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Dynamics of Fiber Optics in Optical Communication Network

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Abstract: This paper presents an overview of the fiber optics and its principles in optical communication network. Fiber nonlinearities are bounded factors for optical communications systems, in specific for wavelength division multiplexing .Among the nonlinearities effect is four-wave mixing ,which is a nonlinear process that generates new frequency components from existing frequency components. FWM is the primary factor which ultimately restricts the channel density and capacity of WDM systems. In the ROF-WDM system, the optical modulation technique plays an imperative role in amount of fiber nonlinearity impact. Various aspects of fiber optics and its related parameters in terms of different elements have been touched in this paper.

Keyword: Wavelength division multiplexing (WDM); Radio over fiber (ROF); Four Wave mixing (FWM).

I. Introduction

As the strength of fiber transmission systems increases, the distance between wavelength division multiplexing (WDM) channels needs to lower down to make optimal and efficient use of limited optical low loss spectrum window. Furthermore, high data rate communication of 10 or 20 Gb/s and long distance between amplifiers in a chain require large optical powers to inject into the fiber to match signal-to-noise ratio (SNR) requirements. The integration of high-power values and the close spacing between channels increase nonlinear crosstalk between the channels due to the nonlinear properties of the transmission fiber. The most important nonlinear property of fiber which can limit the data rate of the system are Self phase modulation (SPM) Cross phase modulation (XPM) Four wave mixing (FWM), Stimulated Raman Scattering (SRS) and Stimulated Brillion scattering (SBS) [1,2,3]. Therefore, to improve the rate of communication of any WDM optical communication system, theses nonlinear effect of fiber need to be neutralized. As a matter of fact, the fiber nonlinearity exists in any communication system which uses the fiber optics as a medium. Therefore, Radio-Over-Fiber (ROF) system is also affected by this unexpected phenomenon. Fiber nonlinearity is the main destructive phenomena in high data rate optical communication systems. Because of limited low loss optical spectrum, DWDM is an efficient technique to increase spectral efficiency. To have more channels in the low loss optical spectrum, the channel spacing must decrease. As channel spacing decreases, the fiber nonlinearity effects increase and cause to performance degradation of optical system [4,5]. This degradation even is more critical for the long haul transmission where we need to supply high level of power to the fiber. Injecting the high volume of power to the fiber not only increase the XPM and FWM effect but also cause to activate the effect of other fiber nonlinearity phenomena like SRS and SBS. Many methods have been proposed to resolve and mitigate the fiber nonlinearity issues. Among these methods we can refer to unequal channel spacing and dispersion compensation shifted (DCS) fiber as well as applying high bandwidth optical amplifier. However, the problem of fiber nonlinearity in the ROF system is a quit new issues and it needs to be investigated more [6].

II. Fiber Optics

To further improve and explore the advantages of the high bandwidth provided by optical fiber, multiplexing is an effective solution which combines multiple numbers of wavelengths into the same fiber in the width of 1300-1600 nm spectrums [7,8,9]. With the advent of lasers with extremely narrow line widths, more channels can be multiplexed into the same fiber which provides the basis for Dense Wavelength Division Multiplexing (DWDM). As it is shown in Figure-1, the main elements of the DWDM system are the multiplexer at the transmitting end and the de-multiplexer at the receiving end. The multiplexer combines the different wavelengths and they are separated back at the receiving end with a de-multiplexer.

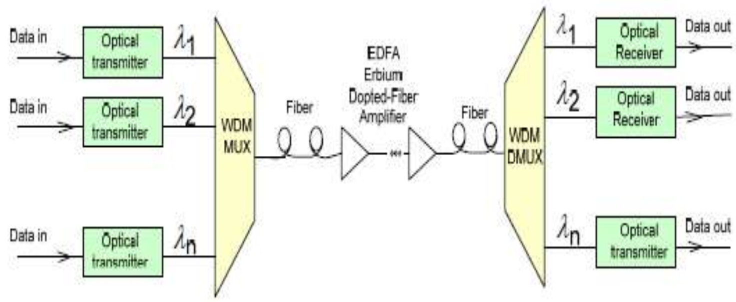

Fig.1: Optical system using WDM Technique

In the transmitter side, various light sources are modulated individually by signal. For good linkage, the frequency spectrum of individual channel should be as narrow as possible [10]. By now, laser carrier line width 4M/250 MHZ can be achieved by external / directly modulating optical wave using double feedback laser diode (DBF-LD).As it can be seen from the Figure-1, for long-haul transmission optical amplifier needed to compensate the fiber loss. Desirable optical amplifier is EDFA since it has high gain, large saturated output power and wide bandwidth. Theoretically, the number of channel within low loss window (1330nm-1580nm) is 1250, therefore, Potential capacity of WDM is
$C = 1250 \times 10 = 12.5$ Tb/s

