Optimization of Maximum Achievable Bit Rate of A Next Generation Passive Optical Network

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Abstract

Optic fiber is a medium used in communication to propagate light through a glass or waveguide. The present bit rate of the next generation optical network does not give room for optimization at shorter fiber length. This is common in many areas of fiber link within campus network. It consequently causes users to connect at lower data bit rate. In this study a model was developed to optimize the maximum bit rate that a fiber link can carry at shorter distance than specified by the international telecommunication union standard. The model used OptiSystem simulator for a range of 10 km distance commonly found on campus fiber links in Nigeria. Two common next generation model were developed for time wave division multiplexing and 10 Gigabit passive optical network respectively. The data obtained shows that more bit rate can be achieved at the shorter fiber link distance for each model within the acceptable bit error rate (BER) of 10^{-9}. The benefit of this model is to optimize maximum bit rate which will lead to better Internet service delivery when used for information and communication technology using optic fiber. Therefore this will reduce congestion on fiber link due to low bit rate during busy period.

Keywords: Bit rate; passive optical network; optic fiber; TWDM; OptiSystem simulator.

I Introduction

The rise in data consumption by subscribers of both fixed and mobile broadband drives the standard to move in order to meet with this challenge. The next generation access network (NGaccess) will provide a very high data rates over long distance to be able to cope with the growing demand for high capacity broadband network. This effort was initiated by The Full Service Access Network (FSAN) and the ITU-T/IEEE. They proposed The first, The next generation PON stage 1(NGPON1), which supports a capacity of 10 Gbit/s Upstream and downstream, which is now standardized by ITU-T as XGPON [1]. In 2011 FSAN initiated the next Generation stage 2 (NGPON2) which will enable a capacity beyond 10 Gbit/s [2]. Among the requirements is higher capability up to or greater than 40 Gbit/s and a 40 km reach with 1: 64 split ratio and at least 1 Gbit/s access rate per optical network unit (ONU) [2]. This is aimed at an aggregate capacity of not less than 40 Gb/s. The optical access network will accommodate all kinds of information (voice, data, video, triple play multimedia 3-D) to be transported uniformly using packet based transport switching media [3].

Present trend shows that future video service, such as high definition television (HDTV) will require higher data rate and guaranteed bandwidth and the next generation access network must be such that it can meet up this requirement or demand. To this end the ITU-T/FSAN[4] have been working on how the next generation access network must be able to handle the convergence of voice, data and video which will suggest higher data rate and capacity[1]. The main objective of an optical access network is to provide access to the user (customer). This type of connection is commonly referred to as Fiber to the Premises (FTTP) or FTTH. That is, a fiber link from the central office (CO) provides service to multiple users or customer using transmitter(s) over a single fiber link, that provides downstream and upstream for each user connected to the link (this link is shared by all the users). This type of infrastructure used is referred to as passive optical network (PON), which uses a point to point or multipoint architecture and there are no active or electrical powered element between the central office (CO) and subscriber location as the name implies, hence, lower power required [3].

A passive optical network is the most suitable to satisfy this demand for high capacity, speed, and lower cost. Hence it is not surprising that Next Generation access standardization is in this direction. Currently, time division multiplexing (TDM-PON) are dominant or largely deployed such as Gigabyte PON (G-PON), ethernet PON (E-PON) in many part of the world [4] but in this system the bandwidth is shared among users in the system. Today the present demand drives the need for higher data rate. Telecommunication interest groups such IEEE/ITU-T and FSAN have proposed next generation PON (NGPON) [4]. The next generation PON is divided into two as earlier mentioned NGPON1 and NGPON2.

