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Power budget Analysis for Passive Optical Network Deployment as Mobile Communication Backhaul Network

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***Keywords*— PON, Power budget, upstream, downstream, DCF, margin, attenuation, ONU, OLT,**

Abstract*— This study focused on providing a robust power budget analysis for Passive Optical Network (PON) deployed as a backhaul network for a mobile communication network in Port Harcourt Nigeria. In this research, optimal power budget model for both upstream and downstream transmission was introduced. The power budget model developed is a bidirectional Passive Optical Network transmission tailored for Cellular Backhaul purposes. The focus is SMILE 4G Mobile Networks, operating in the geographical area of Port Harcourt, Rivers State, Nigeria. Utilizing the coordinates of all the SMILE eNBs in port Harcourt, and adopting systematic/ automatic approach for optimal splitter coordinates, fibre lengths between each eNB and the splitter was obtained. This approach ensures the lowest length of fibre which translates that cheapest cost of deployment was achieved. Employing parameters like attenuation, margin, etc, power budget analysis for both downstream and upstream transmission was obtained. From the results, it was evident that eNBs with longer fibre cable lengths exhibit correspondingly higher levels of fibre attenuation but lower margin values. This consistent pattern was observed across all the eNBs within the network for both Upstream and Downstream transmissions. Power Budget achieved in this research ensured that attenuation was greatly reduced and significant power was available for both transmitter and receiver sensitivity.

I. INTRODUCTION

Passive Optical Network, known as a PON, is essentially an optical network that operates in a point-to-multipoint or multipoint-to-point configuration. It facilitates the optical transmission of various forms of information, including voice, data, and video, between a central point referred to as the Optical Line Terminal (OLT) and other endpoints known as Optical Network Units (ONUs). A typical PON setup comprises a central node, the OLT, and multiple ONUs connected by fiber optics and splitters. When designing Passive Optical Networks with cellular backhaul capabilities, several factors need to be taken into account to ensure the project's success. One of these crucial considerations is power budgeting. In this research Power budget analysis for a PON network is presented. PON is a fibre optic technology and fibre optics can be categorized into different classes (Class A, B, B+, C, and C+) based on their power budget. These classifications are determined by various Passive Optical Network (PON) deployment scenarios, which take into account both the split ratios and the available power budget. A white paper presented by ADC Telecommunications in 2006 [1] specifies that for Broadband PON (BPON) with a maximum split ratio of 32 falls into Class A, B, and C optics when the power budget is 20dB, 25dB, and 30dB, respectively. Similarly, Gigabit PON (GPON) with a maximum logical split ratio of 64 is classified into Class A, B, B+, and C optics, depending on whether the power budget is 20dB, 25dB, 28dB, or 30dB.

In a related study, the Calix User Group presented an article during their conference in 2016 [2] that also categorizes PON networks into classes, assigning power budgets as follows: Class A, Class B, Class B+, Class C, and Class C+ with power budgets of 20dB, 25dB, 28dB, 30dB, and 32dB, respectively. It's worth noting that despite these classifications, the actual optical link budgets may sometimes be influenced by factors such as the operator's choice of active components, including lasers, receivers, and PON chips, as well as the type of protection mechanisms employed.

The calculations for the power budget in this study are conducted in two parts: downstream and upstream budgets (downstream-when OLT is sending while ONUs receiving and Upstream-when ONUs are sending while OLT is receiving). According to [3], commercially available single-mode connectors typically exhibit losses of less than 0.5dB, while the splice loss for a single-mode fibre is approximately 0.1dB. The National Electrical Contractors Association [4] also confirms a splice loss of 0.1dB for single-mode fibre. Transition networks [5], suggests that the typical distance between two splices is 6km, and the minimum value for the safety margin usually starts at 3dB, though it may vary depending on the specific design.

