Impact of nonlinearity phenomenon FWM in DWDM optical link considering dispersive fiber

William S. Puche*a, Ferney O. Amayaa, Javier E. Sierraa

a Research Group on Development and Application in Telecommunications and Informatics - GIDATI, Universidad Pontificia Bolivariana, Laureles Campus Circular 1 No.70-01, Medellin Colombia.

ABSTRACT
The increasing demand of network traffic requires new research centers; improve their communications networks, due to the excessive use of mobile and portable devices wanting to have greater access to the network by downloading interactive content quickly and effectively. For our case analyze optical network link through simulation results assuming a DWDM (Dense wavelength Division Multiplexing) optical link, considering the nonlinearity phenomenon FWM (Four Mixed Wavelength) in order to compare their performance, assuming transmission bit rates to 2.5 Gbps and 10 Gbps, using three primary wavelengths of 1450 nm, 1550 nm and 1650 nm for the transmission of information, whose separation is 100 GHz to generate 16 channels or user information. Tests were conducted to analyze optical amplifiers EDFAs link robustness at a maximum distance of 200 km and identify parameters OSNR, SNR and BER, for a robust and effective transmission.

Keywords: Wavelengths, DWDM, OSNR, SNR, Four Wavelength Mixed, Optical Fiber, Dispersion, Optical Amplifier.

1. INTRODUCTION
The increase in interactive entertainment services currently provided by telecommunications networks, as well as the trend towards convergence of IP voice services over a single network platform allow users of these services begin to make use mass of these tools, increasing traffic levels and especially the bandwidth. For this reason it is necessary to establish performance parameters offered by the different optical access techniques for improving the quality of information in robust networks and applied to a greater distance in its spread [1]. The results of the simulations allow to contribute to the problem of establishing how best medium access technique for a set operating environment, looking for the highest performance possible (high-speed operation, low distortion, etc.) and low costs. This knowledge may be of interest to a company that has optical networks; it would help to determine the best configuration of equipment and technology to achieve high competitiveness in the medium.

How is a technology that has recently taken a high boom relatively new research and implementation in our country, there is an accurate model to simulate and project performance parameters and nonlinear phenomena (FWM) in an all-optical network, for long distances [2]. This sparked an interest in this model and determines depth study of this technology. Basically, the problems of this type are based on the massive use of the Internet and the rapid development of applications such as email, web pages, chat, virtual education, video games, video conferencing, interactive TV, among many others. This establishes that required project and expand the bandwidth of the network, thereby supporting this traffic, increase the speed of operation and especially the low cost projected for future years. It is very important to note that what is sought with this degree project is to improve the transmission and receipt of information on this type of optical networks [3].

Among the major research centers in optical communications who study these phenomena whose impact is high worldwide have the optical communications laboratory of University of Southern California, The research center of the university has a lot of technology for the measurement parameters, observation of nonlinear phenomena applied to optical systems, among others. Within their teams, have different optical devices and simulation tools as OptSim, making this a very reliable computational tool [4]. We also found the University of Arizona, which is highly recognized worldwide for its capabilities and infrastructure. Among the areas of interest for the development of practice and experimentation is the issue design methodology for DWDM backbone networks using FWM -aware heuristic algorithm...
This article is intended to show the efficiency of the optical network through simulations, delving into the technical aspects of an optical link in the access network, the different services that can be offered, taking into account the modeling techniques access specified in the optical network to be used, which are key points to keep in mind when designing these networks.

These models allow the development of simulations, considering multiple users with simultaneous access of different transmission rates. The results will be valuable for those companies that are in the implementation stage of this kind of technology, as well as providers of this type, where applications will be supported by broadband infrastructure with best speed of operation. This will result in benefits for suppliers, enhancing the effect of their investments to satisfy the users with high quality services in a timely and affordable.

The organization of the paper is as follows: Chapter II presents a brief summary of the optical access network. Chapter III presents nonlinearity phenomena and analysis fourth wave mixing (FWM) in the optical network. Chapter IV presents the analysis and simulation results. Finally, Chapter V presents the conclusions.

