

Reduction of Fiber Nonlinearities in 5G

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Abstract —The evaluation technology of today is 5G. The 5G increases the data rate and reduces the bit error rate. The Wavelength Division Multiplexing technique is used for transmitting more number of channels through a single fiber. In Wavelength Division Multiplexing (WDM) system of 5G, arises nonlinearity and the major nonlinearities that arise in fiber are FWM and SRS. We use single-mode fiber for transmission. When the optical signal is propagating through the fiber, it undergoes power loss, scattering, and bending which results in crosstalk, power transmission, and phase modulation. Due to this, the performance of the WDM system gets degraded. In this paper, the effect of Four-Wave Mixing (FWM) and Stimulated Raman Scattering (SRS) in Wavelength Division Multiplexing (WDM) system of single-mode fiber is reduced. The reduction of FWM and SRS effects for 4 channels, 8 channels is done here to improve the efficiency of 5G.

Keywords — WDM, Nonlinearities, SRS, FWM, Power Tilt, Unequal channel spacing, Equal channel spacing, Dispersion.

I. INTRODUCTION

In 5G, IoT expansion is going to take place; it will generate a huge amount of data and connect several networks. The 5G provides low delay, high availability, high reliability, low jitter, and more capacity. For efficiency, fiber helps us in the backhauling of 5G. Thus fiber serves as the backbone for 5G. The optical fiber is a medium where the light source is produced via laser or LED and transmitted through glass or plastic fiber having two layers called core and cladding which differ in their refractive index, and the light is received through the photo detector and converts it to electrical signals. The fiber is divided into single and multimode fiber. The single mode fiber was a single strand of glass having 8.3micron to 10 microns of diameter. It has a narrow diameter, so one mode of propagation takes place in it. It carries higher bandwidth than multimode fiber but it has to have a narrow light source for it. The wavelength used for it was 1310nm and 1550nm. The multimode fiber will have a diameter of 50 to 100 microns and it is used for a very short run only. The multimode fiber is having a large diameter of 62.5micron and transmits only for short distance with the light source as LED, but the single-mode fiber will transmit a narrow light source of 8 to 10 microns produced by laser for a long distance. So the single-mode fiber is used for 5G. The Optical communication system will operate at a range of few mill watts power. In fiber Wavelength Division Multiplexing system is implemented as it does not pose any real problems like traffic and data rate. WDM provides much better latency. WDM has the efficiency

of transporting a large amount of data in single fiber by separating them with a unique wavelength. WDM, as the data rate increases, the time decreases. There are other systems like TDM, PDM, etc. The WDM will increase the capacity of single-mode fiber and it can transmit signals of digital, analog, etc. also network capacity is expanded, so WDM is used in 5G. While using fiber as a mode of propagation, there arise nonlinearities. The nonlinearities are of two categories. Inelastic scattering and Refractive index effect are the types of nonlinearities. The scattering is due to the light in the medium made of silicon of optical fiber when it impinges on the molecule inside the fiber. There are two types in it, known as SRS and SBS. The refractive index is due to the bending of light while it passes from one medium to another. The refractive index effect will lead to FWM, XPM, and SPM. In 5G as the number of channels increases, these effects become more prevalent. This paper aims to reduce those nonlinear effects such as FWM and SRS that occur in fiber while transmission of signals.

II. FOUR WAVE MIXING

Four-wave mixing is a prevailing non-linearity of in 5G. FWM is an intermodulation phenomenon due to the refractive index effect, as it is the mixing of three input waves and forming a new fourth interfering output wave. The new terms that lie near the wanted wavelength can be removed using a filter but when the new terms coincide with the wanted wavelength it cannot be removed using the filter, so they are considered as interfering terms. Such interfering FWM terms can cause cross talk, decrease power efficiency. To remove such interfering FWM terms several techniques is used. The FWM equation is,

$$\lambda_{\text{FWM}} = \lambda_i + \lambda_j - \lambda_k \quad (1)$$

The FWM terms are found by using a formula,

$$\text{No. of FWM terms} = \frac{N^3 - N^2}{2} \quad (2)$$

When the input signal is fed into a fiber, it can mix and form new terms of the different and same wavelengths which are given by equation (1) and the number of new terms that arises is given by equation (2), N is the number of channels used. The FWM effect is shown in fig.1

