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Evaluation of Passive Optical Networks based on Transmitting Power Constraint

[1] Amrit Singh Bhatia, [2]Sanjay Kumar
[1] (M-Tech Scholar, PDM College of Engineering, Bahadurgarh, Haryana)
[2] (Assistant Professor, PDM College of Engineering, Bahadurgarh, Haryana)

Abstract: - In this paper, we evaluate the passive optical network based on the transmitting power constraint. A theoretical analysis is carried out to evaluate the performance of a Passive optical network (PON) in the presence of crosstalk due to optical fiber nonlinearities. In this paper most significant nonlinear effects such as four wave mixing (FWM), stimulated Raman scattering (SRS) are investigated in the presence of thermal short noise. Simulation result shows the performance of the passive optical network is bound to a limited range of the transmitting power. Experimental results concluded that four wave mixing (FWM), stimulated Raman scattering (SRS) can limit the launched power which is the basic requirement. Small launched power limit network expansion including length, distance, covered areas, and number of users accessing the network, unless suitable precautions are taken to reduce the effects of these nonlinearities in PONs.

Index Terms: **Passive optical network (PON), four wave mixing (FWM), stimulated Raman scattering (SRS), Optical fiber, transmitting power.**

I. INTRODUCTION

Due to the rapid development of fiber optic communication systems requires higher transmission data rate and longer reach. This paper deals with the limiting factors in design of long-haul fiber optic communication systems and the techniques used to suppress their resulting impairments. These impairments include fiber chromatic dispersion, the Ker nonlinearity and nonlinear phase noise due to amplified spontaneous emission. We focus on the impact of transmission impairments in high speed optical networks. Specifically it focuses on the impact of nonlinear impairments in long haul fiber optic data transmission systems.

The optical passive networks (PONs) communication system suffers from performance degradation due to fiber attenuation, chromatic dispersion and fiber nonlinear effects including stimulated Raman scattering (SRS), stimulated Brillouin scattering, four wave mixing, self- and cross-phase modulation [1-2]. Among all these effects, stimulated Raman scattering (SRS) and four waves mixing are the major limitations of system performance. One of the non-linear effect is four wave mixing (FWM) in which two signals at different wavelengths interact resulting in generation of "sum and difference" wavelengths [2]. The generated FWM components give rise to interference. The number of FWM components generated increases with the increase in number of users [3].

The Raman scattering effect is the inelastic scattering [4] of a photon with an optical phonon, which originates from a finite response time of the third order nonlinear polarization [5] of the material. When a monochromatic light beam propagates in an optical fiber, spontaneous Raman scattering occurs. It transfers some of the photons to new frequencies. The scattered photons may lose energy or gain energy. If photons at other frequencies are already present then the probability of scattering to those frequencies is enhanced. This process is known as stimulated Raman scattering.

In this paper, we evaluation the passive optical network based on the transmitting power constraint is presented. A theoretical analysis is carried out to evaluate the performance of an optical Passive optical network (PON) transmission system in the presence of crosstalk due to optical fiber nonlinearities. The optical signal performances degrade during transmission due to physical layer impairments of the network.

The rest of the paper is organized as follows: In section II, explain the basic of passive optical networks (PONs). In Section III, detail of the four waves mixing is given and how this affects the performance of PONs. Section IV explains the scattering based nonlinearity stimulated Raman scattering. In Section V, shows the simulation results of optical passive networks in the presence of the nonlinearities such as four wave mixing and stimulated Raman scattering. Result also shows the comparative analysis of PONs with respect to this nonlinearity. Finally, a conclusion is made.

II. PASSIVE OPTICAL NETWORKS (PONS)

A PON is a fiber network that only uses fiber and passive components like splitters and combiners rather than active components like amplifiers, repeaters, or shaping circuits. Such networks cost significantly less than those using active components. The main disadvantage is a shorter range of coverage limited by signal strength. While an active optical network (AON) can cover a range to about 100 km (62 miles), a PON is typically limited to fiber cable runs of up to 20 km (12 miles). PONs also are called fiber to the home (FTTH) networks [6-7].

The term FTTx is used to state how far a fiber run is. In FTTH, x is for home. You may also see it called FTTP or fiber to the premises. Another variation is FTTB for fiber

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to the building. These three versions define systems where the fiber runs all the way from the service provider to the customer. In other forms, the fiber is not run all the way to the customer. Instead, it is run to an interim node in the neighbourhood. This is called FTTN for fiber to the node. Another variation is FTTC, or fiber to the curb. Here too the fiber does not run all the way to the home. FTTC and FTTN networks may use a customer's unshielded twisted-pair (UTP) copper telephone line to extend the services at lower cost. For example, a fast ADSL line carries the fiber data to the customer's devices.