2. OPTICAL ACCESS NETWORK

Optical access networks, known as FTTx (Fiber to The x) have grown in popularity as they allow greater reach, bandwidth and quality of service than the access networks based on copper. According to ITU G.983.1, the components of an optical access network (OAN) are:

- Optical Distribution Network (ODN) provides the optical transmission medium from the OLT to the users.
- Optical Line Terminal (OLT) provides the interface to the network side of the OAN and is located in the HE or CO and serves a number of ONUs on a point-to-multipoint topology or tree.
- Optical Network Unit (ONU): the user interface side of the OAN, which corresponds to the OLT optical fiber ends. In FTTH called Optical Network Terminal (ONT).

Section ODN can be active or passive and architecture can be point to point or point to multipoint. Some architectures for optical access networks OAN for FTTx, FTTx architectures differ in the proximity of the UN with the end user, with the architecture Fiber to the Home (FTTH) the most close, followed by the architecture Fiber to the Building / Running (FTTB / C, Fiber to the Building / Curb) and finally Fibre to the Cabinet (FTTCab, Fiber to the Cabinet).

FTTB architecture has two scenarios, one for multi-dwelling units (MDU Multi - Dwelling Unit) and the other for businesses [5, 6].

In FTTB MDU asymmetric services are used such as digital broadcasting services, video on demand (VOD, video on demand), and downloading files. Also used symmetric services such as content delivery, email, file sharing, distance learning, telemedicine, and online games. These services can be supplemented with telephone service (POTS Plain Old Telephone Service) and integrated services digital network (ISDN). In Enterprise FTTB lend symmetrical broadband services such as applications for Workgroups, content delivery, email and file sharing, complementing with POTS. In FTTH architectures, FTTC, FTTCab offered asymmetric and symmetric services as used in FTTB MDU or depending on the business scenario.

FTTH has grown in popularity and respects are two choices: point to point and PON (Passive Optical Network) the latter being more economical [7].
2.1 Limitations of Optical Networks

Currently the deployment of optical networks has some drawbacks, which are listed below [8, 9]:

- Low maturity recent DWDM devices.
- Existence of chromatic dispersion and polarization mode fibers already installed.
- Accumulation of earnings differences for different wavelengths in networks with serial EDFA (Doped Fiber Amplifier Erbium).
- Packet switching on the optical layers requires the availability of storage buffers in optical nodes.
- The tunable devices are expensive and have low tuning range which reduces the amount of multiplexing channels.
- Absence of effective methods of administration and network management.

3. PHENOMENA OF NON-LINEARITY AND ANALYSIS OR FOUR-WAVE MIXING OF FOUR WAVE MIXING (FWM) IN OPTICAL NETWORK

Understand that optical communication systems behave linearly is an adequate approximation when operating at moderate power levels. However, at high speeds and very high power, they begin to be noticeable the effect of nonlineairties, and in the case of WDM systems these effects are significant, limiting the number of channels in the system and the separation between them [10, 11].

As is known, nonlinearities can be categorized into two categories:

- Those that occur due to the dependency of the refractive index with the field intensity (also known as Kerr effect) applied, which in turn is proportional to the square of the amplitude: autotamge modulation (SPM), cross-phase modulation (CPM) and four wave mixing (FWM).
- The effects which are caused by scattering in the fiber, due to the interaction of light waves with phonons (molecular vibrations) in the silicon to stimulated Raman scattering (SRS) and stimulated Brillouin scattering (SBS).

Any dielectric response to electromagnetic fields is a nonlinear response. Therefore, by applying an electric field to an optical fiber $E$ is a field-induced polarization resulting $P$ is nonlinear with $E$ field. In terms of homogeneity, isotropy, but non-linearity, the field $P$ can be expressed as [12]:

$$ P_{(t,r)} = P_L(r,t) + P_{NL}(r,t) $$

(1)

Where $P_L(r,t)$ corresponds to linear polarization and $P_{NL}(r,t)$ condition is called nonlinear polarization, which as its name suggests arises due to nonlinearity conditions. Furthermore it holds that [12]:

$$ P_{NL}(r,t) = e_0 c^{(3)} E^{(3)}(r,t) $$

(2)

Where $c^{(3)}$ is called the nonlinear susceptibility of the third order. The susceptibility of the second order nonlinear $c^{(2)}$ is not taken into account as unimportant materials with molecular symmetry as in the case of SiO2.