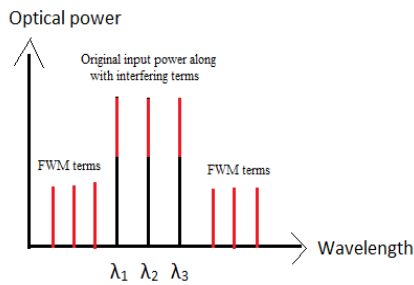


Fig.1 Spectrum of WDM with FWM terms

The FWM effect is more in equal spacing and more interfering terms appear in the equal spacing technique. To reduce the interfering terms, the unequal spacing technique has been used here. In unequal spacing technique the interfering terms will be reduced and also dispersion will reduce the FWM effect in fiber. This is done for 4 channel and 8 channel using OptiSystem software.

III. SELF PHASE MODULATION

The self-phase modulation is nonlinearity due to the refractive index effect. It means that self-induced phase shift induced while the light is transmitted through the fiber. The SPM will broaden the bandwidth. SPM is said to be the most reach limiting nonlinear effect of the WDM system.

IV. CROSS PHASE MODULATION

The cross-phase modulation occurs due to the nonlinear refractive index based on the intensity of the beam. It will result in spectral broadening and BER will increase.

V. SIMULATED RAMAN SCATTERING

The Stimulated Raman Scattering is one of the inelastic scattering effects, which was considered to be nonlinearity in fiber transmission. The SRS behaves incoherently and thus it is unpredictable and dangerous. The SRS effects occur due to the inelastic scattering, energy is transferred from shorter wavelengths to higher wavelength channels (if two channels have the same power). The inelastic scattering is the incoherent or random movement of the photon to impinge on the molecules of fiber and to lose its energy. In the SRS effect, the power gets transferred to the later wavelength which leads to the power loss in one channel and additional power gain in another channel.

$$P_m(k) = P_t(k) - \text{Power transferred to higher channel } (>k) + \text{Power coming from the lower channel } (<k) \quad (3)$$

where, $P_t(k)$ = Power transmitted to the k^{th} channel

The equation (3) gives the amount of power transferred to k^{th} channel. Fig.2 shows the SRS effect while transmitting through fiber in optical communication for 5G. Equation (4)

gives the Threshold optical power at which SRS effect is being started.

$$P_{th} = \frac{16 A_{eff}}{g_R L_{eff}} \quad (4)$$

where, P_{th} = Threshold optical power in Watts
 A_{eff} = Effective area of the fiber core in m^2
 L_{eff} = Effective length of the fiber in meter
 g_R = Raman Gain coefficient in $cm / Watt$

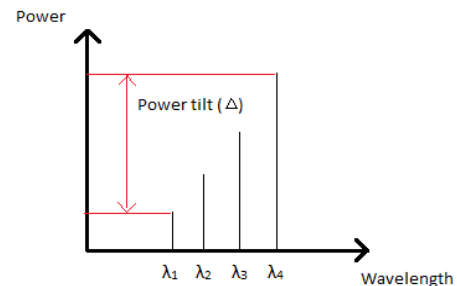


Fig.2 Spectrum of Stimulated Raman Scattering

The SRS will induce cross-talk and it increases as the length of the transmission fiber increases, to reduce the SRS effect dispersion can be applied up to a certain level.