Next Generation PON Stage 2

The standard requirement as stated in ITU-T recommendations G.989.1 and G.989.2 [4] respectively are:

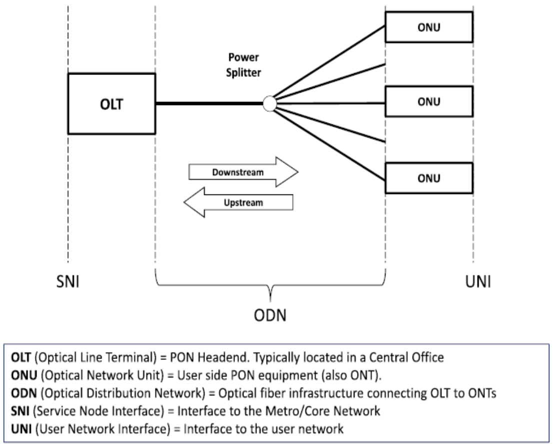
- ✓ Ability to provide 128 Gb/s up to 500Gb/s;
- ✓ Support from 256 up to 1024 ONU's user per feeder fiber;
- ✓ Support up to 20 to 40 km extended passive reach option for working path;
- ✓ Low energy consumption;
- ✓ Low capital and operational cost [7];
- ✓ Coexistence with existing technology.

II Passive Optical Network System

Passive optical network (PON) allows the sharing of a single fiber link (feeder fiber) between many users. It provides a link without an active or electrically powered component, which in effect reduces installation cost of the fiber link and by extension reduces ongoing operation and maintenance cost [3]. PON operates by using a single or multiple wavelengths to carry downstream and upstream data and voice traffic, as well as video broadcasting traffic on a single strand of fiber [10].

PON Architectures

The key elements of the architecture as shown in Figure 1 are the optical line terminal (OLT) sometimes called PON head-end and commonly found in the central office. The optical network unit (ONU) commonly found at the subscriber premises and in between is the optical distribution network (ODN) (this is made up of fiber and optical power splitters) [2].



OLT (Optical Line Terminal) = PON Headend. Typically located in a Central Office
ONU (Optical Network Unit) = User side PON equipment (also ONT).
ODN (Optical Distribution Network) = Optical fiber infrastructure connecting OLT to ONTs
SNI (Service Node Interface) = Interface to the Metro/Core Network
UNI (User Network Interface) = Interface to the user network

Figure 1: PON Architecture [2]

The optical splitter divides the incoming input optical signal from the feeder fiber between a number of output fiber links or customers. This is in the downstream direction. In the upstream direction, it combines all the input flow from the customer premises or fiber link into a single optical signal over the feeder fiber link towards the central office direction [2]. The number of fiber link supported by an OLT port is the maximum splitting ratio and is limited by the power budget considerations. The structure of the optical distribution network (ODN) and the class of optics that are deployed determines the value of the maximum splitting ratio [2]. For instance EPON and GPON specifications include nominal power budgets for each specific class deployed, which indicates the admissible power loss in the ODN. This in turn will limit the maximum power splitting and/or the maximum allowable distance from an ONU to the OLT [11]. The Splitter introduces a splitting loss of 3n dB where n is the number of splits.

Two most likely candidates to see widespread future deployment are Time Division Multiplexing and Wave Division Multiplexing PON. In this project two type of PON will be considered viz: the time division multiplexing passive optical network (TDM-PON) and Time wavelength division multiplexing (TWDM-PON).

Model of a 40 Gb/s TWDM-PON architecture

This model will be used to demonstrate the performance of 40Gb/s TWDM-PON under varying lengths to investigate its performance characteristic at acceptable bit error rate of 10^{-9} based on the ITU-T G.989 recommendation of 40Gb/s downstream and upstream bandwidth, using the wavelength range of 1596 nm -1603 nm [25] in the L-band. It will also be used to determine the maximum bit rate at a distance not less than 10 km within the acceptable BER. Comparison of both models' simulated results and arriving at a conclusion and summary also suggesting anticipated future work that can done on the project.

