Optimized of Erbium-Doped-Fiber Amplifiers (EDFA) Parameters in Hybrid Passive Optical Network (WDM/TDM-PON) Systems with 512 Users

Bentahar Attaouia and Kandouci Malika

University of Djilali Liabes, Sidi Bel Abbes, Algeria

Abstract: This paper evaluates the impact of opt-geometric parameters of the Erbium doped fiber amplifier (EDFA) used as a booster such as ions-ions interaction, temperature … and the effect of those parameters to optimize the gain G and the performance in terms of BER of the hybrid (WDM/TDM) passive optical network (PON) with 64x8 users or 512 ONUs (Optical Network Units) up to distance 40km by taking in to consideration only downstream signal. The gain degradation of erbium-doped fiber amplifiers (EDFA’s) with high erbium ion (E\(^{3+}\)) concentration at 980 nm pump wavelengths is modeled by introducing the quenching concentration.

Key words: Hybrid PON · Erbium doped fiber amplifier · Amplifier optic · Ion-ion interactions · Quenching concentration

INTRODUCTION

The PON architecture allows for easy service upscale should the need for more even more bandwidth arises. This can be elegantly accomplished through the Time division multiplexing (TDM) and the wavelength-division multiplexing (WDM) PON schemes in the access fiber. Another way to increase PON-system scalability, to obtain the best topology properties for signal transmission and to exploit the advantages offered by the TDM-PON and WDM-PON technologies is to use a hybrid WDM/TDM-PON architecture. This later can a smooth migration from the current PON (i.e. TDM PON) to the future PON by incorporating the WDM technology and one of its advantages is the possibility to share the capacity of any wavelength among more than one user [1, 2].

In an access network, increases in the transmission distances between the OLT and the ONUs, as well as increases in the TDM splitter ratio, result in significant increases in loss, so optical amplifiers are required to compensate the loss. Erbium- doped fiber amplifiers (EDFAs) have previously been introduced to compensate for losses when the splitter ratio is increased in a TDM PON [3].

Erbium doped fiber amplifiers (EDFA) is widely used in fiber optical networks. EDFA can amplify signals over a band of almost 30 to 35 nm extending from 1530 to 1565 nm, which is known as the C-band fiber amplifier and from 1565 to 1605 nm, which is known as the L-band EDFA. The great advantage of EDFAs is that they are capable of simultaneously amplifying many WDM channels and there is no need to amplify each individual channel separately and are attractive candidates for next generation of PON reach extension. [3,15].

They can be designed to provide low noise figure (NF) and fast gain dynamics in the 1550 nm. Also the development of other types of DFAs for amplification in the remaining optical bands has been actively investigated. Praseodymium-doped fiber amplifiers (PDFAs for upstream) and thulium-doped fiber amplifiers (TDFAs for downstream) were developed to amplify signals around 1300 and 1490 nm, respectively [4, 5].

System Setup: The proposed Hybrid TDM/WDM-PON solution, which is based on the key idea of TDM-PON systems with OLT (Optical Line Terminal) and ONU (Optical Network Unit), consists in adding the multiple wavelength division multiplexed channels to increase the overall bandwidth. Figure 2 shows an downstream transmission with a low seed channel power of 5 dBm is made feasible over a total reach of 40 km for 8–WDM channels and 64 TDM splits with 20 dB of loss. On the transmission side of the system the eight lasers multiplexed signals in the wavelength region of 8 nm (1550 nm-1558nm) with frequency spacing of 0.8 nm. All channels modulated with modulation rate to achieve data transfer rate of 2.5 Gbit/s, NRZ (Non-Return to Zero)
1043

Fig. 1: The system setup for 2.5 Gb/s over 40 km of SMF of WDM/TDM-PON system with 8x64 users

Table 1: The EDFA parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Symbol</th>
</tr>
</thead>
<tbody>
<tr>
<td>Signal input power</td>
<td>5 dBm</td>
<td>$P_{in}$</td>
</tr>
<tr>
<td>Signal wavelength</td>
<td>980 nm</td>
<td></td>
</tr>
<tr>
<td>Pump power</td>
<td>200 mw</td>
<td>$P_p$</td>
</tr>
<tr>
<td>Amplifier length</td>
<td>20 m</td>
<td>$L_{ampl}$</td>
</tr>
<tr>
<td>core diameter</td>
<td>2.2 µm</td>
<td>$D$</td>
</tr>
<tr>
<td>Erbium ion concentration</td>
<td>$1e+25/m^3$</td>
<td>$C$</td>
</tr>
</tbody>
</table>

format was used for signal coding. For multiplexing eight channels into a single fiber (SMF) with an attenuation coefficient of 0.2 dB/km, the optical multiplexer with 10 GHz channel bandwidth and 100 GHz channel frequency spacing is used.

