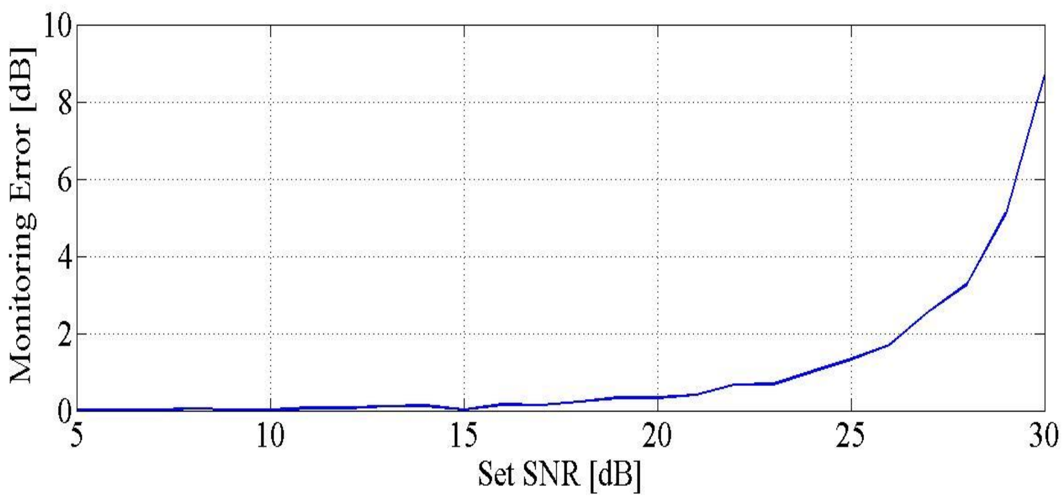

Fig.3.2 Set SNR verses Error curve of 16-QAM by conventional second and fourth order moment method.

It is clear from Fig.3.1 that conventional second and fourth order method of estimation of OSNR can estimate low OSNR easily. For high SNR the corresponding error is also high. In this literature our main aim is to develop an algorithm such that conventional method can be used to estimate OSNR so that it can estimate SNR correctly at the receiver end.

3.4 Principle of proposed technique

From the above discussion it is evident that second and fourth order moments method is not suitable for high SNR estimation, but it is good for 4-QAM. A modification in the OSNR monitoring technique and using the formula of 4-QAM of current second and fourth order method this problem can be solved.

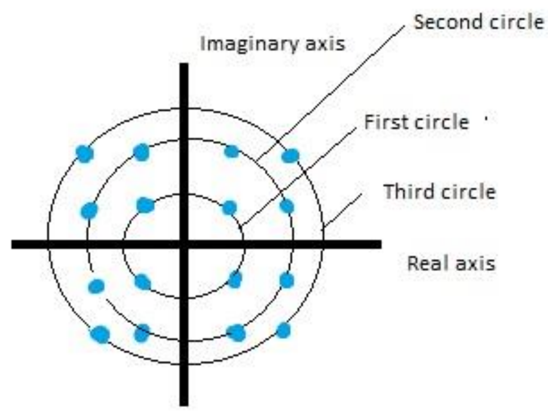

Fig.3.3 Constellation diagram of 16-QAM.

Constellation diagram of 16-QAM is shown in Fig.3.2. It is seen that there are three circle in the constellation diagram and at each circle the magnitude of the constituents signal is the same. The first and third circle is identical except magnitude. By comparing the square of the magnitude we can choose the first and third circle only. At the middle point of two consecutive circle taking as threshold and comparing the incoming data we can easily extract the data of first and third circle. Now, by dividing the magnitude of third circle by a suitable value and cascading them together we can make a constellation which is so far like a constellation diagram of QPSK or 4-QAM.

As second and fourth order moment method shows excellent result for 4-QAM and QPSK, we can apply the formula of 4-QAM and QPSK to calculate optical fiber signal to noise ratio

(OSNR). But, this process is defective too. Because the first circle has the least radius and the third circle has large radius. The first circle is highly susceptible to noise whereas the third circle is least susceptible to noise. If we use the first circle for OSNR monitoring by using the formula of 4-QAM, it will under estimate OSNR. Similarly, if we use the third ring then it will over estimate OSNR. Now only the middle ring is available. The middle ring has average magnitude, average power and the probability of the signal is half. Hence we can use the third ring. The performance of middle ring is given below.