Given the typical 6km distance between two splices, the design plan anticipates three splicing points (worst case) for each OLT-ONU connection, considering the fibre length as given in table 3. Table 1 presents the expected losses within the system, including connector losses at OLT, ONU, WDM mux, WDM demux, power splitter, fibre ends, DCF ends, and the switch. The switch will be utilized to transfer transmissions to the protection link in the event of a failure. To ensure a consistent OLT transmit power for each OLT-ONU pair, a variable margin will be applied. This margin, denoted by varying values in the design, accounts for unforeseen losses and those stemming from the chosen protection scheme. It's important to note that the ITU-T specifies a maximum loss of 32dB for Class C+ optics.

Table 1: Expected losses per component in the system

Components Losses	**Quantity**	**Values (dB)**
Splice	3 x 0.1	0.3dB
Connectors with insertion loss from OLT, ONU and Switch	(each 0.5dB)	0.5dB each
Fibre Attenuation @ 1560 or 1310	Length x attenuation	0.25dB/km at 1550nm and 0.3dB/km at 1310 nm
WDM Mux/Dmux	(8x1)/(1x8)	< or = 3.5dB
Margin Power Splitter/Combiner	Protection and other Loss 1 x 4/4 x1	Variable 6.8dB per OLT-ONU pair
DCF attenuation	0.6dB/km	

II. RESEARCH METHODOLOGY

1.1 Location of Study

The study location is Port Harcourt, which is both the capital and the largest city of Rivers State in the southern region of Nigeria. Positioned along the Bonny River, Port Harcourt is situated 41 miles (66 km) upstream from the Gulf of Guinea. This locale has experienced significant population growth primarily attributed to the discovery of oil, subsequent exploration activities, and the development of related industries. Port Harcourt has become a hub for major oil and gas companies, which has, in turn, catalyzed substantial commercial activities within the city. As per Wikipedia [6], it is estimated that Port Harcourt is home to approximately 1,865,000 residents. Figure 2, shows a satellite view of Port Harcourt situated along the Bonny River upstream from the Gulf of Guinea.

The population of Port Harcourt can be segmented into three distinct subdivisions as follows:

(i) Densely Populated Areas: These regions are characterized by a high concentration of various establishments, including schools, hotels, residential and commercial buildings, places of worship such as churches and mosques, and the presence of multinational companies, among others. Notable areas falling under this category encompass D line, GRA phase 1-5, Aba Road, Woji, and more. Prominent businesses in these localities include the Port Harcourt Pleasure Park, Shell residential area, Meridiane Hospital, and Agip, to name a few. Given the significant population in these areas, a multitude of eNBs (enhanced Node B, a key component in mobile telecommunications) are strategically situated to support robust mobile network coverage.

(ii) Medium Population Areas: This classification pertains to areas with a moderate population density and a notable presence of businesses such as banks, schools, churches, and multinational companies. Notable examples include Rumuokoro market, Choba market, and the University of Port Harcourt (Uniport).

(iii) Low Population Areas: In this category, areas with a sparse population and fewer business establishments are found. Locations like Emeoha, Ndele, and Elele communities fall within this classification.

Port Harcourt, owing to its dense population and urbanized environment, serves as a significant base for numerous mobile telecommunication network operators in Nigeria, contributing substantially to mobile traffic. It is worth noting that this research primarily focused on the SMILE 4G network provider.

For optimal power budgeting, the geographical location of the telecommunication nodes is a vital operation. The approach used to identify SMILE eNBs (enhanced Node Bs) in Port Harcourt involves the following steps:

(i) Data collection involving the acquisition of latitude and longitude coordinates for 60 eNB stations through the use of a network monitor application.

(ii) Data analysis, including the conversion of coordinates into radian measurements, the calculation of great circle distances, and the determination of walking distances between these coordinates.

In the quest to ascertain the best and optimal locations for the splitter for Passive Optical Network (PON) deployments, two methods, namely the 'Manual' and 'Automatic' approaches, were employed. The entries generated represented the highest and lowest values for fibre length, as well as the cost of fibre and attenuation incurred, respectively. Opting for the coordinates 4.82778640N, 7.0265820E as the optimal location results for splitter location, a total cumulative fibre length of 440.745 km was obtained. This choice, in turn, reduces both the cost of fibre procurement and the attenuation within the design. A comparison of the optimum splitter coordinates obtained from both methods, as presented in Table 2, reveals that both the manual and automatic/systematic methodologies yielded similar results for both locations and total distances. Table 2 also showed that both approaches yielded very similar values for both the great circle distance and walking distance. Additionally, it is evident that both approaches resulted in locations that are closely aligned.