The demultiplexer has the same parameters as the multiplexer in terms of channel bandwidth and channel spacing. On the receiver side of the system, the eight avalanche photodiodes (APDs) to detect signals and eight low pass Bessel filters are needed to suppress amplified spontaneous emission (ASE) [15], 3R regenerator. The analyzers estimate the Q factor and BER values for the signals. To visualize optical spectrum, waveforms, eye diagrams with various values different analyzers are to be used like optical spectrum analyzer, power meter etc. The Q factor and BER values are also observed to verify the results.

As was mentioned above, Erbium Doped Optical Amplifiers (EDFA) in position booster has been chosen to amplify wavelength around 1550 nm in the downstream of hybrid PON. The characteristic of EDFA used in this simulation is shown in the Table 1.

RESULTS AND DISCUSSIONS

In hybrid WDM/TDM PON system using EDFA as booster amplifier, combined signals (data, video) are transmitted by varying the fiber length different waveforms will be observed. The Q factor and BER is observed by varying the fiber length and observe eye diagrams. Several numerical models of optical fiber amplifier have been developed. These models solve the dynamics of different energy states of erbium ions and optical wave evolution that propagates in active medium. Three possible models or approximations can be used in the erbium doped fiber EDF: Saleh, Jobson and Giles model.

Figure below represent a comparison between the different models as a function of fiber length. According to the curves found, it is seen at 40 km of transmission, that the lowest Min log of BER is found in case of EDFA using Jobson model with value around -25 and the best Q factor of 6.58 by Saleh models with -23 and Q factor of 6.31 respectively, however performance reduces when the Giles model is used with Min of log BER around -16 and Q factor of 5.58.

So, in the simulation, we used Jobson model. This model could be successfully applied to the study of the signal gain and given an optimum signal gain [8].

To analyze the temperature which allows optimizing the gain and flatness of the EDFA used Jobson model several simulations are made. The temperature dependence in an EDFA manifests through the variation in the absorption and gain coefficients (or absorption and
Fig. 2: Min. log of BER as a function of fiber length showing the first channel for different models

Fig. 3: Min. log of BER as at 40km of fiber length for different models showing the first channel

emission cross-sections) [9,10]. Figure 9 shows the gain spectrum of the EDFA used Jopson model at different temperatures. In the simulation the EDF length is fixed at 20 m and the input signal and pump power are fixed at 5 dBm and 200 mW, respectively. As shown in Figure 4, the gain of the amplifier increases with increasing temperature for shorter wavelengths than 1560 and decreases at the longer wavelengths with the increment of temperature however the maximum gain was obtained at higher temperature of 80°C with 50 dB in C band. Also the gain spectrum is flat at wavelength region of 1560 to 1600 nm with the uses of lower temperature (0°C).
Fig. 4: Gain as a function of wavelength showing the first channel for different temperature

Fig. 5: Min. log of BER as a function of fiber length showing the first channel for different temperature
In the term of the quality and performance of the system, the Min log of BER is plotted by varied the fiber length from 0 km to 60 Km for three values of the temperature (T) of EDFA (0, 40 and 80C). It is seen from graphs that, this later increases with increasing of fiber transmission and the temperature. So the simulation shows, at 40 km of fiber length and 0 C of temperature; the best result which the BER is minimum (over -24) with best Q factor of 6.58 is found (Figure 5 and Figure 6), however we provide a high value of Min Log of BER around -10 and Q factor of 4.96 for 80 C of temperature.

Many studies reported the Erbium-Doped Fiber Amplifier (EDFA) performance degradation with Er3+ concentration increase. In general, these additional losses are attributed to energy transfers between neighboring ions. The most important ion-ion interactions for EDFA are: homogeneous up conversion effect (HUC) and inhomogeneous pair-induced l (PIQ) [10,14].

If the doping concentration of Er3+ in fiber is increased, the pumping efficiency of the EDFA is reduced because of concentration quenching. Concentration quenching caused by cluster formation is known as pair-induced quenching (PIQ). Pair-Induced Quenching (PIQ) effect means that the energy transfer rate between two or more ions is on a time scale significantly faster than that of the pump rate [12]. In other hand and for randomly distributed ions the process is called uniform or homogeneous up conversion (HUC). This effect is an interaction effect and its impact on the EDFA performance is linked to the concentration of erbium ions in the fiber [11]. It causes gain reduction that can be compensated by increasing pumping power.