Since the refractive index is related by the equation susceptibility [13, 14]

$$ \hat{n}(E) = n + \frac{3}{8n} X^{(3)} E^2 $$

(3)

Nonlinear polarization that is causing the refractive index comes to depend on the field intensity giving rise to nonlinear effects such as SPM, CPM or FWM.

Moreover, the effects of scattering, a photon of the incident wave disappears to give rise to a lower frequency photon and phonon energy and the right time. In this way, as the incident wave propagates through the fiber loses power it will stop another wave called Stokes wave. In general, scattering phenomena are characterized by a gain coefficient $g$, and a power threshold at which effects begin to be noticeable. [14]
3.1 Optical Access Network fourth wave Mixing (FWM)

FWM is a phenomenon whereby when several waves propagate frequencies \(w_i, w_2, \ldots, w_N\), where the intensity dependence of the refractive index not only induces phase shifts within each channel but also the appearance of new waves frequencies \(w_i \pm w_j \pm w_k\). Among these signals, the most problematic are those that relate to:

\[w_{(i,j,k)} = w_i + w_j - w_k,\]  
(4)

with \(i\) and \(j\) different from \(k\).

Because media in which the dispersion is not zero the rest of them can be neglected due to the lack of phase matching. To understand the effects of FWM can be considered a three-channel WDM system where the electric field is of the form [15]:

\[E_{(i,j)} = \sum_{i=1}^{3} E_i \cos(w_i \tau - \beta_i z),\]  
(5)

where \(w_{(i,j)} = w_i + w_j - w_k\), \(i, j, k = \{1,2,3\}\) with \(i\) and \(j\) different from \(k\).

Even in the presence of dispersion, they can satisfy the phase matching condition by having an almost constant propagation constant for those frequencies, but the other components will not be satisfied, and therefore may be neglected. Taking into account losses in the fiber, the power of these new waves generated due to the FWM effects [15, 16], is:

\[P_{i,j,k} = \left(\frac{w_{i,j,k} \eta d_{i,j,k}}{3 \times c \times A_c}\right) \times P_i \times P_j \times P_k \times \eta \times e^{-\alpha z},\]  
(6)

where \(d_{i,j,k}\) degeneration is a factor whose value is 3 when \(i = j\), and value 6 when \(i\) is other than \(j\).

Of the various devices used to induce FWM photonic, optical fibers are one of the most studied. As mentioned in the introduction, for the generation process to be efficient, it is necessary to work near the wavelength of zero dispersion. Therefore, dispersion-shifted fibers become the leading candidate. Then we will study the characteristics of FWM on these devices. FWM process in optical fibers has been extensively studied [15, 16, 17]. Their origin is due to induced polarization in the medium is nonlinear with respect to the applied field, but contains a nonlinear term whose magnitude depends on the nonlinear susceptibility of the third order \(x^{(3)}\) according to [15]:

\[P_{NL} = \varepsilon_0 \times x^{(3)} \times E,\]  
(7)

where \(E\) is the electric field, the polarization \(P_{NL}\) is induced nonlinear and \(\varepsilon_0\) is the vacuum permittivity. Now considering four optical waves oscillating at frequencies \(w_1, w_2, w_3\) and \(w_4\) linearly polarized along the same axis \(x\), the total electric field vector can be written as:

\[E = \hat{x} \left[\frac{1}{2} \sum_{i=1}^{4} E_i \exp\left[j(w_i \tau - k_i z)\right]\right] + c,\]  
(8)

where \(k_i = \frac{n_i w_i}{c}\), and \(\hat{n}\) is the refractive index of the \(i\)-th wavelength, and assuming that all the waves propagate in the same direction \(z\). If then substitute (8) in Eq. (9) and express \(P_{NL}\) of the form [15]:

\[P_{NL} = \hat{x} \left[\frac{1}{2} \sum_{i=1}^{4} P_i \exp\left[j(w_i \tau - k_i z)\right]\right] + c,\]  
(9)
is that for $i = 1,2,3,4$, consisting of a large number of product terms involving three electric fields. For example, $P_{NL}$ may be expressed as [16]:

$$
P_4 = \frac{3E_0}{4} \left\{ \left| E_4 \right|^2 + 2 \left| E_2 \right|^2 + \left| E_3 \right|^2 \right\} \left\{ E_4 + 2E_2E_3 \exp(j\theta_2) + 2E_1E_3 \exp(j\theta_3) + \ldots \right\},
$$