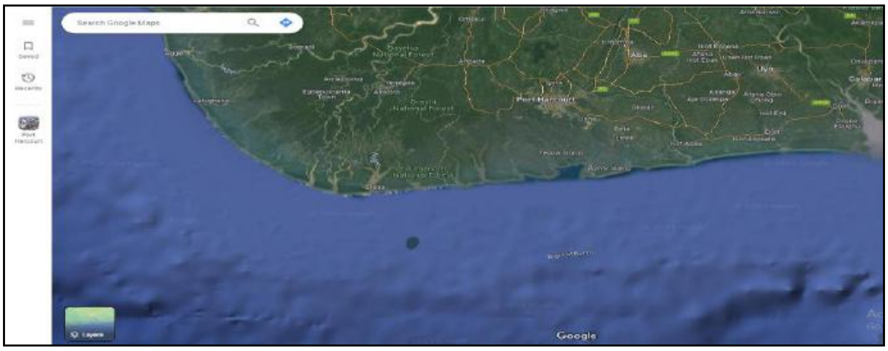

Fig.2: Satellite view of Port Harcourt

Table 2: Coordinates from Manual and Automatic/Systematic Methods (Computational Analysis of Optimal Splitter Coordinates for Passive Optical Network (PON) Deployment, R.O Okeke and V.E Idigo (2021))

METHOD	LOCATION	GREAT CIRCLE DISTANCE	WALKING DISTANCE
MANUAL	4.8277864, 7.026582	440.7447 KM	577.7 KM
AUTOMATIC	4.8276, 7.0254	440.2402 KM	564.45 KM

Based on research conducted by R.O Okeke and V.E Idigo in [7], the coordinates 4.82778640N, 7.0265820E is chosen as the optimal splitter location, optimal splitter location is needed to help determine the fibre length distribution for power budget calculation. Table 3 shows distribution of fibre lengths from the Splitter situated at the chosen optimal splitter location. For the purposes of this research, a total route length of 577km from table 3 is approximated 580km and was considered as the total fibre length. This approximation allows for contingencies and unforeseen factors during the design and power budgeting process. Furthermore, the walking distance values obtained from the Automatic approach were adopted for various OLT – ONU pairs.

Table 3: Breakdown of distances between coordinate 4.8277864^{0}N, 7.026582^{0}E, Exchange/ switch and eNBs