Figure 7 (a, b), shows the gain as a function of pump power and erbium ion density with include different cases ion-ion interaction (homogeneous (HUC), inhomogeneous (PIQ)) and without effect. After the simulations, the gain versus pump power curves was plotted for each fiber of transmission. Figure 7a, shows the results found in the simulations. So it is cleared from graphs for threes cases, the degradation in the performance of the EDFA due the homogeneous up conversion and inhomogeneous pair induced quenching effect. To compensate for the decrease in the gain, the pump power has to be increased. These results agree well with those in [1].

Also, the gain increase with increasing of erbium ion concentration for the lower concentrations of $1e+025/m^3$, however up of this value, the homogeneous and the inhomogeneous effect provides a similar allure and relate to the issue of energy transfer between rare earth ions (Figure 7b). This can have a negative impact on amplifiers, whereas the best gain (14.5 and 13.8 dB respectively) it’s found when doping concentration is near $1e+025/ m^3$ with ideal model (no quenching) and homogeneous model because of its dependence on ion concentration, homogeneous up conversion is negligible at low concentrations compared with inhomogeneous pair induced quenching.

The erbium concentration is fixed at $1e+025/m^3$ and the effect of ion-ion interaction on the system is investigated by relationship between the BER and optical fiber length (Figure 8). The hybrid system without ion-ion interaction is performed with lowest BER (of - 45) at short distances (lower of 30km) and the performance reduces when we increase the fiber length. Also Figure 9 shows
Fig. 7: The gain calculated as function of pump power (a) and as function of erbium concentration (b) using quenching model (homogeneous, inhomogeneous) and no quenching (ideal model). In the quenching model, the percentage of ion pair, up-conversion coefficient is 2%, 9e-024 m³/s, respectively.
Fig. 8: Min Log of BER as a function of fiber length showing the first channel for ions-ions interactions.

Fig. 9: Eyes diagram of fiber length 40 km showing the first channel for ions-ions interaction (without, homogeneous and inhomogeneous effect).

Eyes diagram for different cases of ion-ion interactions at 40 km of fiber length. We can notice best result with Min Log of BER around -25 and Q factor of 6.58 with ideal model followed by the homogeneous model (HUC) with Min log of BER around -23, Q factor of 6.10 and lower result for inhomogeneous broadening (PIQ) with Min log of BER around -10 and Q factor of 4.96.

Figure 10 (a,b) demonstrates the effect of erbium lifetime on the performance of amplifier at 40 km of fiber of transition, all fiber parameters are kept constant except for the relative number of ion per clusters and up-conversion coefficient is varied. The calculated results indicate a high degradation in the performance of an EDFA and hybrid PON due to the effect of inhomogeneous pair-induced
Fig. 10: Min. log of BER as a function of relative number of ion per clusters (a) and as function of up conversion coefficient (b) showing the first channel for different erbium lifetime at 40 km
quenching (PIQ) especially when K increased (K = 12%) and when erbium lifetime decrease. Additionally, the difference between the two erbium lifetimes (8 and 12 ms) has a very small influence in the Min log of BER when k = 0% but up this value the difference become considerable (Fig. 10a).

Moreover, the reduction of the performance of system amplifier with increasing of homogeneous up conversion coefficient (HUC) is illustrated by Figure 10b. It is observed that the gain decrease when up conversion coefficient increase and when erbium lifetime decrease however the better performance of the EDFA with Min value of BER (around of -25) is found when erbium lifetime = 16 ms and the coefficient of homogeneous up conversion UPC = 9e-024 m/s, whereas the difference between the two erbium lifetimes (8 and 12 ms) is neglect compared with inhomogeneous effect.

This part of the study considers the optimization of numerical aperture (NA) we used the same parameters (Table 1) but for varied values of numerical aperture (0.3, 0.6 and 0.9). It is cleared from graphs that 0.6 improved and gives better system performance in term of lowest BER.

CONCLUSION

In the present work, the characteristic of EDFA operating in C band and pumped at 980nm used in position booster of 2.5 GB/s hybrid WDM/TDM- PON with large number of users (64x8) for optical fiber length varying up to 60 km is investigated. We have shown that an EDFA operates as a booster amplifier provides a sufficient gain of 14.5 dB for both downstream signals at 20 km of fiber length and in other hand signals performance of the system is affected by some parameters of EDFA such as temperature, ions-ions interaction.

However it was seen that the gain and performance degradation of erbium-doped fiber amplifiers with doping concentration more than 1e+025 ion/m³ are modeled by introducing ion-ion interaction (homogeneous and inhomogeneous) effect. Moreover, it’s found that the PIQ strongly dominates over homogeneous processes because this later is more rapid than the homogeneous up-conversion (HUC). Also, we can notice that hybrid PON with 512 users and 40 km of fiber length given the best result of Min log of BER around -25 and Q factor of 6.58 without ion-ion effect when temperature T = 0°C.

RÉFÉRENCES