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Impact of SRS in WDM Systems and Its Mitigation by Maximum Likelihood Sequence Detection

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Abstract : Non linear effects play a major role in hindering the progress of optical communication systems in terms of higher data rates and long haul transmissions. Maximum Likelihood Sequence Detection (MLSD) has been proposed to combat the nonlinear effects in optical channels. The main objective is to extract the original signal from the received signal which is distorted due to the non linear effects arising in the fiber. MLSD is an optimum detector as it uses the Viterbi detection through the Trellis structure. In this paper, the impact of SRS in the transmitted signal and its mitigation by MLSD are analyzed. MLSD is implemented for DWDM systems with 4 and 8 channels and its performance is compared with the direct detection receivers.

Index terms— Maximum Likelihood Sequence Detection (MLSD), WDM systems, Stimulated Raman Scattering, Viterbi detector.

I. INTRODUCTION

A long-haul transmission optical system commonly relies on high power laser to transmit optical pulse over long spans to overcome attenuation. Unfortunately, by using high power and increasing the number of optical channels, nonlinear effects become a prominent effect in WDM systems. Fiber nonlinearities are of critical concern because it limits the performance of optical fiber communication systems. The non linear effect can be divided in two categories. The first category is refractive index based phenomena, which cause phase modulation. This gives rise to nonlinearities such as self-phase modulation (SPM), whereby an optical signal alters its own phase; cross-phase modulation (XPM), i.e., the phase of one signal affecting the phase of all others optical signal and vice-versa; and four-wave mixing (FWM), whereby signal with different frequencies interfere to produce mixing sideband. The second category is scattering phenomena which leads to power loss. The scattering phenomenon is divided into two types. It is stimulated Raman scattering (SRS), and stimulated Brillioiun scattering (SBS).

In scattering effects, energy gets transferred from one lightwave to another at a higher or a longer wavelength. Due to the interaction between the light waves, some amount of energy is lost. This lost energy is absorbed by phonons (molecular vibrations in the medium). The wave that loses energy is called pump wave and the wave that acquires energy is called stokes wave. In case of SRS, the pump wave is a high power wave, and stokes wave is the signal wave that gets amplified at the expense of the pump wave. In SRS the power of the lower wavelength signals are transferred to the higher wavelengths. Power penalty is defined to be the difference in the power level between the shorter and longer wavelengths. As the input power is increased the power penalty is also increased.

II. MAXIMUM LIKELIHOOD SEQUENCE DETECTION

The term detection in maximum likelihood sequence detection includes the process of recovering signals that are subject to noise or interference, in our case it may be due to non linear effects. Maximum likelihood detection may include detection of transmitted data and estimation of transmitted symbols which formed part of the data before the effect of noise and/or interference during transmission. Maximum likelihood detection may also include the further step of decoding the data from an encoded format, although this is not an essential feature of a maximum likelihood detector. The detectors usually output an estimate of a signal before encoding or interference. A receiver implementing MLSD results in the optimum receiver as it calculates the most likely received sequence by the use of viterbi detector. The main objective is to find a noiseless output sequence with minimum distance from the detected noisy sequence of symbols. The estimate of {x(t)} is defined to be a sequence of values which maximize the likelihood function L(x) = P(r/x).The likelihood function describes the conditional probability of the received sequence r given the transmitted sequence x. The path metric used is square root metric (SQRT). When the transmitted signal has memory that is the signals transmitted in successive symbol intervals are interdependent, MLSD is a detector that bases its decisions on observation of a sequence of received signals over successive signal intervals. A MLSD algorithm searches for the minimum distance path through the trellis structure.

III. EXPERIMENTAL ANALYSIS

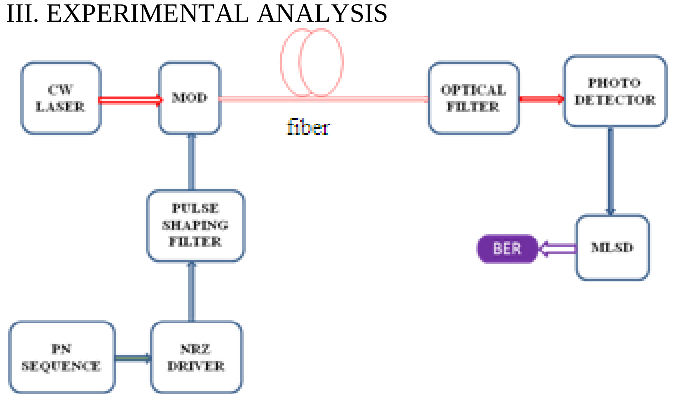

Fig 1: Block Diagram of an Optical Communication System

Figure 1 consists of the main blocks used in an optical communication system and it employs maximum likelihood sequence detector to estimate the received sequence that minimizes the errors due to the non linear effects. The functional blocks inside MLSD are shown in the fig 2