VI. SIMULATED BRILLOUIN SCATTERING

The SBS is a nonlinear phenomenon that is considered to be in terms of three waves in fiber, the incident wave will propagate through fiber reaches the threshold power will excite an acoustic effect and this is unavoidable. This will change the characteristic as fiber including refractive index that makes reflecting waves to propagate in opposite direction. The SBS will cause cross talk, attenuation, and power saturation

VII. METHOD PROPOSED

To reduce the Four Wave Mixing (FWM) unequal channel spacing technique is used to reduce the interfering terms.

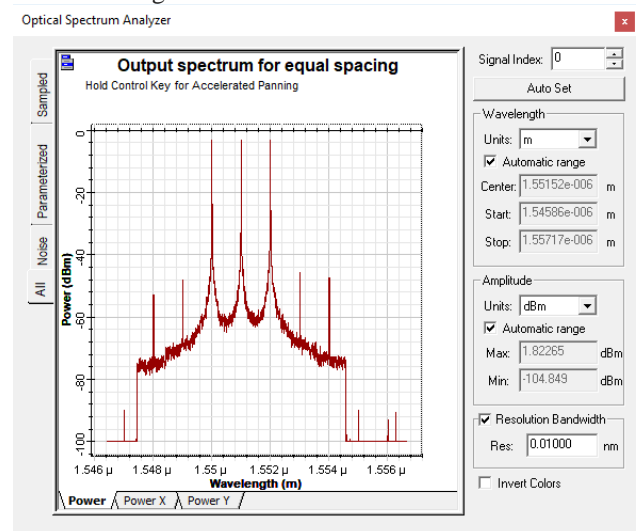


Fig.3 Output spectrum of FWM with equal spacing

The fig.3 shows the equal spacing. Here it has some interfering terms along with the wanted wavelengths; the wavelengths used here are 1550nm, 1551nm, and 1552nm. These wavelengths are used as the fiber used here is the single mode fiber. The fig.4 shows the unequal spacing technique. Here, the FWM terms are not coinciding with the original wanted wavelengths

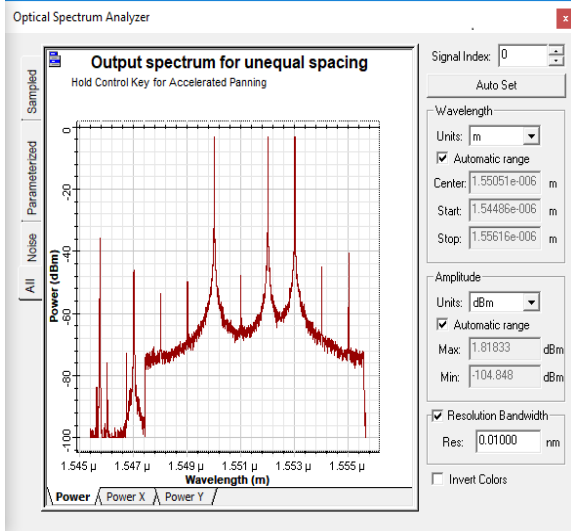


Fig.4 Output Spectrum of FWM for Unequal spacing

SRS will be reduced using the dispersion; there are two types of dispersion called intermodal and intramodal dispersion. The intermodal dispersion is also known as modal dispersion and it occurs only in multimode fiber. The intramodal dispersion occurs in both single and multimode fiber. It is chromatic dispersion and it is used here. When dispersion is applied the power tilt will be reduced, if the dispersion is more that will lead to intersymbol interference, which in turn increase the bit error rate.