(10)

where $x = \frac{3n_0}{8} N^2_2$ and phases are calculated as [16]:

$$
\theta_+ = (w_1 + w_2 + w_3 - w_4) t - (k_1 + k_2 + k_3 - k_4) z, \quad (11)
$$

$$
\theta_- = (w_1 + w_2 - w_3 - w_4) t - (k_1 + k_2 - k_3 - k_4) z, \quad (12)
$$

The term proportional to $E_4$ is responsible for the phenomena of SPM and XPM, while the remaining terms are responsible for FWM. The efficiency of these terms depends on the relative phase between $E_4$ and $P_4$, given by $\theta_+, \theta_-$, or a similar angle. A significant FWM occurs if the relative phase practically vanishes, which requires matching the frequencies besides wave vectors. This requirement is commonly referred to by the name of phase matching (phase matching).

In terms of quantum mechanics, the FWM occurs when two or more photons are destroyed waves and create new photons at different frequencies, so that the net energy and momentum are conserved during parametric interaction. The main difference between the parametric processes and stimulated scattering processes is that the phase condition is automatically satisfied in the case of Raman scattering or stimulated Brillouin, as a result of active nonlinear medium. By contrast, the condition of phase requires an appropriate choice of the frequencies and refractive indices for the parametric processes occur.

Now, there are two types of FWM terms. The first of them corresponds to the case in which three photons transfer their energy to a single photon of frequency $w_4 = w_1 + w_2 + w_3$. This term is responsible for the phenomenon known as third harmonic generation when $w_1 = w_2 = w_3$, or frequency conversion wave $2w_1 + w_3$ when $w_1 = w_2 \neq w_3$.

In general, it is difficult to satisfy the condition of phase so that these processes occur with high efficiencies in optical fibers, so that from now on we will refer to the second of the FWM terms. The latter term corresponds to the case where two-photon frequencies $w_1$ and $w_2$ disappear along with the simultaneous creation of two photons at frequencies such that $w_3 + w_4$ where $w_3 + w_4 = w_1 + w_2$, [16].

### 3.2 Analysis (FWM) in the fiber

Now consider the propagation of the FWM process in SMF. Using similar notation to that of [16], the electric fields of the four waves can be written as:

$$
E_j = A_j(z) F_j(x, y) \exp \left[ j \left( w t - k_j z \right) \right],
$$

(13)

where $F_j(x, y)$ are wave functions that describe the distribution section of each wave in the fiber. $A_1$ and $A_2$ represent pumping waves while $A_3$ is the input signal and $A_4$ the signal generated by FWM conjugate. Note that $A_j$ is not time dependent, since it is analyzing the case of continuous wave (without modulation). In the analysis it is assumed that four frequencies are close to the zero dispersion point of the SMF. However, the spacing between the four waves is assumed large enough to only induce FWM while mixing processes between the higher-order waves generated and the new entry can be ignored. Furthermore, the analysis is performed without considering the SPM or XPM. This is justified in the case of moderate input powers, which is true for laser diodes operating near 1300 or 1500 nm. First, we analyze
the non-degenerate FWM case where four frequencies are considered different. This process is governed by the following system of coupled modes equations [17]:

\[
\frac{dA_1}{dz} = -j\frac{N_2w_1}{c}2f_{1,2,3,4}A_2^*A_1A_4\exp(j\Delta kz) - \frac{\alpha}{2}A_1,
\]

(14)

\[
\frac{dA_2}{dz} = -j\frac{N_2w_2}{c}2f_{2,1,3,4}A_1^*A_3A_4\exp(j\Delta kz) - \frac{\alpha}{2}A_2,
\]

(15)

\[
\frac{dA_3}{dz} = -j\frac{N_2w_3}{c}2f_{3,4,1,2}A_1^*A_2A_4\exp(j\Delta kz) - \frac{\alpha}{2}A_3,
\]

(16)

\[
\frac{dA_4}{dz} = -j\frac{N_2w_4}{c}2f_{4,3,1,2}A_1^*A_2A_3\exp(j\Delta kz) - \frac{\alpha}{2}A_4.
\]

(17)

Where \( f_{i,j,k,l} \) are constants describing the overlapping of the modes in the SMF. As noted, the terms of the SPM and XPM responsible were discarded (14) and (15), like the dispersive effects since there is no modulation of the carrier [17].