III Materials and Methods

The experiment is setup as shown in Figure 2 using OptiSystem 13 [3]. The laser source is made up of four CW laser having wavelength range between 1596 to 1603 nm [5] that is in frequency equivalent 187.5, 187.6, 187.7, and 187.8 respectively separated by 0.1 THz or 10 GHz. These are then multiplexed by a WDM multiplexer. The multiplexed signal is then modulated by a Mach-Zehnder (MZ) modulator to avoid chirp. That is, external modulation is carried out before been transmitted over a feeder fiber with an attenuation of 0.2 dB/km. The signal is applied to a power splitter with attenuation of 14 dB before been distributed to each respective ONU. At each ONU as can be seen in Figure 2, a tunable filter is used to select the wavelength of each ONU to be detected by the receiver.

At the OLT the PRBS Generator generates pseudo random binary sequence according to different operation modes. The order is 7 (that is 2^7) making the sequence length 128, the generated data is applied to the laser bias input via NRZ (non-return-to-zero) pulse generator, the NRZ pulse generator generates coded signal in the form of electrical pulses and its output is connected to the electrical input of MZ modulator to drive the MZM. The continuous wave (CW) laser emits a continuous laser output, and its optical signal output is connected to the optical input of MZ modulator. The MZ modulator provides external modulation which is based on the principle of interferometry. The MZ modulator has extinction ratio of 30 dB and k factor equals to -1; which mean an ideal intensity modulator with zero chirp. The optical signal is then modulated by data stream from PRBS and fed into an optical fiber feeder. The simulation parameters are as provided in Table 1.

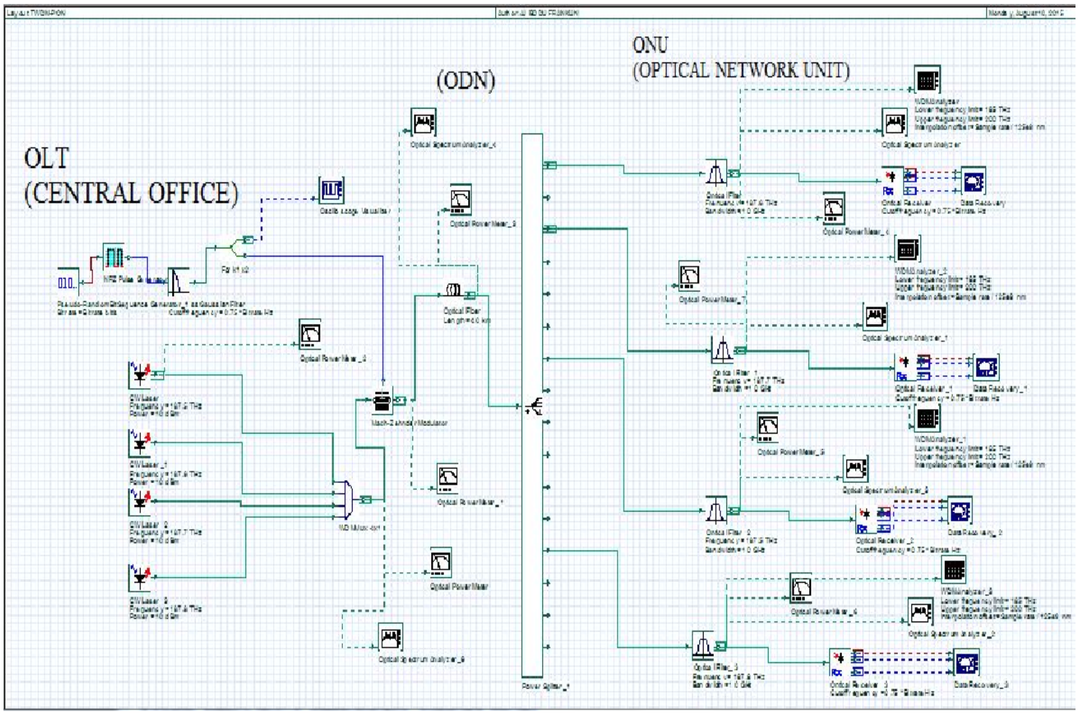


Figure 2: TWDM setup

Table 1: Simulation Parameters

Parameter	Values
Modulator	MZM external modulator
Data rate per wavelength	10 Gb/s
Fiber attenuation	0.2 dB/km
Fiber type	SMF fiber
Distance	20 – 80 km
Number of wavelength	4
Splitter loss (1:16 split ratio)	14 dB
MZM loss	5 dB
Wavelength spacing	10 GHz

Another experimental setup was adopted to investigate the maximum bit rate that can be achieved by the TWDM System. The the bit rate was increased from 10 Gb/s per wavelength in incremental order adjusting the length (reducing) to give an acceptable bit error rate not less than 10^{-9}. This procedure was used to determine the maximum bit rate the TWDM system can support with an acceptable limit of not less than 10 km.

