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Threshold based Bit Error Rate Optimization in Four Wave Mixing Optical WDM Systems

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Abstract: - Optical communication is communication at a distance using light to carry information which can be performed visually or by using electronic devices. The trend toward higher bit rates in light-wave communication has interest in dispersion-shifted fibre to reduce dispersion penalties. At an equivalent time optical amplifiers have exaggerated interest in wavelength multiplexing. This paper describes optical communication systems where we discuss different optical multiplexing schemes. The effect of channel power depletion due to generation of Four Wave Mixing waves and the effect of FWM cross talk on the performance of a WDM receiver has been studied in this paper. The main focus is to minimize Bit Error Rate to increase the QoS of the optical WDM system.

I. INTRODUCTION

Since the mid 90's, optical fibers have been used for point to point communication at a very high speed. Fiber-optic communication is a method of transmitting information from one place to another by sending light through an optical fiber. Fiber-optic communication systems have revolutionized the telecommunications industry and played a major role in the advent of the information age. Often the optical fiber offers much higher speed than the speed of electronic signal processing at both ends of the fiber. Because of its advantages over electrical transmission the use of optical fiber has largely replaced copper wire communication in the developed world. The main benefits of fiber are it exceptionally low loss with allowing long distances between amplifiers and repeaters and its inherently high data-carrying capacity such that thousands of electrical links would be required to replace a single high bandwidth fiber. The another benefit of fiber is that even when run alongside each other for long distances and fiber cables experience effectively no crosstalk in contrast to some type of electrical transmission lines. Other main advantages of the optical fiber communication are the large capacity, high speed and high reliability by the use of the broadband of the optical fiber. Huge bandwidth of optical fiber communication system can be utilized to its maximum by using multiple access techniques.

OPTICAL wavelength division multiplexing (WDM) networks are very promising due to their large bandwidth with their large flexibility and the possibility to upgrade the existing optical fiber networks to WDM networks [2]. WDM has already been introduced in commercial systems. All-optical cross connects (OXC), however, have not yet been used for the routing of the signals in any of these commercial systems. A number of OXC topologies have been introduced but their use has so far been limited to field trials and usually with a small number of input–output fibers & wavelength channels. The practical systems have many signals and wavelength channels which influence each other and cause significant crosstalk in the optical cross connect that has probably prevented the use of OXC's in commercial systems. The crosstalk levels in OXC configurations presented so far are generally so high that they give rise to significant signal degradation and to an increased bit error probability. Because of the complexity of an OXC is different when sources of crosstalk exist and this makes it difficult to optimize the component parameters for minimum total crosstalk.

Optical communication is any form of telecommunication that uses light as a transmission medium. Optical communication system consists of a transmitter which encodes a message into an optical signal channel which carries the signal to its destination and a receiver which reproduces the message from the received optical signal. Optical communication systems are used to provide high-speed communication connections [1]. Optical communication is one of the newest and most advanced forms of communication by electromagnetic waves. It differs from radio and microwave communication only in the sense that the wavelengths employed are shorter or equivalently or the frequencies employed are higher. In another very real sense it differs markedly from these

older technologies because for the first time the wavelengths involved are much shorter than the dimensions of the devices which are used to transmit or receive and otherwise handle the signals.
The advantages of optical communication are threefold. First, the high frequency of the optical carrier (typically of the order of 300,000 GHz) permits much more information to be transmitted over a single channel than is possible with a conventional radio or microwave system. Second, the very short wavelength of the optical carrier (typically of the order of 1 micrometer permits the realization of very small, compact components. Third, the highest transparency for electromagnetic radiation yet achieved in any solid material is that of silica glass in the wavelength region 1–1.5 µm. This transparency is orders of magnitude higher than that of any other solid material in any other part of the spectrum [2]. Optical communication in the modern sense of the term dates from about 1960, when the advent of lasers and light-emitting diodes (LEDs) made practical the exploitation of the wide-bandwidth capabilities of the light wave.