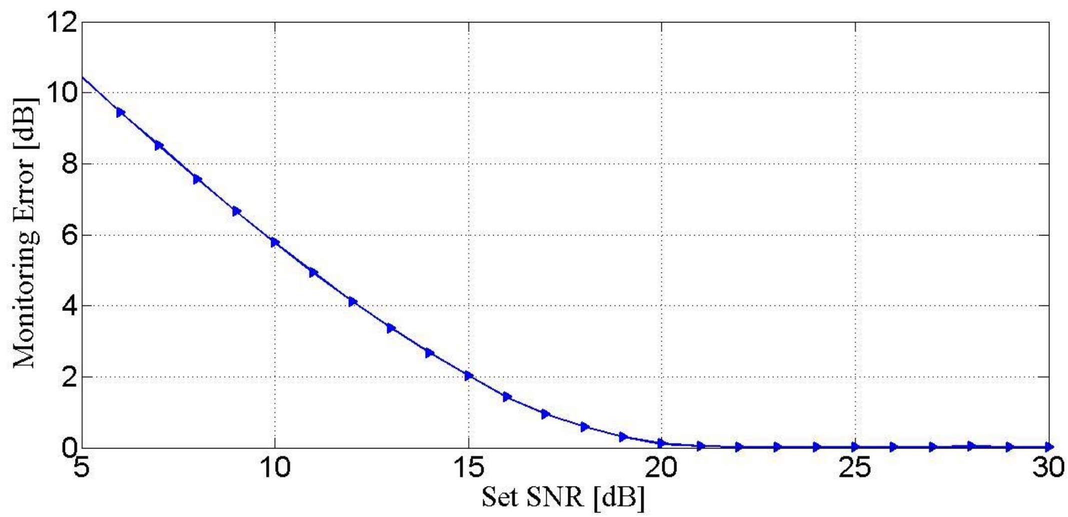

Fig.3.4 Set SNR verses Monitoring Error curve for 16-QAM signal for middle ring considering AWGN only.

From the fig.3.4 it is seen that for middle ring, initial error is high for low value of SNR but with the increasing value of SNR monitoring error becomes lower. Initially monitoring error is high because low SNR means high noise power. The noise from the lower and upper ring are overlapped with the middle ring. Thus the rate of interference is also higher. The following figure shows the comparison between middle ring and the conventional M_2M_4 method.

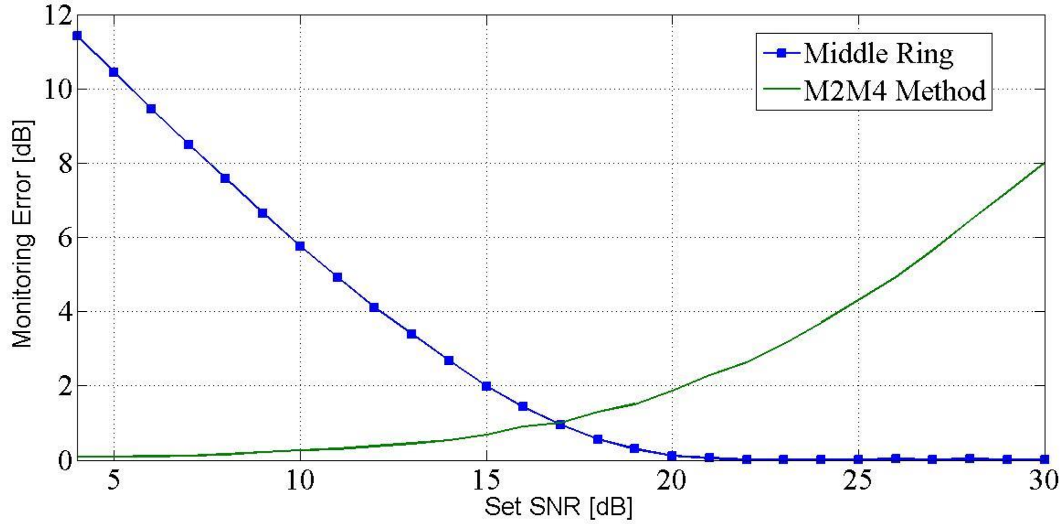

Fig.3.5 Set SNR verses Monitoring Error curve for16-QAM signal for middle ring and M_2M_4 method.

