Experimental Investigation Between WDM-PON and DWDM-PON Using Different Channel Spacing

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Abstract. A different channel spacing characteristics was analysed using wavelength-division Multiplexing (WDM) and Dense Wavelength Division Multiplexing (DWDM). In a system has 32 channels using only Single Mode Fiber (SMF) (without any amplifier or DCP) over a frequency range (100 – 400) GHz. Then compare their effectiveness, according to the distance to cover, Q factor, bit error rate (BER) and power needed, by means of advanced modulation schemes return-to-zero (RZ) in order to determine the best frequency channel. It is observed that the 100 GHz channel spacing has the maximum transmission coverage up to 90 km with acceptable power, BER and Q-factor which it is equal to 10 dB, 2.08 \times 10^{-29} and 11.19 respectively.

Keywords — WDM- PON, BER, Q-Factor, DWDM- PON, channel spacing.

1. Introduction
In last decades the big growth in the communication industry has raised the needed for large bandwidth [1, 2]. The current need for applications has obliged network engineers to find a method to keep up with the modern generation demand that required higher data rate, only fiber optical can provide such a high-speed data transmission as high as several Gbps with an economical price [3, 4].

The evaluation of optical networks is increasing as fast as the demand, especially in passive. A lot of invention of Passive Optical Network (PON) were made and used in our life now, like, Fiber to the Curb (FTTC), Fiber to the Building (FTTB), Fiber to the Node (FTTN) and Fiber to the Home [FTTH] [5-10].

Transporting data by several multiplexing techniques are used for PON to increase the data transfer ratio, from Central Office (CO) that has the Optical Line Terminal (OLT) through optical distribute network (ODN) to our house that has the optical network unit (ONU) [11,12]. The main multiplexing techniques were used is Time Division Multiplexing Passive Optical Network (TDM-PON), but now it reached stages that difficult for it to keep up with the requirements of users and the market, therefore the developers start to go with WDM-PON which will be our subject to discuss. WDM-PON is physically expensive (infrastructure, equipment and technology) but flexible in terms of data capacity
requirements. On the other hand, it has arisen as the extreme agreeable method for gateway of any network because of its huge effectiveness and strict safety [13,14]. In the average expression, WDM transmission hold on major numbers of wavelengths that may be integrated with non-linear techniques or with RZ, because return-to-zero (RZ) data format dominate better future in working with big access powers and the long range, [15]. In spite that, weak price operation and running of wavelength choosing light sources is yet the largest affront of diffusing great area in WDM-PON systems [16].

In addition, one of the most hopeful settlement to face the high request for bandwidth is the operator of any light sources at particular wavelengths creates the ONU and make it various from each other's. Consequently, will not let the transponder industrialist to have the interest of big fabrication., optical transmitters must also save up all the various types of at their warehouse by the provider of the service to be prepared for all kinds of service insufficiency happened with the optical sender collapse [17, 18]. Regardless of the disadvantages above, many wavelengths have been multiplexed to employing state of the art technology like DWDM. The DWDM system include transfer technology that authorizes a lot of wavelengths to proceed through an SMF as shown in the Figure 1. It can be run for long-haul range, having a massive bit rate, and can be easily expand to support multichannel system [19, 20].

2. Material and Method
As we know the channel spacing of DWDM is less than 200 GHz and above 200 GHz is WDM. to do our investigations we applied a variation in power and distance to discuss the effectiveness of all channels spacing (100, 200, 300, 400) GHz with the identical receiver system, as shown in Figure 2, a design of the DWDM/WDM - PON system is suggested with 0 , 5, 10 dB input transport power with RZ modulation format.

DWDM/WDM- PON has one key advantage of the possibility to improve them on a channel by channel basis so for that the reason we chose it. To evaluate the ultimate number of channels that supply with such systems, one serious element is the type of fiber being utilized which we used Single Mode Fiber (SMF).