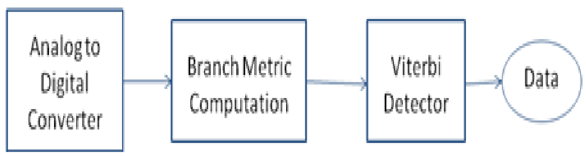

Fig 2: Blocks inside MLSD

The output of CW operated laser is externally modulated by a chirp-free single-electrode Mach-Zehnder modulator. The impact of the modulator extinction ratio (ER) was found to be modest across all metrics, but an infinite ER tends to be a "worst case" for the SQRT metric. The modulator driving signal is obtained by filtering ideal rectangular pulses of duration $T_b=1/R_b$. Where $R_b=10.7$ Gbit/s is the bit-rate, using a 5-pole low-pass Bessel electrical filter with bandwidth 7.5GHz. The fiber of length L [km] is linear and purely dispersive, with a dispersion value D=16ps/(nm km) approximately that of a SSMF.

At the RX input there is a second-order super-Gaussian optical filter with a-3dB bandwidth equal to 35 GHz, a value that is realistic for commercial dense wavelength-division-multiplexing (DWDM) systems with 50-GHz channel spacing. The optical filter is followed by an ideal photo-detector, followed in turn by a 5-pole Bessel post detection filter of bandwidth 7.5GHz. The RX electrical circuitry is assumed noiseless. The output of the filter is fed to an MLSE processor that consists of an A/D converter taking 4 samples per bit. The samples are then sent to a parallel array of branch metric computation stages. The extracted metric data is passed on to a 13-state Viterbi processing. For now, the A/D resolution is assumed infinite. The metric used in the MLSE processor in the Square root metric. It is the simple and an easy metric whose computation requires only one parameter, mean. The performance of MLSD receiver is compared and analyzed with that of the direct detection receivers. The fig.3 shows the blocks used in direct detection receivers respectively.

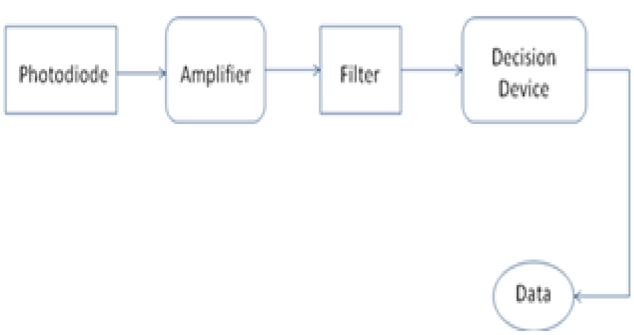

Fig 3: Blocks of a Direct Detection Receiver

IV. RESULTS AND DISCUSSIONS

The layout for WDM with 4 channels is shown in fig 4. System which we selected for analysis of SRS consists of CW lasers for input, ideal WDM multiplexer, optical fiber and optical spectrum analyzer to observe the output results. For SRS analysis in optical fiber communication system at various power levels, we vary the number of channels and power by keeping length of fiber unchanged.

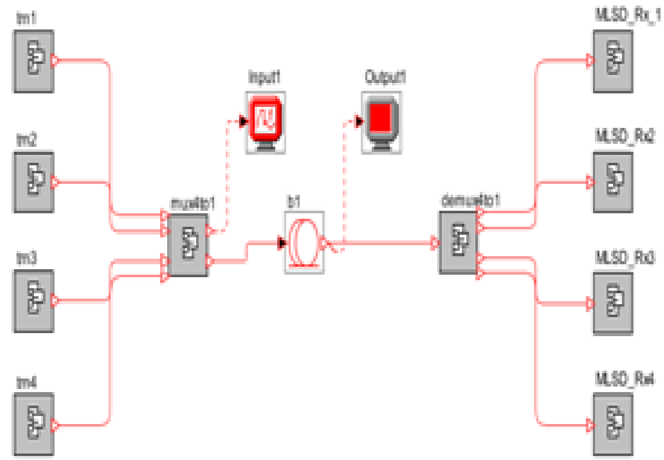

Fig 4 : Optsim layout for WDM systems for 4 channels

The compound component trn1 corresponds to individual transmitter whose look inside view is shown in the fig 5.