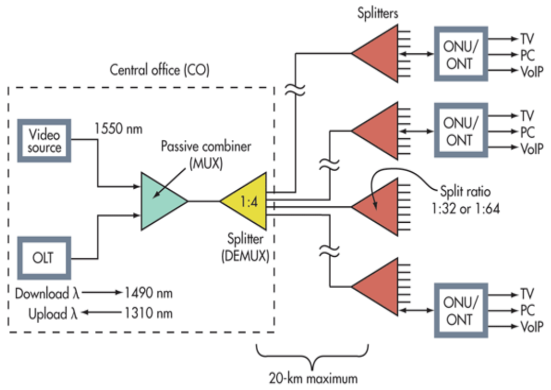

Fig. 1 Passive optical Network configuration

The typical PON arrangement is a point to multi-point (P2MP) network where a central optical line terminal (OLT) at the service provider's facility distributes TV or Internet service to as many as 16 to 128 customers per fiber line In fig. 1. Optical splitters, passive optical devices that divide a single optical signal into multiple equal but lower-power signals, distribute the signals to users. An optical network unit (ONU) terminates the PON at the customer's home. The ONU usually communicates with an optical network terminal (ONT), which may be a separate box that connects the PON to TV sets, telephones, computers, or a wireless router. The ONU/ONT may be one device [8]. In the basic method of operation for downstream distribution on one wavelength of light from OLT to ONU/ONT, all customers receive the same data. The ONU recognizes data targeted at each user [9-10].

III. FOUR-WAVE MIXING

Four-wave mixing is an intermodulation phenomenon in non-linear optics, whereby interactions between two wavelengths produce two extra wavelengths in the signal. It is similar to the third-order intercept point in electrical systems. Four-wave mixing is a nonlinear effect arising from a third-order optical nonlinearity, as is described with a $X_{(3)}$ coefficient. It can occur if at least two different frequency components propagate together in a nonlinear medium such as an optical fiber [11]. Assuming just two input frequency components f_1 and f_2 (with $f_2 > f_1$), a refractive index modulation at the difference frequency occurs, which creates two additional frequency components. In effect, two new frequency components are generated: $f_3 = f_1 - (f_2 - f_1) = 2f_1 - f_2$ and $f_4 = f2 + (f2 - f1) = 2f2 - f1$. Furthermore, a pre-existing wave the frequency f_3 or f_4 can be amplified.

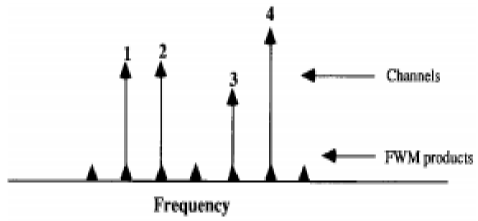

Fig.2 Effect of four wave mixing

The simplest picture of the four-wave mixing process in fibers can be illustrated by the transmission and cross-phase modulation of four equally spaced channels shown in Fig. 2 Channels 1 and 2 interfere, producing an index of refraction which oscillates at the difference frequency. This modulation in refractive index modulates channel 4, producing sidebands at channels 3 and 5. This is only the simplest combination of frequencies. Four-wave mixing allows any combination of three frequencies beating together to produce a fourth. If the fourth frequency lies within a communication band, that channel can be rendered unusable [12].

This channel interference can affect either closely spaced channels, as one encounters with coherent communications, or the rather widely separated channels of a PONs system [8]. Efficient four-wave mixing requires phase matching of the interacting waves throughout the interaction length widely separated channels will therefore be phase matched only in a region of low-fiber dispersion [18].

IV. STIMULATED RAMAN SCATTERING

SRS is due to interaction of incident light wave with vibrational modes of silica molecule i.e., if two or more optical signals at different wavelengths are injected into a fiber, SRS causes energy from lower wavelength channels to be transferred to the higher wavelength channels [13]. This in turn reduces the signal-to-noise ratio of the lower wavelength channels and introduces crosstalk on higher wavelength channels which can lower the information carrying capacity of the system [14]-[17]. The threshold power in case of SRS can be estimated as

$$P_{th} \approx 16 A_{eff} / g_R L_{eff} \quad (1)$$

Where gR is the Raman gain and Leff the effective length of the fiber. If the fiber is sufficiently long, then Leff ≅ 1/α. In that case

$$P_{th} \approx 16 A_{eff} \alpha / g_R \quad (2)$$

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The value of gR is 1 x 10-13 m/W for silica at λ =1550 nm. The value of α as 0.2 dB/km and Aeff as 55 2 µm, results in Pth equal to 570 mW. Hence, the effect of SRS is insignificant in case of single channel.