From fig.3.5 it is seen that for lower value of OSNR conventional M_2M_4 method has low monitoring error while middle ring has low monitoring error. If we start estimating error initially by conventional second and fourth order moments method and choose a threshold value as reference and if SNR is greater than the threshold value we will shift our SNR monitoring by middle ring method.

For low OSNR the estimator will follow the conventional second and fourth order moment method, then after certain value as per our analysis OSNR per symbol 18dB or OSNR per bit 14dB middle ring method will be used.

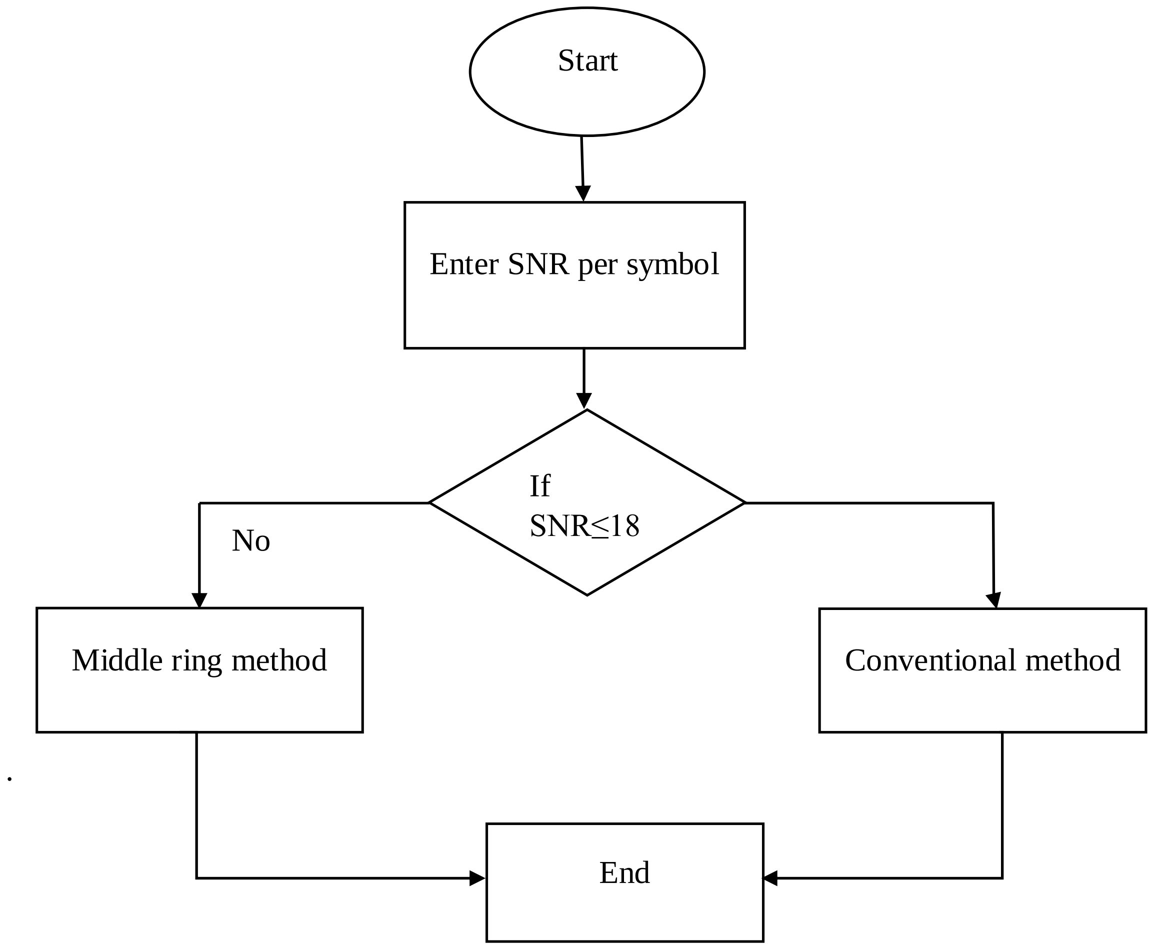

Fig.3.6 Flow chart of proposed algorithm.