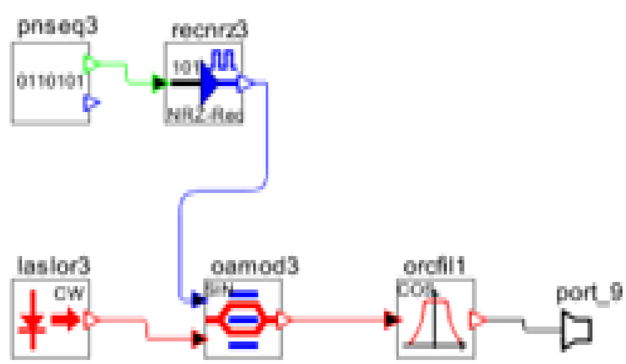

Fig 5: Look inside view of an individual transmitter

The SRS affected optical pulse for two levels of input power (3 dBm and 10 dBm) is shown in the fig 6 and fig 7 respectively. The green color spectrum indicates the optical signal before entering into the fiber and the red color spectrum corresponds to SRS affected spectrum after passing through the fiber. There is a power tilt in the signal after passing through the fiber as a result of SRS. It is seen that as the input power increases the power tilt between the lower and higher wavelengths also increases.

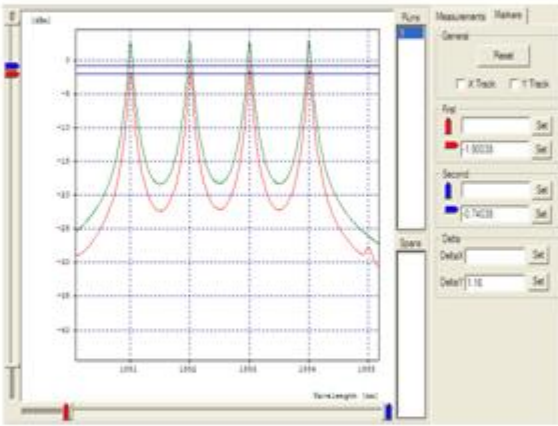

Fig 6: Spectrum of WDM for 4 Channels each with input power of 3 dB

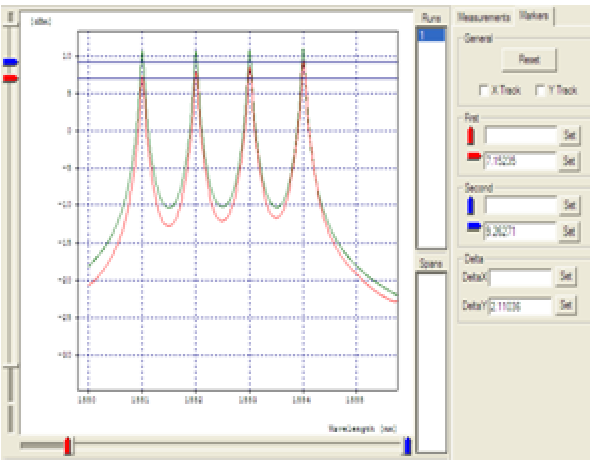

Fig 7: Spectrum of WDM for 4 Channels each with input power of 10dB

In case of MLSD at the receiver side, after the optical signal is received, it follows a photo diode where the optical signal is converted into its corresponding electrical signal. This analog electrical signal is converted into digital sequence.

Table1: BER performance for WDM with 4 channels

	Wavelengths in nm	BER [MLSD receiver]	BER [Direct detection receiver]
λ1	1548	0.66003E-03	0.11765E-01
λ2	1549	0.45902E-03	0.35714E-01
λ3	1550	0.31101E-04	0.47059E-01
λ4	1551	0.72003E-04	0.37296E-01

The next block is the branch metric computation as mentioned in the fig 2. It computes the branch metrics for received sequence and traces the minimum distance path through the trellis corresponding to that of the NRZ coding. In the case of direct detection receivers there is a decision device which decides whether the bit is 0 or 1 depending on a certain threshold value. BER is the number of bit changes in the received sequence versus the bits in through the trellis are calculated for a WDM system with 4 channels and tabulated in table1.

