FUNDAMENAL LIMITATIONS on INTRODUCING LOW COST OPTICAL SOURCES in HYBRID 40/100G PON

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Abstract— **Most of the considerations of the benefits of Next Generation Passive Optical networks (NG PON) have been focusing on opportunities associated with bandwidth availability. This article describes the fundamental limitations of low cost optical sources combined with current existing optic fiber in the network to resolve challenges in achieving targeted high data rates of 40Gb/s and 100 Gb/s in NG PON. A hybrid model of wavelength division multiplexing using 10 Gb/s optical sources with relatively large spectrum has been simulated with COMSIS. Key parameters as bandwidth at -3dB of the sources, wavelength division multiplexing scheme, optimal range and number of users are considered. Analysis that emerge from this work can serve as a basis for brainstorming on aspects of migration to the groups responsible for standardization.**

Keywords— **40/100 G PON, WDM, low cost optical sources**

I. Introduction

Networking applications bandwidth requirements are increasing every year [1-4]. The information and communication technology environment is rapidly changing to broadband. Customers are more attracted by high capacity networks with the ability to carry out at the best quality all the services they have applied for. Indeed, with the advent of television broadband, the increasing sizes of digital photos and video, the proliferation of online high definition video games and the need to share and exchange files through internet as quickly as possible and from any terminal in the world, the need for bandwidth is constantly growing. In fact, the emerging of broadband networks is becoming a reality. Telecom carrier, Internet Service Providers (ISP) are all aiming at offering integrated services as triple play, quadruple play including mobility.

The goal of access network providers is to meet this need and provide a network with more symmetrical data rate in upstream and downstream. For access network, cooper and optical fiber are media types provided to meet these needs. Currently, xDSL (Digital Subscriber Line) dominates the market for broadband access. However, xDSL have started to yield ground to FTTx technologies, which can better meet the future demands of services requiring a high speed. A variety of residential access technology leads to a mixture of cooper and fiber optic configurations. These access technologies are fiber-to-the-cabinet (FTTCab), fiber-to-the-curb (FTTC), fiber-to-the-building (FTTB) and fiber-to-the-home or office (FTTH/O). The backhaul of future generation wireless base station depends on fiber optic. The FTTH (Fiber To The Home) architecture which was chosen is the one of PON (Passive Optical Network). PON technology aims at deploying fiber to the home with passive components. Next generations passive optical networks increase the bandwidth allocated to the subscribers. This consists in upgrading current GPON (gigabit passive optical network, with downstream bit rate of 2.5 Gb/s and upstream bit rate of 1.2 or 2.5 Gb/s) to 10Gb/s or upper PONs.

Standards bodies, like the FSAN (Full Service Access Network) which bring together major incumbents including historical telecoms companies as well as suppliers, are interested in the ways to increase data rate. Under this theme, a working group has been formed in 2006 in order to study the evolution of the G-PON (gigabit PON) and establish the characteristics of the future generations of optical access networks (10 Gb /s, 100Gb/s etc..).

IEEE is also working on standardizing optical access networks. It has already normalized the E-PON (Ethernet PON) which enables a symmetric bandwidth (in upstream and downstream) of 1.25 Gb/s shared between 16 or 32 users. The increase in overall throughput of a PON at 10 Gb/s is being considered by the standardization group with the future expected standard: 10G-EPON.

WDM-PON is a potential solution for NG- access network. It presents the advantages of bandwidth scalability and possibility to adapt the per-wavelength bit rate.

To increase user bit rates if appropriate in existing PONs, the splitting ratio or the number of customers is reduced. The allocation of 1Gb/s to a user is almost impossible to achieve. A very cost effective migration scheme from GPON to new generation PON could consist in changing just the end devices (OLT: optical Line Terminal and ONT: optical network terminal) and in some cases upgrading the splitter capacity.

In this paper, a Wavelength multiplexing of 10 Gb/s low cost sources is simulated for 40/100 PON using COMSIS simulation tool. By varying the isolation power of the sources spectrum, the fundamental limitations of NG PON is evaluated.

The paper is organized as follows: Section II sets the underlying assumptions and describes the considered NG

PON key parameters. Simulations and results are provided in section III. Then Section IV, conclusion ends the paper.