CHAPTER 4

SIMULATION RESULTS AND DISCUSSIONS

4.1 Simulation Setup

In order to confirm the effectiveness of our proposed method for estimating OSNR, we conduct computer simulations under the following conditions: Each wavelength channel consists of a dual polarization single-carrier 25-Gbaud QPSK signal or a dual-polarization single-carrier 25-Gbaud 16-QAM signal .At the transmitter , the spectrum of the signal on each carrier or subcarrier is shaped by the Nyquist filter with a roll of factor of 0.5.The channel thus obtained are aligned in the frequency domain without any guard band. As system impairments, CD, the laser phase noise, and the ASE noise take into account. Assuming that the ASE noise as white Gaussian noise, we control OSNR by changing its average power. At the receiver side, the signal is received by an optical homodyne receiver and delivered to the DSP circuit. In the DSP circuit, the signal on each carrier or subcarrier are separated by the Nyquist filter with a roll of factor of 0.5; then, the separated signal is eight fold over sampled and fed into a 21-tap half symbol spaced finite impulse response filter, which is adapted by the constant modulus algorithm (CMA) for the QPSK signal or the radial directed equalization (RDE) algorithm for the 16-QAM signal, we estimate OSNR by using equation (28)-(30).

4.2Results

The previous chapter, we have disscussed about the principle of proposed method for16-QAM signal OSNR monitoring considering AWGN (Additive White Gaussian Noise). In this chapter the simulation results for the above simulation set up and actual long haul communication system is shown. In fig.4.1 the simulation result for middle ring is shown. In fig.4.2 both conventional second and fourth order moments method and middle ring method performance is shown together. In fig.4.3 set SNR verses estimated SNR curve is shown.

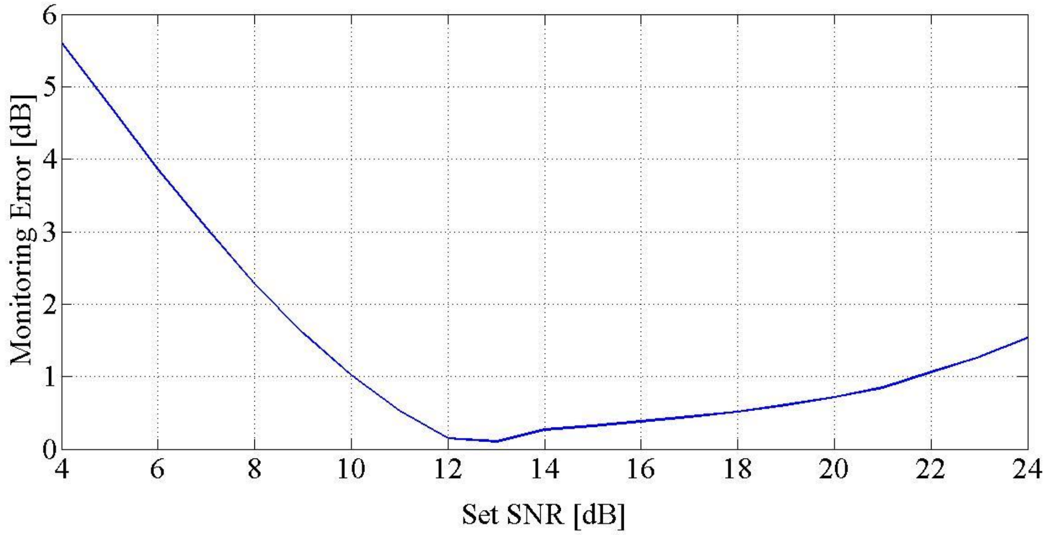

Fig.4.1 Set SNR verses Monitoring Error curve for middle ring.