IV Results and Discussion

In evaluating the performance of the TWDM-PON model BER and eye diagram signal measurement was obtained. The BER was measured at the receiver using a data recovery monitor at the ONU measuring each wavelength after tuning the filter to the desired wavelength. Each wavelength carries data at 10 Gb/s. The optical spectra for the four wavelength are shown in Figure 3.

The optical spectrum of the downstream signal showing the four wavelengths 1596.34, 1598.04, 1597.19, 1598.89 nm represented in frequency as 187.5 THz, 187.6 THz, 187.7 THz and 187.8 THz respectively. The wavelength measured at each ONU are display below in Figure 4 and Figure 5 shows the 10 GHz band spectrum of each wavelength.

It can be inferred that the maximum bit rate that can be supported by TWDM-PON system is 52 Gb/s which meets the minimum requirement of 40 Gb/s bit rate specified by ITU-T 989.2.

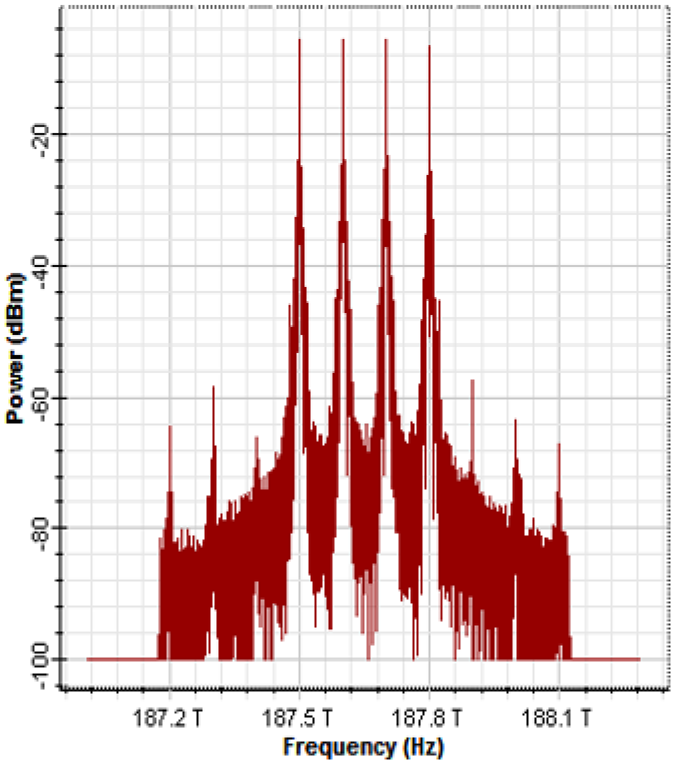
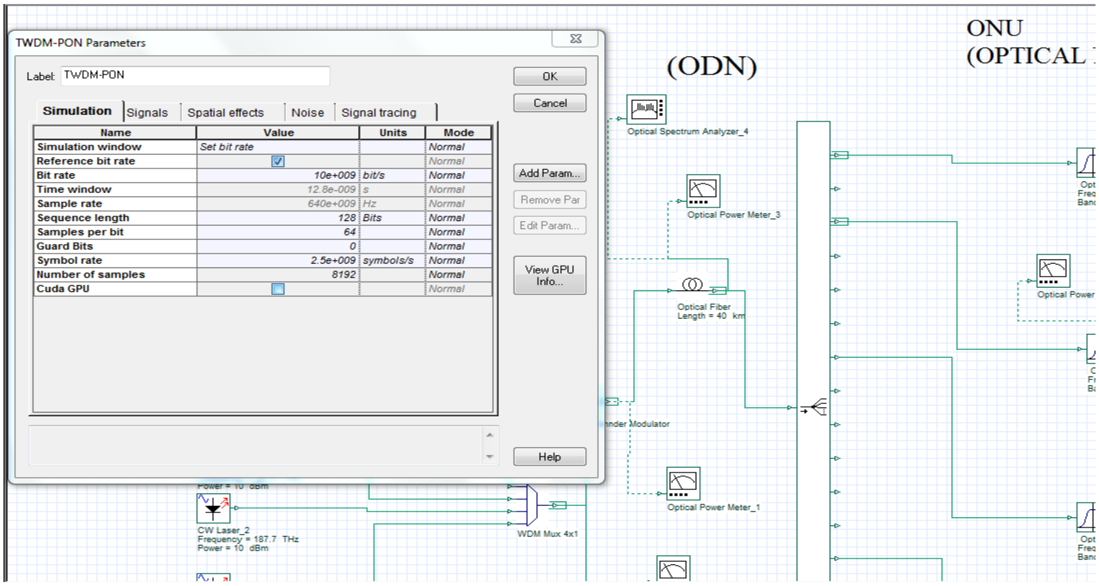