II. OPTICAL MULTIPLEXING SCHEMES

2.1 Orthogonal frequency-division multiplexing (OFDM):

Orthogonal frequency-division multiplexing (OFDM) — It is identical to Coded OFDM (COFDM) and Discrete multi-tone modulation (DMT) — is a frequency-division multiplexing (FDM) scheme utilized as a digital multi-carrier modulation method.Large number of closely-spaced orthogonal sub-carriers are used to carry data. Data is divided into several parallel data streams or channels one for each sub-carrier. Every Sub-carrier is modulated with a conventional modulation scheme (such as quadrature amplitude modulation or phase-shift keying) at a low symbol rate maintaining total data rates similar to conventional single-carrier modulation schemes in the same bandwidth [11]. OFDM has developed a popular scheme for wideband digital communication, whether wireless or over copper wires, used in applications such as digital television and audio broadcasting, wireless networking and broadband internet access.

The primary advantage of OFDM over single-carrier schemes is its ability to cope with severe channel conditions — for example attenuation of high frequencies in a long copper wire and frequency-selective fading due to multipath — without equalization filters. The channel equalization is simplified because OFDM may be viewed as using many slowly-modulated narrowband signals rather than one rapidly-modulated wideband signal.The Low rate symbols makes the use of a guard interval between symbols affordable and making it possible to handle time-spreading and eliminate intersymbol interference (ISI). This mechanism also facilitates the design of Single Frequency Networks (SFNs), where several adjacent transmitters send the same signal simultaneously at the same frequency as the signals from multiple distant transmitters may be combined constructively rather than interfering as would typically occur in a traditional single-carrier system [13].

2.2 Wavelength division multiplexing (WDM)

In fiber-optic communications wavelength-division multiplexing (WDM) is a technology which multiplexes multiple optical carrier signals on a single optical fiber by using different wavelengths (colours) of laser light to carry different signals. This thing allows for a multiplication in capacity in addition to enabling bidirectional communications over one strand of fiber. It is a form of frequency division multiplexing (FDM) but is commonly called wavelength division multiplexing [12].
The term wavelength-division multiplexing is commonly applied to an optical carrier (which is typically described by its wavelength) on the other hand frequency-division multiplexing typically applies to a radio carrier (which is more often described by frequency).Since wavelength and frequency are inversely proportional and since radio and light are both forms of electromagnetic radiation the two terms are equivalent in this context.

A WDM system uses a multiplexer at the transmitter to join the signals together and a demultiplexer at the receiver to split them apart. By using the right type of fiber it is possible to have a device that does both simultaneously and can function as an optical add-drop multiplexer.

As explained before, WDM enables the utilization of a significant portion of the available fiber bandwidth by allowing many independent signals to be transmitted simultaneously on one fiber and each signal located at a different wavelength. The routing and detection of these signals can be accomplished independently with the wavelength determining the communication path by acting as the signature address of the origin destination or routing. The components are therefore required that are wavelength selective allowing for the transmission recovery or routing of specific wavelengths [6].

In a simple WDM system each laser must emit light at a different wavelength with all the lasers light multiplexed together onto a single optical fiber. Being transmitted through a high-bandwidth optical fiber combined optical signals must be demultiplexed at the receiving end by distributing the total optical power to each output port and then requiring that each receiver selectively recover only one wavelength by using a tunable optical filter. The laser is modulated at a given speed the total aggregate capacity being transmitted along the high-bandwidth fiber is the sum total of the bit rates of the individual lasers.The example of the system capacity enhancement is the situation where ten 2.5-Gbps signals can be transmitted on one fiber and producing a system capacity of 25 Gbps.Wavelength-parallelism circumvents the problem of typical optoelectronic devices which do not have bandwidths exceeding a few gigahertz unless they are exotic and expensive.Speed requirements for the individual optoelectronic components are therefore relaxed even though a significant amount of total fiber bandwidth is still being utilized.