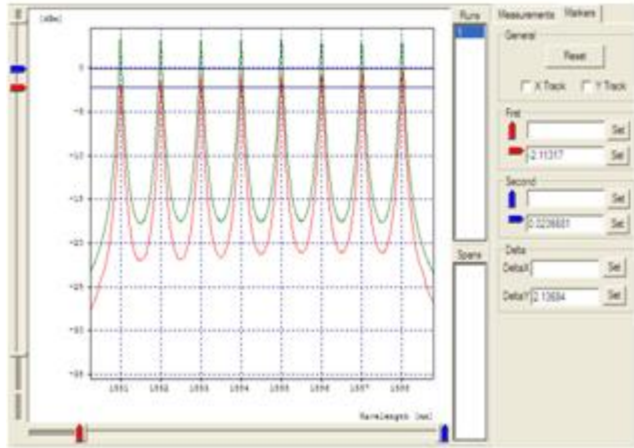

Fig 8: Spectrum of WDM for 8 Channels each with input power of 3 dB

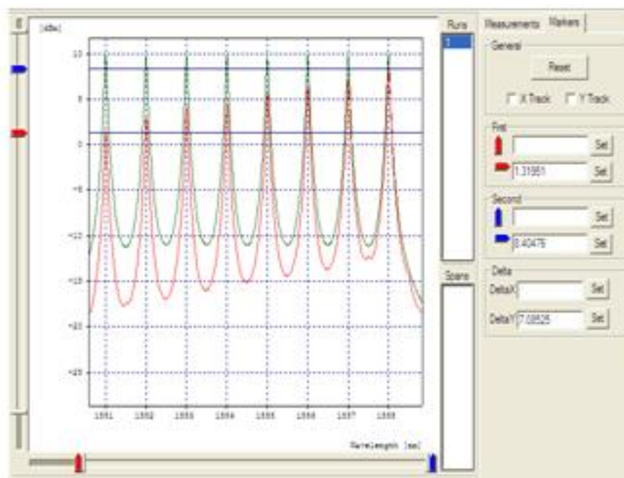

Fig 9: Spectrum of WDM for 8 Channels each with input power of 10 dB

It is evident that MLSD provides tolerable BER even in the presence of intense non linearity whereas the direct detection receivers provide large BER. The spectrum shown in the fig 8 and fig 9 corresponds for WDM system with 8 channels with two different levels of input power (3 dBm and 10 dBm). For the input power level of 10 dBm there is a maximum power tilt of 7.085 dBm. The main purpose of the MLSD receiver is to extract the original bits that were transmitted in spite of the power tilt present in the signal. Table 2 shows a comparison of MLSD and direct detection receivers for two different input power levels. It shows the maximum and the minimum range of BER obtained in both MLSD and direct detection receivers. The techniques here studied may be introduced in an optical communication system without touching the fiber already installed, and from the results here obtained, it may be observed that they are very effective in counteracting the effects produced by nonlinear effects such as SRS.

Table 2: Performance of MLSD and direct detection receivers

Number of channels	Input power (in dBm)	Power tilt (in dBm)	BER (MLSD)		BER (Direct Detection)	
			max	min	Max	min
4	3	1.16	0.70E-04	0.5E-05	0.59E-01	0.38E-02
4	10	2.110	0.45E-03	0.31E-04	0.47E-01	0.11E-01
8	3	2.136	0.82E-03	0.98E-04	0.19E-01	0.75E-02
8	10	7.085	0.14E-03	0.95E-04	0.32E-02	0.72E-02

V. CONCLUSION

There are many ways by which these SRS can be reduced. When the Input power is decreased, it is observed that the unwanted optical power tilt is also reduced. However by reducing the input power, number of channels in a WDM system is reduced. Hence Optimum power level settings in the fiber have to be set for WDM. Optimal processing is a key aspect for better exploiting the theoretically achievable spectral efficiency in the presence of fiber nonlinearities. This experiment shows that the MLSD at the receiver completely reduces the non linear effects and produces an acceptable range of bit error rates.

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