II. System Description

Channel bandwidth is becoming an important consideration. We have considered a 40G/100G passive optical network using 10G low cost optical sources at transmitter side and ideal PIN photodiode at receiver side. Direct modulation of optical sources are assumed.

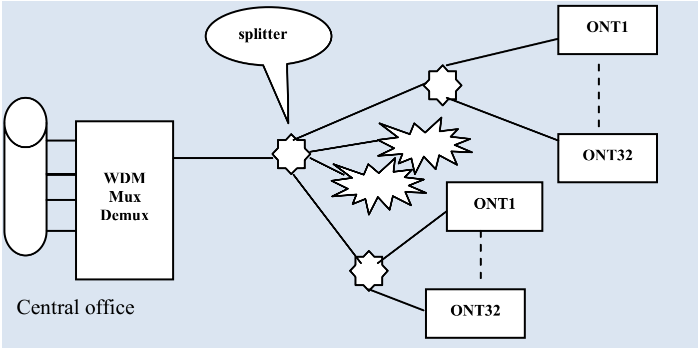

Figure 1. WDM PON access network.

The considered access network depicted in Figure 1 maximum capacity is 128 users. Thanks to time division multiplexing, up to 32 users can share the same WDM channel. Then four WDM channels are multiplexed to get the targeted capacity. In the downlink, the data addressed to a group of 32 users in the same sub-area are coloured at WDM multiplexer and affected a same wavelength. The signals are amplified before and the output of the optical signal feeds the common shared fiber leading to a 1:4 splitter connecting the four sub-areas of the access network to the OLT. This splitter could be located in the cabinet and also connected though a fiber to four 1:32 splitters supposed to be at the curb or in a building. The splitters distribute the optical signal to the end users. These 1:32 splitters in each sub-area enable the users to receive their data at the ONT. The splitters input in the downlink are supposed to be equipped with the right WDM filter in order to select its allocated wavelength and avoid interference with the data sent to the users of the other sub-areas. In the uplink, the users optical sources are assumed to be low cost coloured components.

Since the optical sources at the central office and at users side are low cost components, their spectrum is relatively large and supposed to overlap with those of adjacent WDM channel.

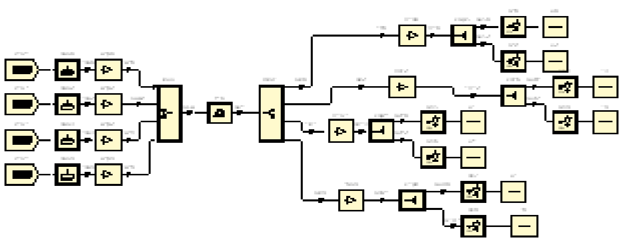

Figure 2. 40G WDM PON downlink simulation screen with COMSIS.

The simulation of the system has been done with COMSIS software. This simulation tool contains all the modules we need to build our system and gives the performances of the considered system based on the built system parameters.

Figure 2 is a screen capture of the optical system which has been simulated with COMSIS software. In the downlink, four low cost Lasers are directly modulated by a bit stream of 10Gb/s and the output signal of each optical source is amplified and coloured before being coupled with the other input signals. EDFA's (Erbium doped fiber amplifier) optical amplifiers are used to compensate the power budget.

The process of coupling coloured light is represented by a WDM multiplexer which can be easily built with adequate low cost components.

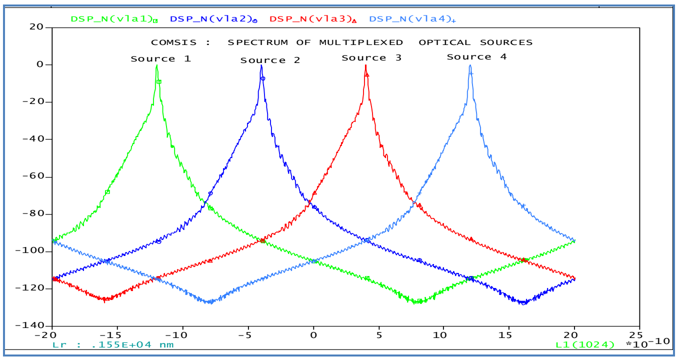

Figure 3. WDM inter-channel interference simulated with COMSIS

The choice of low cost components to colour the light introduce interference as shown in Fig. 3. It shows the case of four wavelength for 40G PON. In the case of 100G PON, 10 WDM Channels might be considered. The resulted light coming from the four different kind of sources feeds the fiber. The propagation of the signal in a single mode fiber is describes by the envelope of the amplitude ''A'' in [5] as :