4. ANALYSIS AND RESULTS

In this study we evaluated the behavior of the transmitted signal, from a brief explanation about the topology of this technology. Analyze the simulation scenario for a video signal wavelength of 1450 nm, 1550 nm and 1650 nm of 20-200 km with the idea of analyzing the FWM nonlinear effects, and the power spectrum is generated due to FWM at the output of an optical fiber. The simulation in a certain part considers a system consisting of three different shades of the third transmission window whose power does not exceed one watt. Moreover parameters are analyzed signal to noise ratio, Q factor, eye diagram and optical power in the link. It is important to look at the behavior of nonlinear phenomena at these distances, allowing us to identify how robust is the link and we can look forward to improved streaming link of 1500 km (in research), improving the number of repeaters, splitters, amplifiers, filters, etc. Given these analyzes I can determine how effective the link.

![Figure 1. Employed optical network link](http://proceedings.spiedigitallibrary.org)
rates and spectral widths for distances between 20 km and 200 km in fiber length. The tests were performed using the PIN detector.

For the propagation of the signal in the optical link taking into account the non-linear effect FWM, tests were implemented rates Gbps and 10 Gbps 2.5, enough to transmit video to all network users. Tests were conducted with different values of spectral width (FWHM). The spectral width of the optical source directly affects the cost.

Fiber type was used standard 20 km, 40 km, 60 km, 90 km, 120 km, 150 km, 170 km, 200 km in length and was tested with different number of users on the network using DWDM.

In Figure 2 we analyze the link test for the three wavelengths set, but the idea is to implement a wide range between the minimum wavelength to the maximum, allowing users to have more numbers and see how robust is behaves.

For our case in Figure 3, considering I simulate 32 channels with the parameters established in the beginning of ie wavelengths from 1450 nm to 1650 nm with a main length of 1550 nm.

In this figure 4 we can observe the behavior of the input and output signal power in the spectrum, given the FWM. For the case are spreading the 32 channels with significant power consumption.
The simulation in Figure 5 we can see the power spectrum generated by the effect of four wave mixing (FWM) from three different shades of the third transmission window. Therefore, the spectrum shows both the power of the wavelength and starting each tone of each of the spurious generated. In addition, to take into account the effect of fiber loss, the user can select the absorption coefficient of the fiber. First placed the following: a first tone $\lambda_1 = 1551$ mm, a second tone $\lambda_2 = 1554.5$ mm, and the absorption coefficient of the fiber $0.217$ dB / km.

In the graphical representation can assess the three tones starting position not yet started to propagate and hence has not generated any spurious, however, the summary table to the right and indicates which wavelengths generate when propagating the spurious tones.
Analyzes and verifies that the wavelengths to which the spurious are generated 1.44, 1.47, 1.48, 1.5, 1.51, 1.54 and 1.55 mm, in Table 1, these correspond to the expression: \( \lambda_{i,j,k} = \lambda_i + \lambda_j - \lambda_k \) for \( i, j, k = \{1, 2, 3\} \) with non-\( k \). Now if we analyze the simulation figures 5 and 6, in several steps, you will see that the tones spread 3 km and 6 km. The spurious start growing in power since despite the loss of fiber, the FWM effect causes the spurious power increase with distance. However, the tones starting to suffer the losses are losing power. It may also seem strange that considering constant losses with frequency, the three initial tones not continue to have the same value of power (power 1 is distinct power 2 and 3).