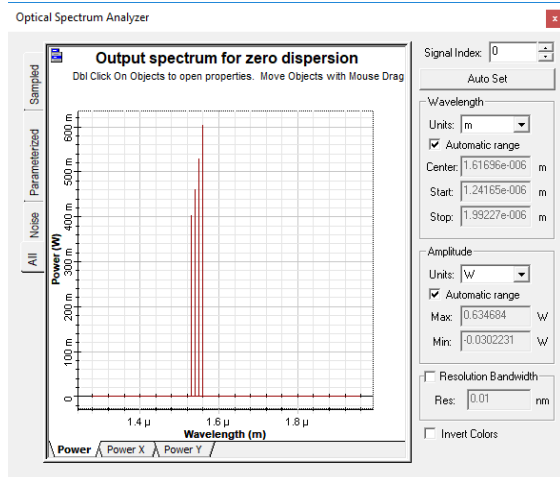


Fig.5 Output spectrum of SRS

The fig.5 shows the SRS effect for four channels. The power tilt is calculated between the first and the fourth channel. The power for the fourth channel is 600mW and the power for first channel is 400mW. So, the power tilt is 200mW. The fig.6 shows the reduced SRS effect after including dispersion of 4ps/nm/km. Here, the power for the fourth channel is 570mW and the power for first channel is 450mW. So, the power tilt is 120mW. So, the power tilt is reduced up to 80mW. While going beyond 4ps/nm/km, it leads to intersymbol interference, which in turn increases bit error rate.