However, many factor limits, the total number of channel in WDM including bandwidth limitation of optical amplifier and fiber nonlinearity. The existence broadband optical amplifier just has 50nm spectrum flat gain[11,12,13,14]. EDFA probably can be considered ideal amplifier since it has high gain, broad bandwidth, and also it works on population inversion principle. Gain variation of optical amplifier is detrimental because It leads to supply insufficient optical power to some WDM channel and supply too much optical power feed to other channel. Too much optical power increase the nonlinearity effect of fiber (XPM-FWM-SRS) while insufficient optical power degrade the system signal to noise ratio (SNR). Therefore, gain flattened amplifier is needed to alleviate the fiber nonlinearity effects. In this way, also we need to apply some techniques to equalize the gain of amplifier. Fiber nonlinearity is another technical challenge which limits the number of channel in WDM. The fiber nonlinearity causes to high interference and channel cross-talk between WDM channels. Therefore, Extra channel spacing is essential. In addition, the simplest approach to avoid fiber nonlinearity effects is keeping the light intensity low. This action nonetheless, is detrimental due to decreasing the system SNR.

A. Fiber Characteristics

The root element that makes the optical communication possible is the optical fiber. The process which guides the light along the optical fiber is the total internal reflection. It is an optical phenomenon which occurs when the incident light is completely reflected. Critical angle is the angle above which the total internal reflection occurs. In case of materials with different refractive indices, light will be reflected and refracted at the boundary surface. This will happen only from higher refractive index to a lower refractive index such as light passing from glass to air. This phenomenon benchmarks the basis of optical communication through fibers. An optical fiber is a dielectric waveguide, it is cylindrical, and mentors the light parallel to the axis [15, 16, 17].The cylindrical structure is dielectric with a radius “a” and refractive index of “n1”. This is the called the core of the fiber the fiber and the layer that encompasses this structure is called the cladding. Cladding has a refractive index “n2” which is lesser than “n1”. This helps in providing mechanical strength and helps reducing scattering losses. It also prevents the core from surface contamination. Cladding doesn’t take part in light propagation.

B. Types of Fibers

Fibers can be categorized as per their core’s material composition. If the refractive index of the core is uniform and changes abruptly at the cladding boundary, then it is called as Step-index fiber. In case the refractive index varies at every radial distance, then it is called as Graded-index fiber [20,21,22]. These fibers can be divided into Single mode and multi mode fibers. Single mode fibers operate in only one mode of propagation. Multimode fibers can support hundreds of modes. Both laser diodes and light emitting diodes (LED) can be used as light wave sources in fiber-optical communication systems. When compared to Laser diodes, LEDs are less expensive, less complex and have a longer lifetime, however, their optical powers are typically small and spectral line-widths are much wider than that of laser diodes. In Multimode fibers different modes travel in different speed, which is commonly referred to as inter-modal dispersion, giving room to pulse spreading.

In single mode fibers, different signal frequency components travel in different speed within the fundamental mode and this result in chromatic dispersion. Since the effect of chromatic dispersion is proportional the spectral line-width of the source, laser diodes are often used in high-speed optical systems because of their narrow spectral line-width.

C. Fiber Losses

For optimum recovery of the received signal, the signal to noise ratio at the receiver must be considerably large. Fiber losses will affect the received power eventually reducing the signal power at the receiver. Hence optical fibers suffered heavy loss and degradation over long distances. To match these losses, optical amplifiers were discovered which significantly boosted the power in the spans in between the source and receiver. However, optical amplifiers introduce amplified spontaneous emission (ASE) noises which are proportional to the amount of optical amplifications they provide [23, 24, 25]. Low loss in optical fibers is still a critical requirement in long distance optical systems to efficiently recover the signal at the receiver. Attenuation Coefficient is a fiber-loss parameter which is expressed in the units of dB/Km.