As shown in Figure 2, a 32 channels are transferring data at 10 Gbps velocity with various channels spacing (100, 200, 300, 400) GHz modulated by RZ data format. An ideal transmitter was used that has 32 outputs as shown in the design.
Figure 2. Simulation setup of WDM system

Each transmitter supposes to contain a data power source, electrical driver, CW as the laser source and Mach–Zehnder modulator as shown in the Figure 3 which represents the content of ideal transmitter for a single wavelength.

Figure 3. Content of ideal transmitter for a single wavelength

A signal of 10 Gbps represents the bandwidth for each channel which is generated by data source, most of the time pseudo random sequence is using. Then the signal is interring in to RZ pulse generator. The signals are coming from the laser and data source (output of RZ) are combined in the Mach–Zehnder modulator after that the modulator output signal is moving on to the multiplexer then the output signal transmitted through SMF without any amplifier or DCF then to ideal demultiplexer. Ideal demultiplexer job is to convert the coming single from the SMF to 32 output signal (still optical signal) and then transform the optical signal into electrical signal with the assistance of electrical filters and PIN photodiode after that can be monitored the signal by BER and an optical spectrum analyser as shown in the figure 4.

Figure 4. Content of ideal receiver for a single wavelength
The optical signal is transported and analysed for the distances of 20, 30, 40, 50, 60, 70, 80, 90, 100 km with different channel spacing 100, 200, 300, 400 GHz at 10 ps/NM/km dispersion (10 represent a lot of dispersion because we simulate working with a very bad kind of fiber) with reference frequency is 192.5 THz, reference wavelength is 1557 nm, fiber polarization mode dispersion as always is 0.2 ps/km with attenuation equal to 0.2 dB/km as showing the simulation setup of WDM system. The 32 channel WDM receiver is utilized to discover all 32 signals, but technically we observe the first one only because each of the 32 wavelengths the result doesn't have a big different from each other.

3. Results and Discussions
For a better transmission capability of the optical network, we ensure a suitable bit error rate (BER) at the receiver side, (as much it’s become close to the 0 as well will be, the minimum amount required is 10 x e^{-12} in receiver side). To do so we need to increase the power of the optical signal at the transmitter but this increase leads to distortion of the transmitted signals, and affect the BER which decrease the transmission effectiveness. This power distortion is different and depending on the channel that used as it will be seen in the Figures below 5, 6, and 7.

1) Power with 0 dB: as shown in Figure 5 and Tables 1, we notice the maximum distance to cover is 70 km to all channels spacing (100, 200, 300, 400) GHz with Q-factor is 6.83, 6.99, 6.55, 7.04 respectively, and the BER as showing in the Table 1 is good for the near distant specially for 20 Km and 30 km that has 0 BER but it is increasing very fast as the distance increase until it reaches 1 in 90 km channel space.

![Figure 5. Q-factor vs. distance with power equal to 0 dB](image)

| Distance | 100 GHZ | 200 GHZ | 300 GHZ | 400 GHZ |
|----------|---------|---------|---------|---------|
| 20 Km    | 0       | 0       | 0       | 0       |
| 30 Km    | 1.9 x e^{-263} | 0 | 0 | 0 |
| 40 Km    | 2.77 x e^{-107} | 2.4 x e^{-257} | 1.13 x e^{-202} | 1.7 x e^{-250} |
| 50 Km    | 4 x e^{-57} | 5.4 x e^{-104} | 4.32 x e^{-91} | 3.37 x e^{-100} |
| 60 Km    | 9.33 x e^{-27} | 5.4 x e^{-37} | 5.31 x e^{-30} | 5.98 x e^{-37} |
| 70 Km    | 3.9 x e^{-12} | 1.3 x e^{-12} | 2.7 x e^{-11} | 9.5 x e^{-13} |
| 80 Km    | 1.19 x e^{-3} | 1.16 x e^{-3} | 2.2 x e^{-3} | 1.12 x e^{-3} |
| 90 Km    | 3 x e^{-2} | 3 x e^{-2} | 1 | 3.1 x e^{-3} |
| 100 Km   | 1 | 1 | 1 | 1 |
2) Power with 5 dB: as shown in Figure 6 and Table 2, we notice that for some channel spacing of 100 GHz and 400 GHz, the maximum distance to cover is 80 km with Q-factor of 9.3 and 11.04 respectively. Then for another channel of spaces 200 GHz and 300 GHz is 70 km with Q-factor of 13.49 and 14.4 respectively. The BER as showing in the Table 2 is very good for the near distant specially for 20, 30, and 40 km that has 0 BER but it is increasing very fast as the distance increase.