Table 1. Relationship wavelength Vs power

<table>
<thead>
<tr>
<th>Wavelength(nm)</th>
<th>Power (mW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1444</td>
<td>0.259</td>
</tr>
<tr>
<td>1470</td>
<td>1.988</td>
</tr>
<tr>
<td>1480</td>
<td>0.245</td>
</tr>
<tr>
<td>1500</td>
<td>0.239</td>
</tr>
<tr>
<td>1510</td>
<td>6.067</td>
</tr>
<tr>
<td>1540</td>
<td>6.067</td>
</tr>
<tr>
<td>1550</td>
<td>1.788</td>
</tr>
<tr>
<td>1570</td>
<td>0.218</td>
</tr>
<tr>
<td>1580</td>
<td>6.067</td>
</tr>
<tr>
<td>1610</td>
<td>1.657</td>
</tr>
<tr>
<td>1620</td>
<td>0.205</td>
</tr>
<tr>
<td>1650</td>
<td>0.197</td>
</tr>
</tbody>
</table>

This is due to the shake base tones caused some spurious generated with different powers on the same frequencies as those of the starting tone. If we change the wavelength of the third tone starting, do not generate any spurious that it overlaps starting tones, and therefore these, although spreading as they are going to lose power, always coincide in value. If we give and analyze the spurious more steps are taking increasing presence in relation to the starting tone.

It is very important to keep this fact, since in general our system will have to meet a certain SNR and therefore limit the FWM distance links. Anyway, from a certain distance, in this case 200 km. approximately for spurious fiber losses will outweigh the effect of FWM and also begin to lose power.

Now if you increase the power of any or all starting tones given the same wavelengths with the same power of 10 mW, was analyzed the value of the spurious power generated at that distance, the effects of FWM increase with the potency of the starting tone is, if we start with greater power tones, the spurious generated will also have greater power. Finally, if we change the value of the absorption coefficient (0.217 dB / km to 0.3 dB / km), to increase the absorption loss increase, and thus starting tones as spurious lose power faster.

It is concluded that these results that as we lower the propagation distance there will be a better performance in signal propagation. Can be seen that increasing the bit rate decreases the value of BER. This effect is attributed to the dispersion of the optical fiber.

Shows that the BER in the video signal increases with increasing bit rate. This is attributed to the Raman Effect, because there is an exchange of power between the wavelength set and the theory predicts that the effect is more noticeable at lower bit rate. Considering Figure 7, the signal to noise ratio (SNR) must be kept at a certain level to maintain the data signal separated from the noise signal by amplifying the signal, noise is also amplified, so that the choice the distance between the amplifiers is an important decision, therefore the higher the SNR, the best performance will be the optical link.
Figure 6. Simulation in step 2 of the FWM effect, Power Vs Wavelength

Figure 7. Simulation in step 2 of the FWM effect, Power Vs Wavelength

Figure 7, shows the simulation of the Q factor and SNR for different simulation results into account optical link: The transmission rate of 2.5 Gbps and 10 Gbps, the distance in km, wavelength used.

The main purpose of the simulations is to measure performance parameters such as the Q factor, signal to noise ratio, Optical signal SNR and the link, mainly affected by chromatic dispersion for different bit rates and spectral widths for distances between 20 km and 200 km in fiber length. The tests were performed using the PIN detector.

For the propagation of the signal in the optical link taking into account the non-linear effect FWM is implemented these transmission rates as it is an effective rate for efficient video transmission to all network users. Tests were conducted with different values of spectral width (FWHM). The spectral width of the optical source directly affects the cost. Fiber type was used standard 20 km, 40 km, 60 km, 90 km, 120 km, 150 km, 170 km, 200 km in length and was tested with different number of users on the network using DWDM.

Figure 7. Simulation results for 2.5 Gbps and 10 Gbps

In the results obtained by the figure we can analyze that as we increase the distance to the propagation rate of the phenomenon of dispersion significantly affects the forward link signal, trying to distort the shape of propagation. This is due to FWM phenomena that as distance increases this rate of speed, increase significantly, resulting in less robust optical signal propagation.
Table 2. Output Parameters for 10 Gbps optical network