D. Fiber Nonlinearities

The non-linear effects of the fibers play a important role in the light propagation [18, 19]. Nonlinear Kerr effect is the dependence of refractive index of the fiber on the power that is propagating through it. This effect is responsible for SPM, XPM and FWM. The other two important effects are stimulated SBS and SRS.

- Self Phase modulation
- Cross phase modulation
- Four wave mixing
- Stimulated Brillouin Scattering

III. Principle of WDM Network

Wavelength division multiplexing operates by sending multiple light waves (frequencies) across a single optical fiber. Information is carried by each wavelength, which is called a channel, through either intensity (or amplitude) or phase modulation [20-25]. At the receiving end, an optical prism or a similar device is used to separate the frequencies, and information carried by each channel is extracted separately. Binary digital signal, which is a full on/off intensity modulation, can also be carried by each individual channel, although the bit rate is expected to be lower than the intensity or phase modulation. As in conventional frequency division multiplexing (FDM) used in electrical signal or radio wave transmissions, the carriers can be mixed onto a single medium because light at a given frequency does not interfere with light at another frequency within the linear order of approximation. The root principle of optical communication, including DWDM, is depicted in Figure 2, in which the transmitter modulates the input signal using amplitude (or intensity)-shift keying (ASK), frequency-shift keying (FSK), or phase-shift keying (PSK) to a carrier light wave at frequency Fs with a very narrow frequency line width - a single frequency laser (or a single color light)[21,22]. This modulated signal, which combines with other signals of different frequencies, is transmitted along the optical fiber to the receiver. The signal is then converted back to the electrical signal by way of an optical detector and a demodulator. Switches or routers of some kind may also be involved between the transmitter and the receiver. Figure 3 depicts the basic architecture and operations of DWDM networks, which consist of end nodes, switch nodes, and optical fiber links. The end nodes consist of modulators/demodulators (or modems) for every channel, and multiplexers and de-multiplexers for combining or separating the lights of different frequencies. The modulators encode digital data into waveform symbols through either intensity or a phase modulation method, and the demodulator reverses the process to obtain digital data. The switches nodes comprise of add/drop multiplexers and demultiplexers, wavelength switches, and wavelength converters. The multiplexers are used to combine the signals of different wavelengths for transmission and the de-multiplexers are used to separate the signals of different wavelengths for switching [23]. The wavelength switches cross matches the input channels to the desired output channels. The function of the wavelength converters is to convert the over-demanded wavelengths to free wavelengths in a given fiber to achieve high channel utilization.

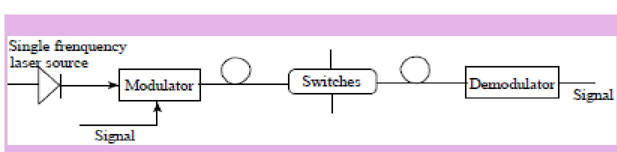

Fig. 2: Principle of Optical Communication

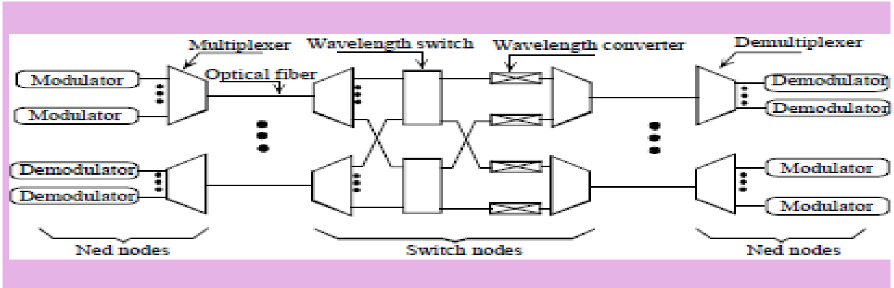

Fig. 3: Architecture of Network

Conclusion

In this paper, different aspects of optical communication network are discussed. Fiber optics scenarios in terms of losses, non- linearity have been presented. Different types of non-linear responses have been occurred in network configurations. High channel utilization for de-multiplexing on different wavelengths should be achieved. Different modulation techniques need to be developed to enhance the performance on fiber optics in communication network.

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