![Figure 6. Q-factor vs distance with power equal 5 dB](image)

Table 2. BER for power of 5 dB.

| Distance | 100 GHZ | 200 GHZ | 300 GHZ | 400 GHZ |
|----------|---------|---------|---------|---------|
| 20 Km    | 0       | 0       | 0       | 0       |
| 30 Km    | 0       | 0       | 0       | 0       |
| 40 Km    | 2.6 x e^{-131} | 0       | 0       | 0       |
| 50 Km    | 9.5 x e^{-82} | 9.19 x e^{-251} | 1.09 x e^{-250} | 7.4 x e^{-292} |
| 60 Km    | 8.3 x e^{-49} | 2.2 x e^{-86} | 2.2 x e^{-102} | 5.05 x e^{-106} |
| 70 Km    | 2.6 x e^{-32} | 7.7 x e^{-42} | 2.2 x e^{-47} | 1.36 x e^{-45} |
| 80 Km    | 4.41 x e^{-21} | 2.27 x e^{-25} | 5.8 x e^{-4} | 1.02 x e^{-28} |
| 90 Km    | 7.08 x e^{-4} | 7.11 x e^{-4} | 6.9 x e^{-4} | 6.8 x e^{-4} |
| 100 Km   | 7.8 x e^{-3} | 6.8 x e^{-3} | 5.9 x e^{-3} | 6.6 x e^{-3} |

3) Power with 10 dB: as shown in Figure 7 and Table 3, we notice that with channel spacing of 100 GHz, the maximum distance to cover is 90 km with Q-factor is 11.19 which is the best result can be achieved in this design. With channel spacing of 200, 300, 400 GHz, maximum distance to cover is 80 km with Q-factor of 13.39, 14.46, 16.01 respectively. The BER as showing in the Table 3 is almost good for all distant specially for channel spacing of 100 GHz and 200 GHz in distance of 20 km which equals to 0 Km.

Finally, in the case of power 0, the range is less than the first two cases and becomes 70 km for all the channel spacing, while the Q-factor and BER near distances is better compared to the energy of 10 dB and almost as good as the quality of power equals to 5 dB. Therefore, we find that with power 0, the systems will be less energy consuming, complex and expensive to power. With 5 dB the system will be better in terms of signal quality as average for all distances, finally when power = 10 dB, the systems will be better in terms of coverage of the geographic area with acceptable Q-factor for all distances.
4. Conclusions

We conclude that 100 GHz channel spacing has the maximum transmission coverage up to 90 km for 32 channels using only SMF (without any amplifier and DCP) and we got an acceptable BER of $2.08 \times 10^{-20}$ and Q-factor of 11.19 which gives the DWDM has advantage over WDM but not all the time as we see with power of 5 dB the 300 GHz (WDM) has an equal performance to 100 GHz (DWDM) this result mean not only the DWDM can be improved. But this does not prevent paving the way for future research related and encourage laboratory experiments to trend towards the 75 and 50 GHz that gives real and certain results which can be based on other studies in wavelengths for long distance coverage in order to make the transmission of the WDM more intensively and Dense to increase the bandwidth capacities transmitted through it.

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