<table>
<thead>
<tr>
<th>Tx Rate</th>
<th>Distance</th>
<th>BER</th>
<th>Factor Q</th>
<th>SNR</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 Gbps</td>
<td>20 km</td>
<td>2.65E-10</td>
<td>26,754</td>
<td>41,32</td>
</tr>
<tr>
<td>10 Gbps</td>
<td>60 km</td>
<td>3.20E-11</td>
<td>24,46</td>
<td>40,865</td>
</tr>
<tr>
<td>10 Gbps</td>
<td>100 km</td>
<td>1.49E-08</td>
<td>20,875</td>
<td>40,135</td>
</tr>
<tr>
<td>10 Gbps</td>
<td>120 km</td>
<td>3.51E-07</td>
<td>18,652</td>
<td>39,854</td>
</tr>
<tr>
<td>10 Gbps</td>
<td>160 km</td>
<td>2.28E-02</td>
<td>15,652</td>
<td>39,032</td>
</tr>
<tr>
<td>10 Gbps</td>
<td>200 km</td>
<td>2.28E-02</td>
<td>13,254</td>
<td>37,854</td>
</tr>
</tbody>
</table>

Table 3. Output Parameters for 2.5 Gbps optical network

<table>
<thead>
<tr>
<th>Tx Rate</th>
<th>Distance</th>
<th>BER</th>
<th>Factor Q</th>
<th>SNR</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.5 Gbps</td>
<td>20 km</td>
<td>1.00E-10</td>
<td>33,65</td>
<td>39,895</td>
</tr>
<tr>
<td>2.5 Gbps</td>
<td>60 km</td>
<td>1.52E-09</td>
<td>30,986</td>
<td>38,7854</td>
</tr>
<tr>
<td>2.5 Gbps</td>
<td>100 km</td>
<td>5.66E-08</td>
<td>30,1023</td>
<td>37,5326</td>
</tr>
<tr>
<td>2.5 Gbps</td>
<td>120 km</td>
<td>8.75E-07</td>
<td>27,564</td>
<td>36,8952</td>
</tr>
<tr>
<td>2.5 Gbps</td>
<td>160 km</td>
<td>1.25E-06</td>
<td>25,075</td>
<td>36,8745</td>
</tr>
<tr>
<td>2.5 Gbps</td>
<td>200 km</td>
<td>3.53E-03</td>
<td>23,8754</td>
<td>35,7854</td>
</tr>
</tbody>
</table>

Now, as the order increases the Q factor nonlinearity phenomenon is smaller, this becomes more effective in improving the output power of the amplifier and dispersive analysis modules that improve the signal propagation. By analyzing the BER rate (Table 2 and Table 3) for 10 Km has a value of 2.65 E-10 being an effective range as discussed in articles and standards simulations [17], now BER limit for effective distance of 100 Km is 1.49 E-08, with a value effective communication systems, but is affected by FWM nonlinear phenomena.

Considering the results of Figure 7 we can see that as the link transmission rate decreases its propagation through the optical network is very effective. The eye diagrams exhibit less distortions and disturbances in their grids generating less noise and robustness in the system. Analyzing the different distances between 20 km and 200 km the error rate is very effective to say the ideal case, we see that the tare between distances of 20 km and 60 km is almost ideal 1.52E -09 and a Q of 38, 7854 for optical media, as well as for 100 km and 160 km the BER 8.75 E-07, is very effective. As for longer distance transmissions around 200 km obtained a rate of 3.53 E-03 with a Q factor of 23, 8754 which means an efficient signal propagation. The SNR can see that is very effective for distances greater than 120 km, (36.8952 dB - dB 36.8745 - 35.7854 dB), given that optical communications worth electric signal to noise ratio was the order of (30 - 40) dB, for our simulation values are very effective due to the mechanism we use optical amplification, with the EDFA gain dispersive fiber regeneration and allowed the work link robust and efficient manner.
Finally figure 8 and Table 4 shows the relationship between the OSNR and optical signals for the two transmission rates, behavior in the optical signal is very effective, considering FWM which is efficient for the distances established thus allowing the link to the electrical and optical part is effective. Their relationship is almost ideal OSNR making the computational engine OptSim and dispersive fiber module optimally generate results.