EXCHANGE/NODB PARAMETERS					SPLITTER PARAMETERS (1km from eNB1 to eNB 2)				GREAT CIRCLE DISTANCE (KM)	WALKING DISTANCE (KM)
	LAT1 (Degrees)	LAT1 (Radians)	LONG1 (Degrees)	LONG1 (Radians)	LAT2 (Degrees)	LAT2 (Radians)	LONG2 (Degrees)	LONG2 (Radians)		
exchange	4.808117	0.08392	6.996657	0.12211	4.8277864	0.0842604	7.026582	0.1226365	3.97211	6.2
eNB 1	4.8366	0.08441	7.0286	0.12267	4.827786	0.08426	7.026582	0.122636	1.005203	1.6
eNB 2	4.7737	0.08332	7.0142	0.12242	4.827786	0.08426	7.026582	0.122636	6.16862	10.2
eNB 3	4.7999	0.08377	6.9939	0.12207	4.827786	0.08426	7.026582	0.122636	4.767435	6.1
eNB 4	4.8294	0.08429	7.0919	0.12378	4.827786	0.08426	7.026582	0.122636	7.239448	10
eNB 5	4.7706	0.08326	7.0224	0.12256	4.827786	0.08426	7.026582	0.122636	6.375677	8.1
eNB 6	4.8746	0.08508	6.983	0.12188	4.827786	0.08426	7.026582	0.122636	7.100198	10.1
eNB 7	4.8692	0.08498	7.1137	0.12416	4.827786	0.08426	7.026582	0.122636	10.69458	13.7
eNB 8	4.7196	0.08237	7.1518	0.12482	4.827786	0.08426	7.026582	0.122636	18.36402	23.6
eNB 9	4.8554	0.08474	7.0641	0.12329	4.827786	0.08426	7.026582	0.122636	5.167951	6
eNB 10	4.7909	0.08362	7.1207	0.12428	4.827786	0.08426	7.026582	0.122636	11.20614	14.3
eNB 11	4.7854	0.08352	7.0082	0.12232	4.827786	0.08426	7.026582	0.122636	5.13441	6.4
eNB 12	4.8327	0.08435	7.0685	0.12337	4.827786	0.08426	7.026582	0.122636	4.676523	7.2
eNB 13	4.8039	0.08384	6.9883	0.12197	4.827786	0.08426	7.026582	0.122636	5.00467	6.9
eNB 14	4.8197	0.08412	7.0656	0.12332	4.827786	0.08426	7.026582	0.122636	4.415736	6.7
eNB 15	4.743	0.08278	7.0417	0.1229	4.827786	0.08426	7.026582	0.122636	9.575454	12.6
eNB 16	4.7939	0.08367	7.0308	0.12271	4.827786	0.08426	7.026582	0.122636	3.796858	5.5
eNB 17	4.748	0.08287	7.0989	0.1239	4.827786	0.08426	7.026582	0.122636	11.955	18.9
eNB 18	4.7773	0.08338	7.062	0.12325	4.827786	0.08426	7.026582	0.122636	6.849545	8.2
eNB 19	4.8341	0.08437	6.9845	0.1219	4.827786	0.08426	7.026582	0.122636	4.715218	6
eNB 20	4.8565	0.08476	7.0405	0.12288	4.827786	0.08426	7.026582	0.122636	3.545691	4.9
eNB 21	4.8064	0.08389	7.0424	0.12291	4.827786	0.08426	7.026582	0.122636	2.954143	4.3
eNB 22	4.8146	0.08403	6.9788	0.1218	4.827786	0.08426	7.026582	0.122636	5.493586	7.6
eNB 23	4.8298	0.0843	6.9588	0.12145	4.827786	0.08426	7.026582	0.122636	7.51357	9.3
eNB 24	4.8923	0.08539	6.9143	0.12068	4.827786	0.08426	7.026582	0.122636	14.36035	16.5
eNB 25	4.848	0.08461	7.0492	0.12303	4.827786	0.08426	7.026582	0.122636	3.366318	4
eNB 26	4.8514	0.08467	6.9835	0.12188	4.827786	0.08426	7.026582	0.122636	5.447904	7.7
eNB 27	4.8081	0.08392	6.9967	0.12211	4.827786	0.08426	7.026582	0.122636	3.969176	5.3
eNB 28	4.9028	0.08557	6.999	0.12216	4.827786	0.08426	7.026582	0.122636	8.88327	11.5
eNB 29	4.9789	0.0869	6.9611	0.12149	4.827786	0.08426	7.026582	0.122636	18.30218	23.7
eNB 30	4.9969	0.08721	6.95	0.1213	4.827786	0.08426	7.026582	0.122636	20.62986	24.4
eNB 31	4.9539	0.08646	7.0111	0.12237	4.827786	0.08426	7.026582	0.122636	14.12764	17.3
eNB 32	4.9669	0.08669	6.9869	0.12194	4.827786	0.08426	7.026582	0.122636	16.08126	20.7
eNB 33	4.8289	0.08428	7.0219	0.12255	4.827786	0.08426	7.026582	0.122636	0.533338	1
eNB 34	4.8169	0.08407	7.0112	0.12237	4.827786	0.08426	7.026582	0.122636	2.09048	3.1
eNB 35	4.9317	0.08607	7.0021	0.12221	4.827786	0.08426	7.026582	0.122636	11.86871	14.5
eNB 36	4.8407	0.08449	6.9681	0.12162	4.827786	0.08426	7.026582	0.122636	6.636936	8.3
eNB 37	4.8598	0.08482	6.9792	0.12181	4.827786	0.08426	7.026582	0.122636	6.342878	8.6
eNB 38	4.8469	0.08459	7.0369	0.12282	4.827786	0.08426	7.026582	0.122636	2.413286	3.3
eNB 39	4.8585	0.0848	6.9658	0.12158	4.827786	0.08426	7.026582	0.122636	7.550949	9.1
eNB 40	4.88	0.08517	7.01	0.12235	4.827786	0.08426	7.026582	0.122636	6.089612	8.1