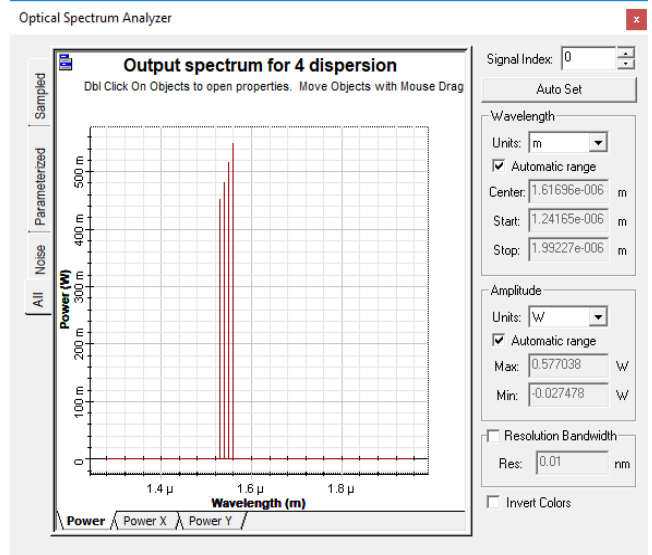


Fig.6 Output spectrum of SRS with dispersion

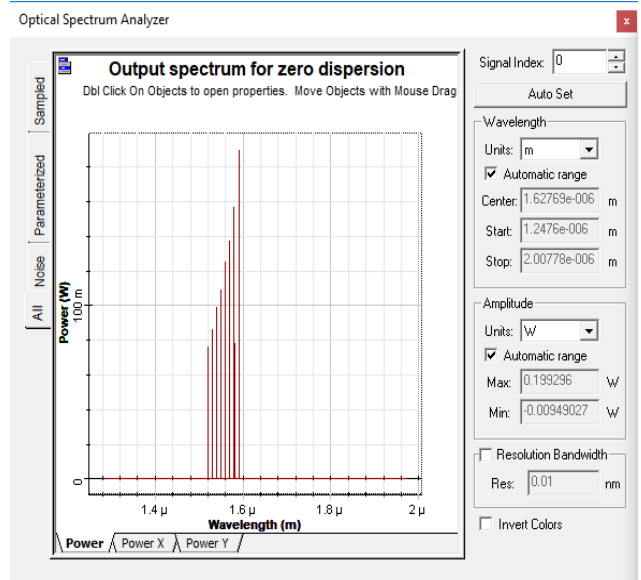


Fig.7 Output spectrum 8 channel SRS

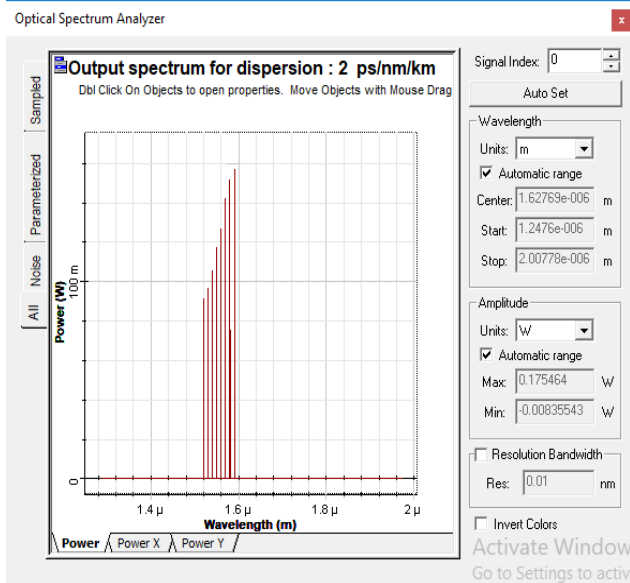


Fig.8 Output spectrum for 8 channel SRS with dispersion

The fig.7 shows the SRS effect for 8 channels. Here, the power for the eighth channel is 190mW and the power for first channel is 80mW. So, the power tilt is 110mW. The fig.8 shows the reduced SRS effect after including dispersion of 2ps/nm/km. Here, the power for the eighth channel is 175mW and the power for first channel is 90mW. So, the power tilt is 85mW. So, the power tilt is reduced up to 25mW. The SBS will be eliminated slightly by using low power channels than the SBS threshold and SBS is not more dangerous in WDM system as it will not create any crosstalk or attenuation. The unequal spacing with dispersion is a combating technique used to efficiently reduce the FWM and SRS effects in the fiber.

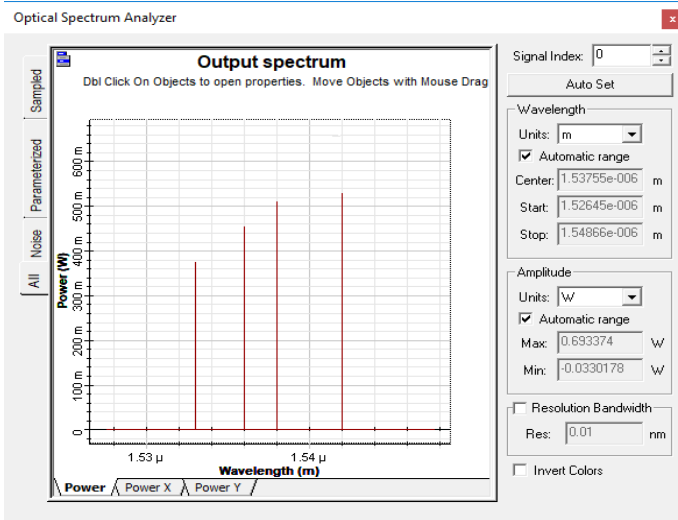


Fig.9 Output spectrum for unequal spacing with dispersion

The fig.9 shows the result of unequal spacing with dispersion of 2.5 ps/nm/km is used and the power of fourth channel is 540mW and first channel is 450mW. The power tilt of them is 90mW.