![Figure 8. Simulation results OSNR for 2.5 Gbps and 10 Gbps](image)

Table 4. Output Parameters OSNR for 2,5 Gbps optical network

<table>
<thead>
<tr>
<th>Tx Rate</th>
<th>Link Values</th>
<th>Tx Rate</th>
<th>Link Values</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Distance</td>
<td>OSNR</td>
<td>Distance</td>
</tr>
<tr>
<td>2.5 Gbps</td>
<td>20 km</td>
<td>28,962</td>
<td>10 Gbps</td>
</tr>
<tr>
<td>2.5 Gbps</td>
<td>60 km</td>
<td>26,8754</td>
<td>10 Gbps</td>
</tr>
<tr>
<td>2.5 Gbps</td>
<td>100 km</td>
<td>25,652</td>
<td>10 Gbps</td>
</tr>
<tr>
<td>2.5 Gbps</td>
<td>120 km</td>
<td>23,1254</td>
<td>10 Gbps</td>
</tr>
<tr>
<td>2.5 Gbps</td>
<td>160 km</td>
<td>19,523</td>
<td>10 Gbps</td>
</tr>
<tr>
<td>2.5 Gbps</td>
<td>200 km</td>
<td>10,6325</td>
<td>10 Gbps</td>
</tr>
</tbody>
</table>

Now, the Optical Power diagram for different simulation results into account optical link: The transmission rate of 2.5 Gbps, the distance in km, wavelength used. As the distance increases the optical power varies in relation to about 4.6 db, but presenting an interesting phenomenon in certain distances. For example in the case of 20 km cash presents a pulse on the order of 28,962 db approximately 60 to 120 the difference is approximately 3 db decreasing its optical power to 2 db to 120 km, and 200 cases km optical power occurs below the threshold of 14 dB.

10Gbps regarding their propagation is very effective and it is envisaged that no pulse behavior deteriorates different phenomena occur to damage the optical pulse. This, in turn, thanks to the phenomenon of their improvement improved dispersive fiber to be added to the simulation to improve nonlinear phenomena.
CONCLUSION

Were determined different propagation effects on the optical link such as dispersion, nonlinear distortion effect and FWM, which basically depend on the wavelengths of operation is working, and the frequency separation. Was analyzed by means of simulation as given non-linearity effects in the actual optical network, especially considering FWM Three basic wavelengths actual operation. Simulations were performed with a separation of 100 GHz, transmitting 16 channels and 32 channels generating considering FWM effect in the optical network, with different bit rates. Link will work, optical amplification and PIN receptors.

The link considering FWM effect, increasing the power of the frequencies or tones starting all given the same wavelengths with the same power of 10 mW , the value of the spurious power generated at that distance and the effects of the FWM power increase with starting tones. ie if we start with greater power tones, the spurious generated will also have greater power. Finally, if we change the value of the absorption coefficient (0.217 dB / km to 0.3 dB / km), to increase the absorption loss increase, and thus starting tones as spurious lose power faster. This would allow the links broader care should be taken to increase power, the most recommended is to study nonlinear phenomena before implementing such links. Similarly if it increases the bit rate value BER decreases. This effect is attributed to the dispersion of the optical fiber or fiber dispersive parameter. Better performance is obtained for the transmission rate compared with 2.5 Gbps 10 Gbps. However, by employing dispersive parameter and optical amplification fiber ideal for signal transport to rates not seen 10Gbps so deteriorated information, allowing you to work effectively employed transmission rates and different distances.

BER can be seen that the various distances is increased by increasing the bit rate at the wavelength of 1550 nm. This is attributed to the Raman Effect, because there is an exchange of power in the wavelength of 1550 nm and theory predicts that the effect is more noticeable at lower bit rate.

In the simulations, in which the effects of FWM have a better performance for fiber lengths less than 60 km, the EDFA can generate better performance for fiber lengths greater than 75 km. This information allows you to decide the type of amplifier to use depending on the length of the link and depending on the performance or value of SNR required. For the types of optical links, the transmission rate is affected more by the effects of propagation and nonlinear effects is the 10 Gbps, but does not mean it is the most inefficient because their graphical results and theoretical values show good behavior implementarles dispersive fiber. In this case there is a better performance at rates of 2.5 Gbps. This analysis predicts a good performance to transport standard video signals and data through the optical fiber. Thus, the optical amplification can be used to extend the length of optical links applications optical links considering dispersive effects in the fiber. Additionally, the results obtained allow as future work to obtain a better understanding of the performance of optical links, knowledge that can be used in future applications to obtain a more complete simulation tool.

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REFERENCES