Figure 3: Optical spectrum of downstream signal

Table 2: Measured Bit rate, Fiber length, Aggregate bit rate of TWDM-PON system

Length (km)	Bit rate (Gb/s)	Aggregate Bit rate (Gb/s)
10	13	52

12	13	52
14	13	52
16	12	48
18	12	48
20	12	48
24	12	48
26	12	48
28	11	44
30	11	44
32	11	44
34	11	44
36	11	44
38	11	44
40	10	40
50	10	40



Label: TWDM-PON

Name	Value	Units	Mode
Simulation window	*Set bit rate*		*Normal*
Reference bit rate	☑		*Normal*
Bit rate	*10e+009*	*bit/s*	*Normal*
Time window	*12.8e-009*	*s*	*Normal*
Sample rate	*640e+009*	*Hz*	*Normal*
Sequence length	*128*	*Bits*	*Normal*
Samples per bit	*64*		*Normal*
Guard Bits	*0*		*Normal*
Symbol rate	*2.5e+009*	*symbols/s*	*Normal*
Number of samples	*8192*		*Normal*
Cuda GPU	☐		*Normal*

Figure 4: Experimental setup to determine maximum bit rate of TWDM-PON system model.

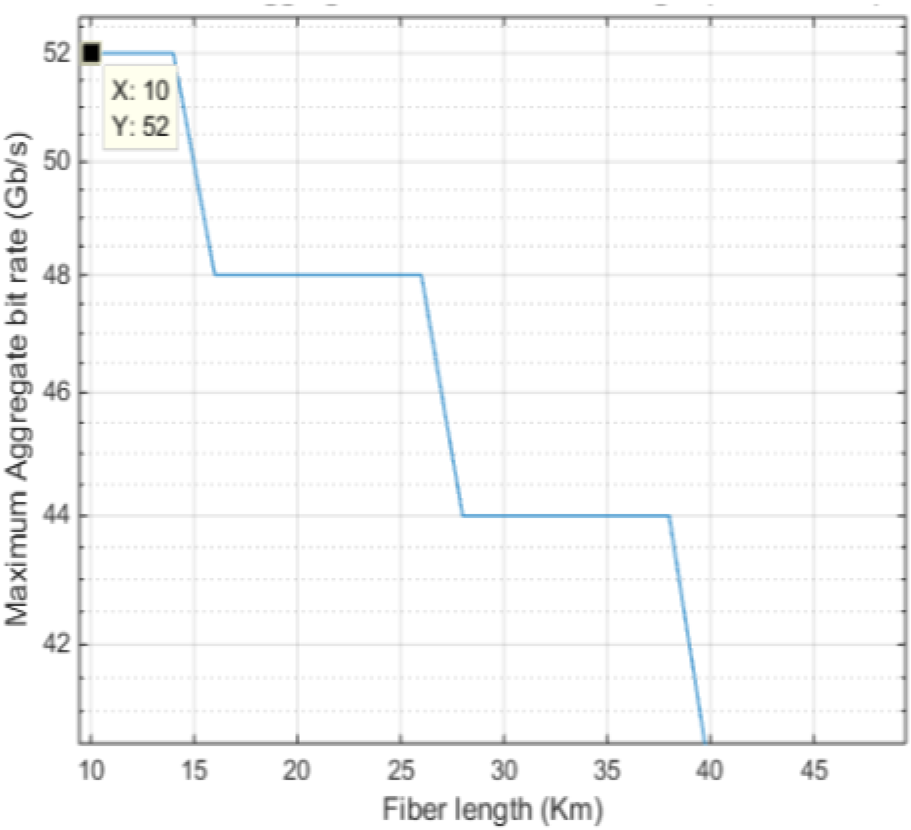


Figure 5: Plot of aggregate bit rate Versus Length

Table 3: Measured maximum bit rate by the XGPON model

Length	Bit rate Gb/s
10	27.5
12	25
14	23
18	20
20	19
22	17
28	16
30	15
34	14
40	13
42	11
60	11
68	10
70	10
72	10