$$\frac{\partial A}{\partial z} = -\frac{\alpha}{2} A + i \frac{\beta_2}{2} \frac{\partial^2 A}{\partial t^2} + \frac{1}{6} \beta_3 \frac{\partial^3 A}{\partial t^3} - i\gamma |A|^2 A - i\xi [S_R(t).|A|^2 A \qquad (1)$$

Where β_2 and β_3 denotes the effect of chromatic dispersion and the slope of dispersion respectively,

SR(t) is the impulse response of the filter simulating the dependence of the Raman gain on the frequency.

The output the common shared fiber feeds a WDM demultiplexer which represents the 1:4 splitter equipped with corresponding filters. This scheme is low cost compared to the case of using a filter at each ONT. Instead of using just four WDM filters, it will be about 128 filters. The same approach is supposed to be applied to the uplink.

Because of the difficulty in representing all the 128 users in our simulation screen, we have replaced the 1:32 splitter by a attenuator and a 1:2 splitter in order to get the right light power at the output of this splitter as with a 1:32 splitter. The ONT are represented by optical receivers called PINs.

III. Simulations and Results

The optical sources are directly modulated by 10 Gb/s data streams with a maximum current intensity of 100mA and

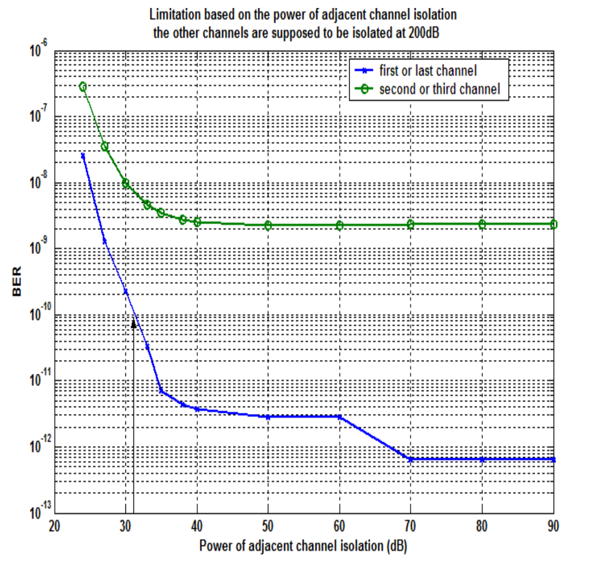

Figure 4. Performance limitation due to adjacent channel power isolation

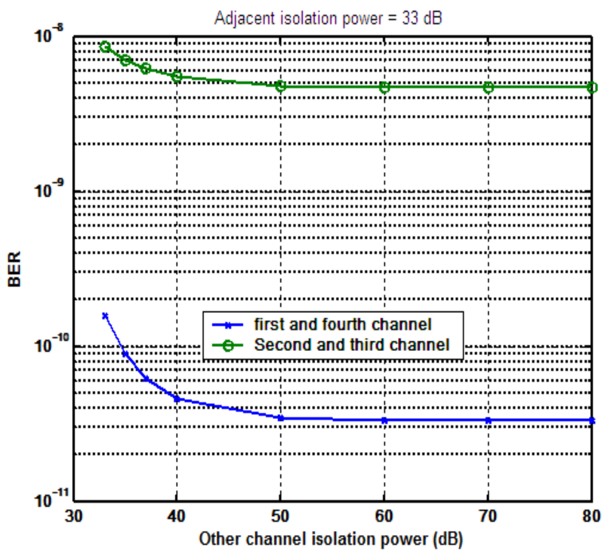

Figure 5. Performance limitation due to other channel power isolation

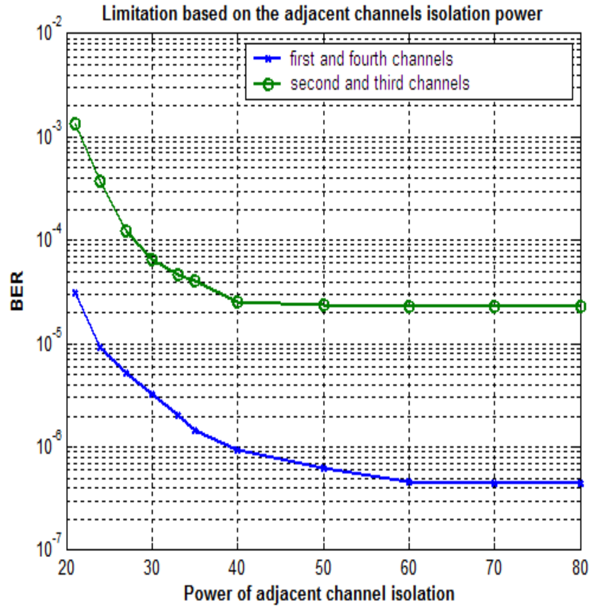

Figure 6. Performance limitation in the case of 50 GHz gap beween adjacent channels

a minimum current intensity of 12 mA. In order to reduce the cost of the sources, cheaper LASERS at the transmission wavelength of 1500 nm are considered. The bandwidth at -3dB with a max current of 100mA is set at 20000 MHz. The WDM multiplexer is centred at 1550 nm and the transmission wavelength gap between two adjacent channels is set at 100GHz but these channels are supposed to have the same 20000 MHz bandwidth at -3dB.

In our simulations, we have set different values of power isolation of the adjacent channel and different values of power isolation of the other channels. The simulations have been carried out for multiplexed wavelength. The result can be used as limitation upper limit for 100 G PONs since it could be assumed lower impact of channels order greater than 2.