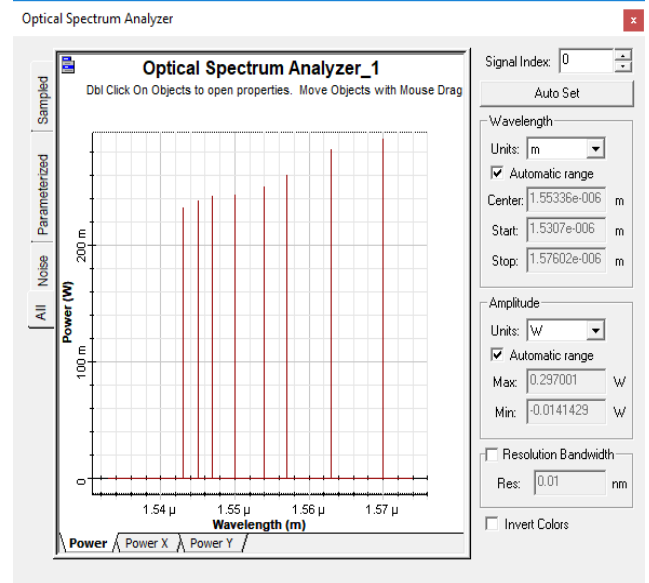


Fig.10 Output spectrum for 8 channel SRS with unequal spacing and dispersion

The fig.10 shows the technique of unequal spacing and dispersion for eight channels. The power of eighth channel is 295mW and the power of first channel is 230mW. So, the power tilt is 65mW. So, here the power tilt has been reduced much as compared to equal and unequal spacing techniques. So, unequal spacing with dispersion is an efficient technique for reducing SRS.

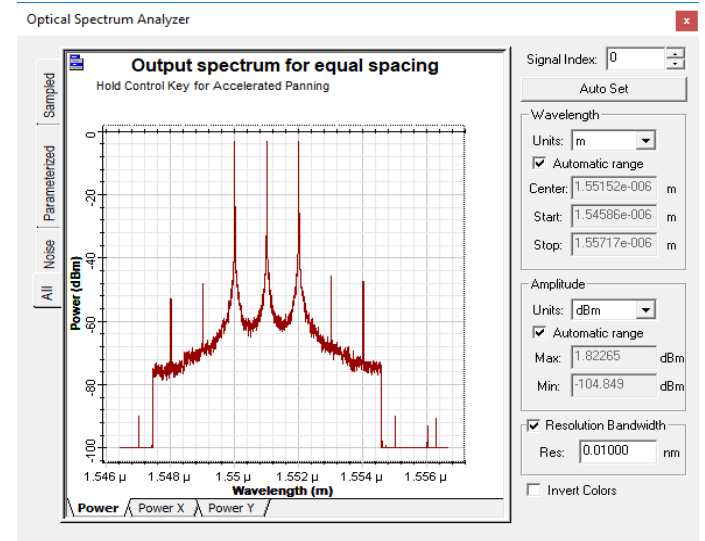


Fig.11 Output spectrum showing FWM terms for unequal spacing with dispersion

The FWM effect in the unequal spacing and dispersion technique as in fig.11 is reduced more compared to the unequal spacing technique alone as in fig 4. The dispersion of 5ps/nm/km is used for the reduction of FWM effect.

VIII. TABLE

Table 1: Four Wave Mixing Terms for different spacing

Technique used	No of FWM terms
Equal spacing	9
Unequal spacing	7
Unequal spacing with dispersion	4

Table 2: Comparing the power tilt of SRS effect

Method used	Number of channels	Power tilt without dispersion (mW)	Power tilt with dispersion (mW)	Comparison of power tilt (mW)
Equal spacing	4	200	120	80
	8	110	85	25
Unequal spacing	4	195	90	105
	8	180	65	115

IX. RESULT AND ANALYSIS

The nonlinearities that reduce the efficiency of the 5G are reduced by the unequal spacing and dispersion in the WDM system. From the above table, it is seen that unequal spacing with dispersion method has reduced more FWM terms and also power tilt is more reduced in this technique. When the two techniques were combined the power tilt is reduced and the amount of dispersion is also reduced for the SRS effect and the FWM terms are minimized. The channels with power less than SBS threshold power value will also reduce the SBS effect.

X. CONCLUSION

The effect of unequal channel spacing and dispersion on SRS and FWM are simultaneously analyzed for WDM systems by OPTISYSTEM layout. The variation of Power Tilt is compared for 4 and 8-channel WDM system for equal, unequal and unequal channel spacing with dispersion. As unequal channel spacing and dispersion are combined to mitigate the effect of SRS and FWM simultaneously, Dispersion process makes the signal to undergo pulse broadening at the initial stage of signal transmission through the fiber. So, the future work is implemented by overcoming this pulse broadening and transmitting the signal with large number of channels in fiber optic WDM systems.

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