It was determined further in this experimental setup the maximum bit rate that can be supported by increasing the bit rate and reducing the distance to achieve a minimum of 10^{-9} BER. At each instance of increase in bit rate the length is reduced to accommodate the increase until a minimum of 10 km (which is still acceptable) is achieved. Table 2 shows the result obtained.

It can be deduced from Figure 3 and Table 3 that the maximum bit rate that can be supported by the XGPON model is 27.5Gb/s hence it does not meet up the minimum requirement for NGPON stage 2 of 40Gb/s minimum bit rate.

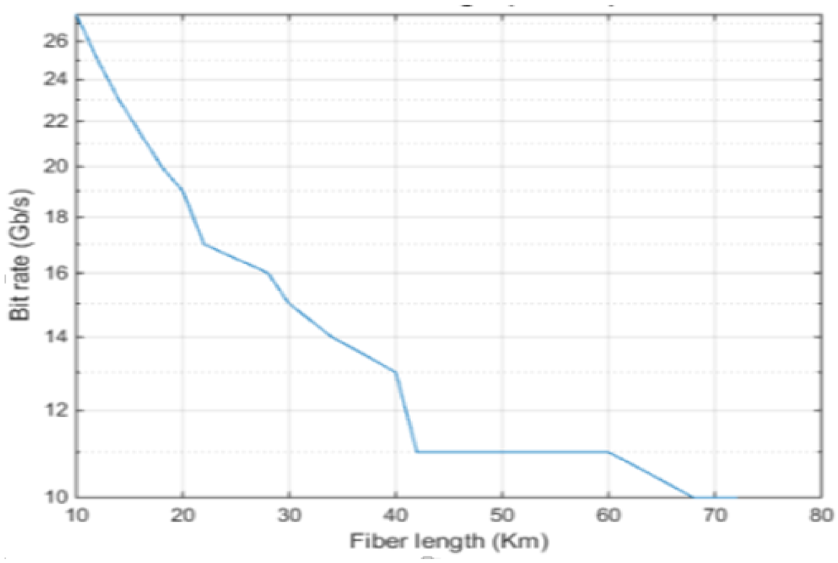


Figure 6: Plot of Bit rate versus fiber length

Conclusions

Figure 5 shows that the maximum bit rate that can be supported by this TWDM model is 52 Gb/s at 10 km of fiber length. For practical applications this will support large volume of data when real time application is required. A Mach-zender modulator is used to reduce the effect of chirp on the measured value using the value obtained in this study. These results suggest that for appropriate information communication technology (ICT) deployment, the model can be used over specified distance to optimize the data bit rate used, which by extension will improve the internet or data delivery over the fiber link.

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