In case of N equally spaced channels with frequency separation between adjacent channels Δf Hz, assuming scrambled polarization and Raman gain g_R to be linear, the power loss due to SRS by the shortest wavelength (i.e., first) channel is given by

$$D = \sum_{i=2}^{N} (m_i) \frac{P_i \gamma_i L_{eff}}{2A_{eff}} \qquad (3)$$

Where m_i is the modulation of i^{th} channel, P_i the power injected in i^{th} channel in watts and γ_i the Raman gain coefficient coupling the i^{th} channel and first channel. Assuming the Raman gain profile to be triangular, γ_i is given by

$$\gamma_i = \begin{cases} \frac{(i-1)\Delta f}{1.5x10^{13}} \gamma_p & \text{for } i\Delta f < 1.5x10^{13}\, Hz \\ 0 & \text{otherwise} \end{cases} \qquad (4)$$

Where γ_p is the peak Raman gain coefficient. Since m_i are independent random variables, power depletion D converges to a Gaussian random variable [19].

V. RESULT AND DISCUSSION

In this section, simulation results are presented for the evaluation of the passive optical networks (PON). To analysis the performance of the system is presented based on these parameters as thermal and short noise, four wave mixing, and Stimulated Raman Scattering. Simulation results present the power transmitted analysis of the different factor individually.

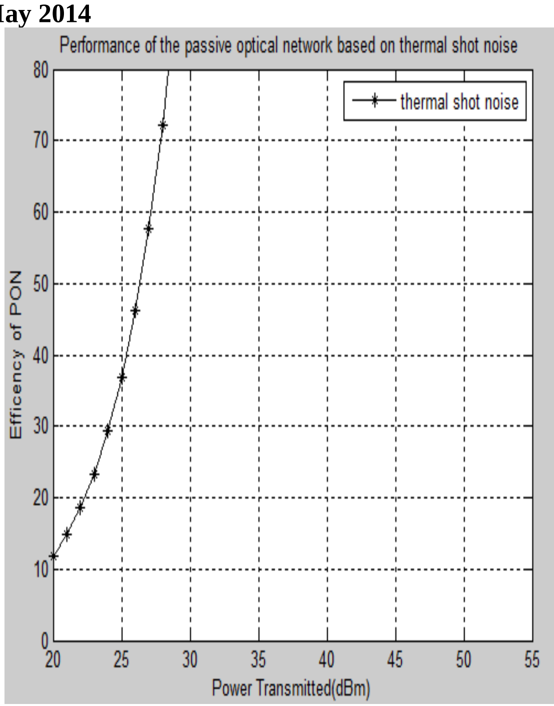

Fig: 3 Efficiency of passive optical networks varied with transmitted power and thermal shot noise

Fig: 3 shows the efficiency of passive optical networks varied with transmitted power and thermal shot noise. Fig: 4 depict the efficiency of passive optical networks varied with transmitted power and four waves mixing. Fig: 5 demonstrate the efficiency of passive optical networks varied with transmitted power and stimulated Raman scattering. Fig: 6 shows the efficiency of passive optical networks varied with transmitted power, four wave mixing and thermal shot noise. The efficiency of passive optical networks varied with transmitted power, four wave mixing, and thermal shot noise and stimulated Raman scattering are presented in fig 7.

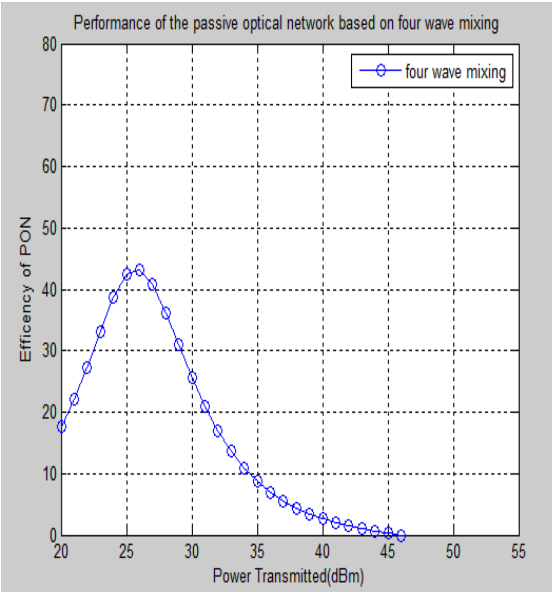

Fig: 4 Efficiency of passive optical networks varied with transmitted power and four wave mixing