eNB 41	4.8669	0.08494	7.03	0.1227	4.827786	0.08426	7.026582	0.122636	4.36567	7.1
eNB 42	4.8378	0.08444	7.037	0.12282	4.827786	0.08426	7.026582	0.122636	1.603808	2.1
eNB 43	4.8842	0.08525	7.138	0.12458	4.827786	0.08426	7.026582	0.122636	13.84695	17.7
eNB 44	4.7815	0.08345	7.0398	0.12287	4.827786	0.08426	7.026582	0.122636	5.351128	6.3
eNB 45	4.8116	0.08398	6.9561	0.12141	4.827786	0.08426	7.026582	0.122636	8.014217	10.6
eNB 46	4.9011	0.08554	6.9269	0.1209	4.827786	0.08426	7.026582	0.122636	13.72697	17
eNB 47	4.9058	0.08562	6.9066	0.12054	4.827786	0.08426	7.026582	0.122636	15.87325	18.4
eNB 48	4.8024	0.08382	6.944	0.1212	4.827786	0.08426	7.026582	0.122636	9.575779	12.4
eNB 49	4.8354	0.08439	7.0528	0.12309	4.827786	0.08426	7.026582	0.122636	3.025785	4.4
eNB 50	4.7947	0.08368	7.0497	0.12304	4.827786	0.08426	7.026582	0.122636	4.482936	5.9
eNB 51	4.7581	0.08304	7.0119	0.12238	4.827786	0.08426	7.026582	0.122636	7.917683	10
eNB 52	4.8269	0.08424	6.9961	0.1221	4.827786	0.08426	7.026582	0.122636	3.378845	4.7
eNB 53	4.815	0.08404	7.0419	0.1229	4.827786	0.08426	7.026582	0.122636	2.214073	3.3
eNB 54	4.71	0.0822	7.165	0.12505	4.827786	0.08426	7.026582	0.122636	20.16908	25.3
eNB 55	4.8233	0.08418	7.0572	0.12317	4.827786	0.08426	7.026582	0.122636	3.428968	5.8
eNB 56	4.815	0.08404	7.0652	0.12331	4.827786	0.08426	7.026582	0.122636	4.508943	6.7
eNB 57	4.894	0.08542	7.0153	0.12244	4.827786	0.08426	7.026582	0.122636	7.467938	10
eNB 58	4.8626	0.08487	7.0153	0.12244	4.827786	0.08426	7.026582	0.122636	4.067895	6.3
eNB 59	4.8276	0.08426	7.0145	0.12243	4.827786	0.08426	7.026582	0.122636	1.338846	2.2
									440.7447	577.7

1.2 Calculating For Downstream Power Budget

In this backhaul network design, a PON (Passive Optical Network) link with a capacity of 160Gbit/s (comprising two 80Gbit/s streams), extending from the Optical Line Terminal (OLT) to the splitter is considered. The PON network is designed to have a bidirectional transmission and these are Downstream (when the OLT is transmitting to the ONUs) and upstream transmission (when each ONUs are transmitting to the OLT). To achieve the 80Gbit/s data rate, eight 10Gbit/s PON connections were employed, and these are aggregated using an 8x1 multiplexer. Additionally, a switch is incorporated to facilitate the seamless transfer of traffic from the active link to the protection link in case of an active network failure. It's important to note that the losses incurred by these components have been factored into the power budget calculations. The individual losses associated with each of these equipment elements are detailed below:

(i) Connection loss from eight 10Gbit/s OLT = 0.5 x 8 = 4dB (need 80Gbit/s)