Fig. 4 depicts two curbs describing the performance limitations these systems. Besides the adjacent channels, the other channels isolation power has been set to 200dB. We aim here to point out the impact of the adjacent channels power isolation to limit the maximum Bit Error rate (BER) of the system. Depending on the position of the channel , it can be seen that the channel at the beginning and the end of the multiplexing bandwidth are not so affected compared to those inside the multiplexing bandwidth. For a BER of 10^{-10}, the extreme channels require at least 33 dB of power isolation. The other channel communication link performance is limited to a BER of 2.10^{-9}.

By setting the adjacent power isolation at 33 dB, we have simulate the impact of varying the isolation power of the other channels. As it can be seen in Fig. 5, the considered WDM system cannot outperform 2.10^{-10} for the extreme channels and 4.10^{-8} for the second and third channels

It is also interesting to observe from Fig.4&5 that increasing the isolation power of the adjacent channel and other channels over 40 dB and 50 dB respectively does not improve the system performance.

For more accurate estimation of the limitations, we have simulated in Fig.6, the performance of the considered system in the case of DWDM with a gap of 50 GHz between adjacent channels. The impact of varying the isolation power of the adjacent channels is shown as in Fig. 4. The isolation power of the channels not directly adjacent are set to 200dB in order to isolate their impact. It can easily be deduced from Fig.6 the worse quality of the link for the second and third channels. The performance of the first and forth channels link is limited by a BER = 10^{-7}. Then, it can be deduced that it is better to consider only the case of 0.8 nm as the gap between two transmitting adjacent wavelength in the case of dense wavelength division multiplexing.

IV. CONCLUSIONS

This paper presents the fundamental limitations of 40/100G PON system based on WDM with low cost optical source components. Actually, WDM PON is considered as a potential migration solution to NG PON. In order to speed the deployment of these optical networks, low cost solutions might be carefully studied. Isolation power of adjacent and other channels are key parameters of limitation of the communication link performance. The system 40/100 GPON cannot outperform a BER of 10^{-13} in the case of 20GHz spectrum bandwidth at -3dB of the optical sources separated by 100GHz with adjacent isolation power over 40 dB and other channels isolation power equal or greater than 50 dB.

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