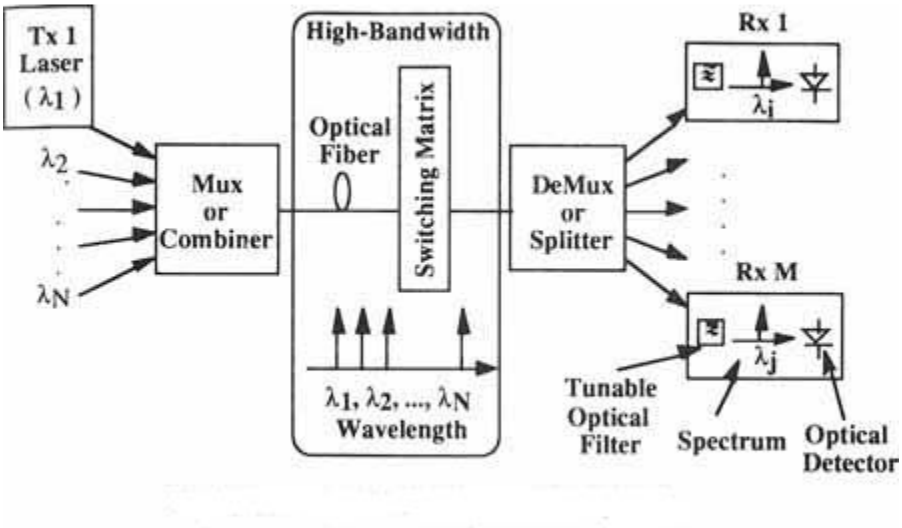

Fig 1: Simple WDM system

A single mode fibre can support many different wavelengths at the same time. If two different colored lasers (different wavelength, fibre chosen in a way that both are single mode) excite a mode in a fibre each and then both of them are multiplexed onto the same singlemode fibre, the fibre has now two first order modes with different wavelengths travelling in it [5]. This is not to be confused with a multimode fibre every color has several different modes! The different channels are independent of each other [4]. The wavelength also serves another purpose: As it is unique for every channel it can be seen as a kind of an address to route the signal. At the end of the fibre, the different wavelengths have to be separated from each other (demultiplexed) and then detected separately [5].

In each of the two different fibres, one channel at a different wavelength gets excited. All the other channels are still unused (in this example, there is only one other channel). Both signals then get multiplexed onto a single fibre (in this example, both available channels are now occupied). As a result, the capacity of the fibre can be doubled without having to increase the bitrate of a single channel.

Advantages of WDM

The wavelength division multiplexing has several advantages over the other presented approaches to increase the capacity of a link:

• It works with existing single mode communication fibre [4].
• It works with low speed equipment [5]
• Is transparent:It doesn't depend on the protocol that has to be transmitted [2].
• Is scalable: Instead of switching to a new technology it adds new channel to existing channels. The companies only have to pay for the bandwidth they actually need [4].
• It is easy for network providers to add additional capacity in a few days if customers need it.Companies using WDM an economical advantage. Parts of a fibre can be leased to a customer who then gets fast network access without having to share the connection with others.

2.3 DWDM System:

Dense wavelength division multiplexing or DWDM for short refers originally to optical signals multiplexed within the 1550 nm band so as to leverage the capabilities (and cost) of erbium doped fiber amplifiers (EDFAs), which are effective for wavelengths between approximately 1525-1565 nm (C band), or 1570-1610 nm (L band). EDFAs were originally developed to replace SONET/SDH optical-electrical-optical (OEO) regenerators which they have made practically obsolete. The EDFAs can amplify any optical signal in their operating range regardless of the modulated bit rate. In multi -wavelength signals so long as the EDFA has enough pump energy available to it so that it can amplify as many optical signals as can be multiplexed into its amplification band (though signal densities are limited by choice of modulation format). The EDFAs therefore allow a single-channel optical link to be upgraded in bit rate by replacing only equipment at the ends of the link while retaining the existing EDFA or series of EDFAs through a long haul route. The single-wavelength links using EDFAs can similarly be upgraded to WDM links at reasonable cost.