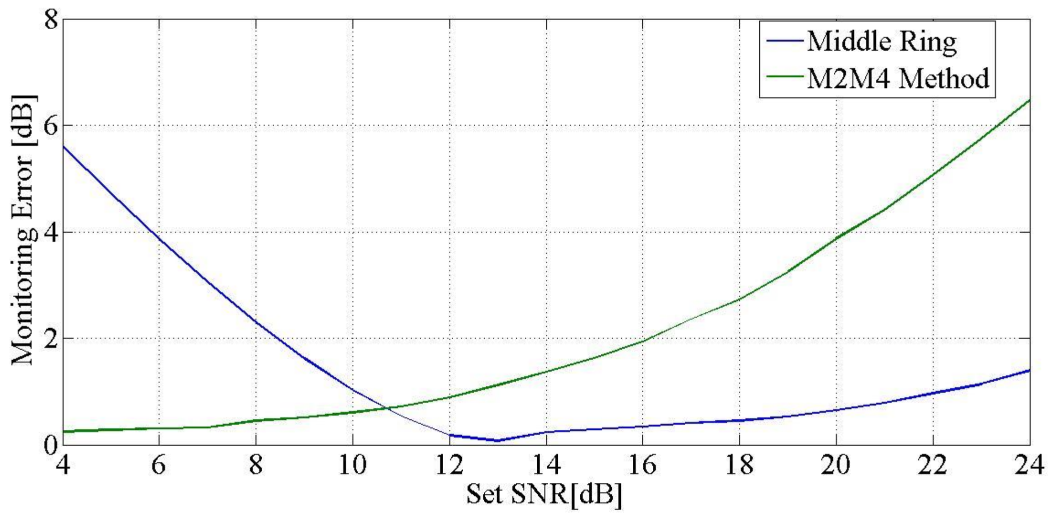

Fig.4.2 Set SNR verses Monitoring Error curve for middle ring and conventional second and fourth order moments method.

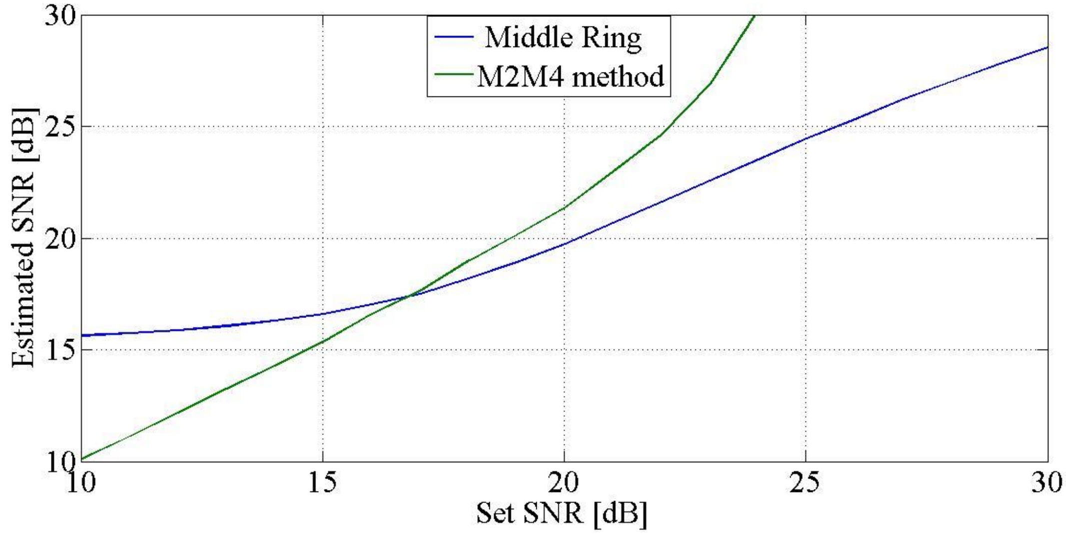

Fig.4.3 Set SNR verses Estimated SNR curve for middle ring and conventional second and fourth order moments method.

By applying proposed algorithm simulation result for 16-QAM signal OSNR monitoring performance is shown below.