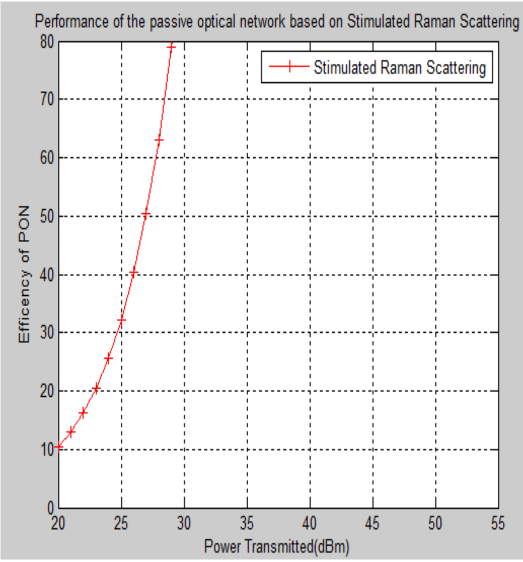

Fig: 5 Efficiency of passive optical networks varied with transmitted power and stimulated Raman scattering

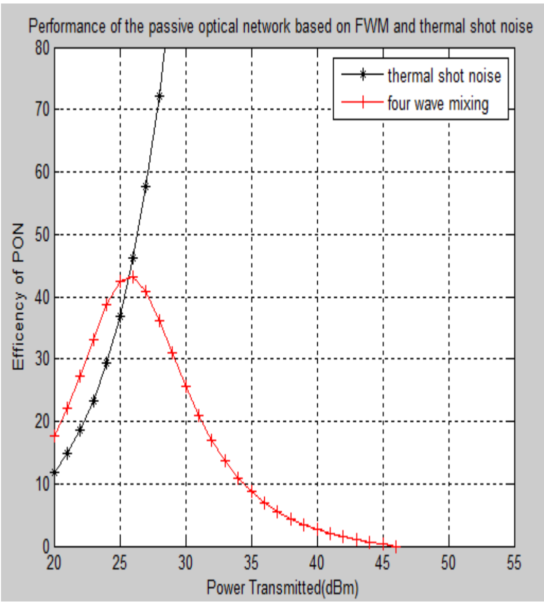

Fig: 6 Efficiency of passive optical networks varied with transmitted power, four wave mixing and thermal shot noise

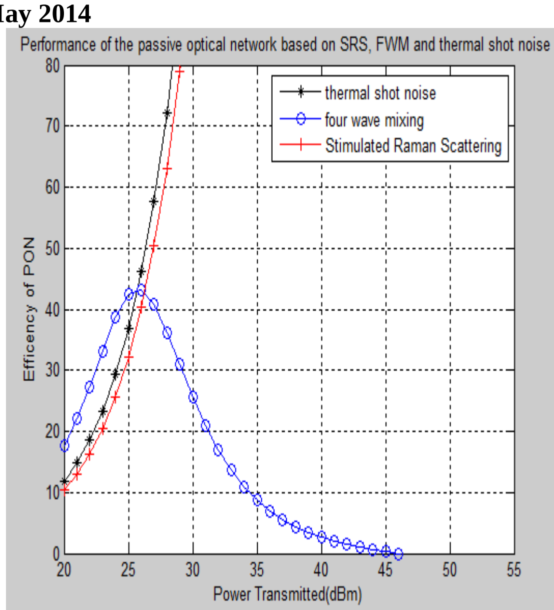

Fig: 7 Efficiency of passive optical networks varied with transmitted power, four wave mixing, thermal shot noise and stimulated Raman scattering

VI. CONCLUSIONS

In this paper, we evaluation the passive optical network based on the transmitting power constraint is presented. Most significant nonlinear effects such as four wave mixing (FWM), stimulated Raman scattering (SRS) are investigated in the presence of thermal short noise. Simulation result shows the performance of the passive optical network is bound to a limited range of the transmitting power. Experimental results concluded that wave mixing (FWM), stimulated Raman scattering (SRS) can limit the launched power which is the basic requirement. Results show the effect of different type of nonlinearities in the passive optical networks and how the transmitted power bound the transmission distance and the number of users in the optical system

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