Tasks in a DWDM / WDM Network

- Generating signals: The stable lightsource, with a narrow specific wavelength and the possibility of fast modulation [8].
- Combining signals: To merging all the different lightsources into one fibre [8].
- Transmission of signals: Controlling parameters as crosstalk and loss. Control over variables as channel spacing or input power. For long links: Amplification needed (flat gain amplifiers to amplify all used wavelengths together). It may further be necessary to remove or add certain wavelengths from the link, before they reach the end [8].
- To separating the received signals at the receiver end (demultiplexing) [8].
- Detecting the separated signals [8].

Combining / Separating: Multiplexer and Demultiplexer

Multiplexers and demultiplexers can either be active or passive devices. Passive devices use prisms, gratings or fixed filters whereas active designs work with tunable filters. The main challenge in designing a (de)multiplexer is to get a high channel separation and low cross talk [9]. The isolation between the channels should be at least 20 dB. This means, that each neighbouring channel gets damped by at least a factor of 100 when detecting the wanted channel [10].

III. FOUR WAVE MIXING

When a high power optical signal is launched into a fiber then the linearity of the optical response is lost. One such non-linear effect, which is due to the third order electric susceptibility, is called the optical Kerr effect. Optical fiber nonlinearities can lead to distortion, interference and excess attenuation of the optical signals which results in performance degradation. Most common nonlinear optical effect of importance in optical fiber communication systems results from the fiber non linear refractive index [13]. The nonlinearity in the refractive index is known as Kerr nonlinearities. Kerr nonlinearity gives rise to different effects, such as self-phase modulation (SPM), cross-phase modulation (CPM), and four-wave mixing (FWM). FWM may include lightpath BER fluctuations in dynamic networks that can affect the optical signal to noise ratio and quality of service in transparent networks under highly complex nonlinear effect and influence the frequency chirp and extinction ratio in the system. Four Wave Mixing (FWM) is one of the dominating degradation effects in wavelength –division multiplexing (WDM) systems with dense channel spacing and low chromatic dispersion on the fiber.

Applications of FWM

Multiwave mixing, especially four-wave mixing (FWM), is a fundamental process in nonlinear optics. Nonlinearity couples the underlying modes that generate new sum and difference frequencies from the original waves. In typical scenario, two pump waves interact with a signal wave that creates a daughter wave that is phase conjugated with the signal. Because dispersion creates issues of phase matching, FWM has proved useful in such applications as realtime holography, super-continuum generation, and soliton communication systems [11]. The most common configuration involves a self-focusing nonlinearity and a backward geometry in which the initial pump beams counter propagate to create a reflection grating. The focusing non-linearity has the advantage of intensity concentration, but higher intensity can lead to other non-linear effects, while the spatial (transverse) extent of interaction is limited by modulation instability. Furthermore, the backward geometry makes it difficult to cascade the wave mixing and follow the evolution of daughter waves.

IV. CONCLUSION

The effect of channel power depletion due to generation of FWM waves has been analyzed for intensity modulated WDM systems with unequal channel spacing. The channel power depletion is assumed to be a binomial random variable. Based on this model, the effect of FWM cross talk on the performance of a WDM receiver has been studied. The bit error rate and power penalty have been calculated in the worst case scenario, i.e., in the nondegenerate FWM case. It has been shown that the BER increases nonuniformly at rapid rates as the number of channels increases. If the channel number increases (four and above), more and more frequency components are generated by FWM and may coincide with the channel frequencies. These deteriorate the system performance and increase the BER. Receiver noise should also be minimized to get improved performance through minimization of cross talk. The power penalty due to FWM cross talk has been shown as a function of input power for different numbers of channels. Power penalty first decreases with input power and ultimately becomes constant. For a fixed input power, as the channel number increases, the power penalty increases quite rapidly. This is because newly generated frequency components due to FWM increases with channel numbers. These frequencies may ultimately mix with other channels in the WDM system and deteriorate the system performance. The variation of the bit error rate with the detection threshold has also been calculated for different numbers of channels. The study on the optimum detection threshold has shown that as the number of channels decreases, the optimum detection threshold increases toward the ideal value. The minimum BER obtained using the optimum detection threshold decreases as power increases. This decrease in BER occurs due to a large signal-to-noise ratio at the destination. As the input power increases, the minimum BER occurs for a higher detection threshold.

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