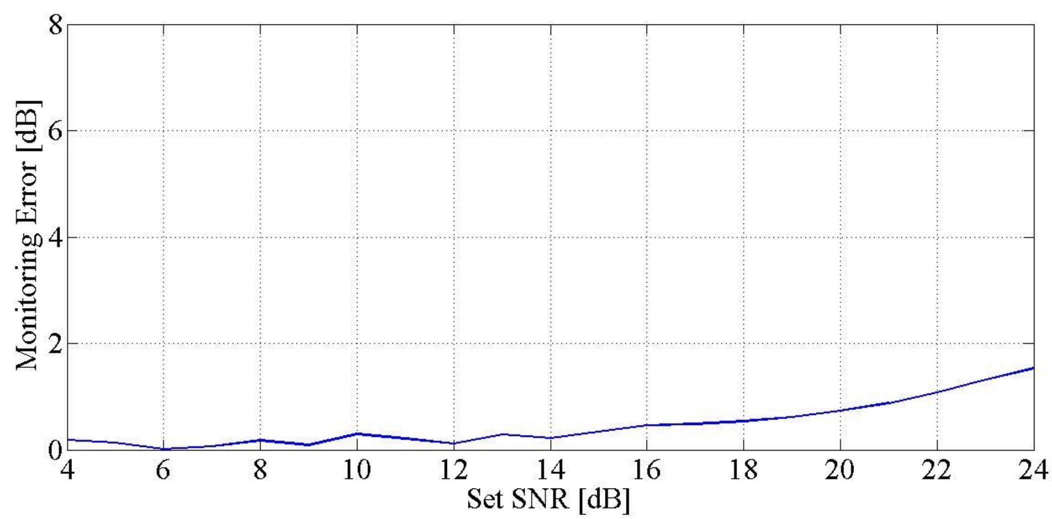

Fig.4.4 Set SNR verses Monitoring Error curve for proposed method.

From the fig.4.4 we can see that proposed method shows low error for high SNR. It can estimate OSNR below an error of 2dB.

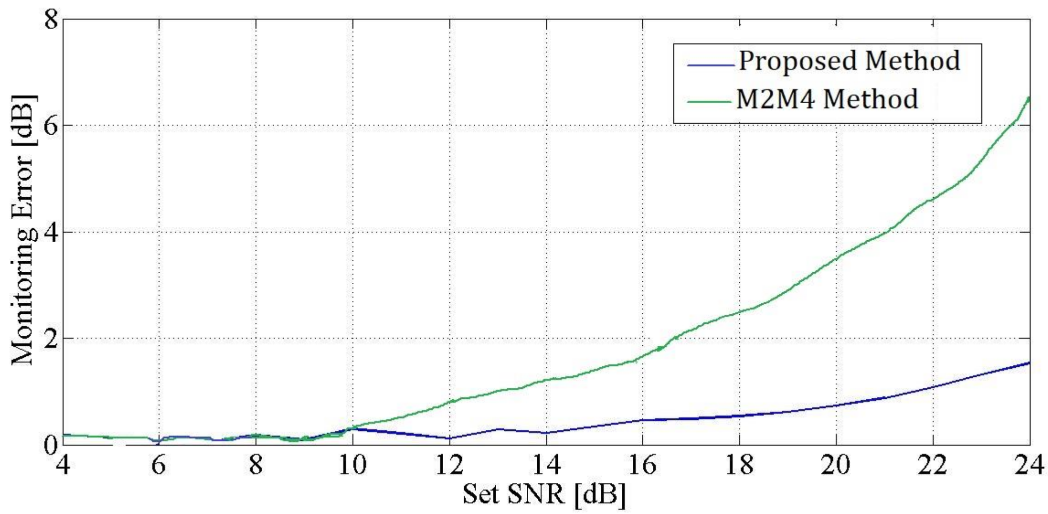

Fig.4.5 Set SNR verses Monitoring Error curve for proposed method and conventional second and fourth order moments method.

A comparison between proposed method and conventional second and fourth order moments method is shown in fig.4.5. it is easily observed that proposed method is more preferable than the conventional second and fourth order moments method for high OSNR monitoring.

CHAPTER 5
CONCLUSION AND DISCUSSION

5.1 Conclusion

Optical fiber communication system is becoming very popular for high speed, enormous bandwidth, high security and low cost communication. Due to frequent use of optical fiber communication, it is necessary to monitor OSNR (optical signal to noise ratio) for quality management.

This research work looked for a good estimator for OSNR monitoring. For this purpose, a modification in the second and fourth order moment method is performed and an algorithm is developed to solve the problem associated with conventional second and fourth order method.

MATLAB simulation and investigation proves that proposed method can successfully estimate higher order OSNR for 16-QAM less than 2dB monitoring error.

5.2 Future works

16-QAM, 64-QAM, 128-QAM and 256-QAM are some popular quadrature amplitude modulation. In this thesis only a proper solution for 16-QAM is examined. There are a lot of scope for future development of the conventional second and fourth order method. Our future goal is to develop algorithm for other higher order QAM. Also investigate the current method with artificial neural network (ANN).

We are hopeful that approaching the same way, we may be successfully develop algorithm for other higher order QAM.

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APPENDIX (If any)