(ii) Connection loss from switch = 0.5dB

(iii) Connection loss from the ONU =0.5dB

(iv) Insertion loss from 1 x 8 WDM demultiplexer = 3.5dB

(v) Insertion loss from 8 x 1 WDM multiplexer = 3.5dB

(vi) 1x 4 splitter insertion loss = 6.8dB

(vii) Attenuation at 1550nm =0.25 x fibre length

(viii) Attenuation at 1310nm = 0.3 x fibre length

(ix) Attenuation of DCF = 0.6 x DCF length

(x) Splice loss = 0.1dB

(xi) Margin = Variable

From the proposed network diagram shown in figure 3, aside connection losses due to i, ii and iii above, the network has additional 4 connections in between and that made up a 2dB loss. Total loss due to connections is 4+0.5+0.5+2 = 7dB. Since the losses in the system is established, the transmit power of the OLT in the downstream direction can also be obtained. Equation 1 is PON power budget formula used for the OLT transmit power calculation in the downstream direction.

$$\begin{aligned} \text{OLT Tx} - \text{ONU Rx} &= \text{atten x fibre length} \\ &+ \text{atten x DCF length} \\ &+ \text{WDM mux loss} + \text{WDM demux loss} \\ &+ \text{Splitter loss} + \text{connector losses} \\ &+ \text{splice losses} + \text{Margin} \qquad (1) \end{aligned}$$

Where OLT Tx = OLT transmit Power; ONU Rx = ONU receiver sensitivity; atten x fibre length = loss due to length of fibre cable; atten x DCF length = loss due to dispersion compensation fibre; WDM mux loss = insertion loss due to WDM multiplexer; WDM demux loss = insertion loss due to WDM demultiplexer; Connector losses = losses accrued due to connectors; Splice losses = losses accrued due to splicing; Margin = varying value of loss in the system that will take care for unaccounted losses and as such keep all OLT Tx and all ONU Rx value constant on every OLT-ONU pair.

The process of determining the losses, margin, and ONU Rx for each OLT Tx - ONU Rx pair, as previously outlined, is replicated for all 60 OLT Tx – ONU Rx pairs employing a spreadsheet. The outcomes of this analysis are presented in Table 4. The margin is applied to ensure consistent losses across all 60 OLT – ONU pairs.

The margin is varied in each case to maintain the same loss for the entire OLT – ONU pairs and as such to maintain constant ONU Rx for each. The range of values for the margin is 3.11– 9.32dB.

Parameters:

(i) Attenuation at 1550nm downstream is 0.25dB/km

(ii) Maximum loss for class C+ is 32dB as specified by ITU –T

(iii) In downstream, OLT Tx is usually from 3 - 7dBm and ONU Rx is -32dBm maximum while in upstream direction, ONU Tx is always from 0.5 – 5 dBm and OLT Rx is -30dBm for a worst case.

OLT - ONU1 pair calculation is as shown;

$$\text{Fibre length} = (4.8 + 1.4)\ \text{km} = 6.2\text{km}$$

$$\text{Attenuation per length} = 0.25 \times 6.2 = 1.5\text{dB/km}$$

$$\text{Loss due to DCF, atten x DCF length} =$$
$$0.6 \times 0.4\text{km} = 0.24\text{dB/km}$$

$$\text{Loss due to connectors} = 4 + 0.5 + 0.5 + 2 = 7\text{dB}$$

$$\text{Loss due to splicing (3 possible splicing)} = 0.1 \times 3 = 0.3\text{dB}$$

Insertion loss due to WDM mux =3.5dB

Insertion loss due to WDM demux = 3.5dB

Insertion loss due to 1 x 4 Splitter = 6.8dB

Margin = unknown (varies)

From equation 1,

$$\text{OLT Tx - ONU Rx} = (1.5\text{dB/km} + 0.24\text{dB/km} + 3.5\text{dB} + 3.5\text{dB} + 6.8\text{dB} + 7\text{dB} + 0.3\text{dB} + \text{M})$$
$$\text{OLT Tx - ONU Rx} = (22.84 + \text{M})\text{dB}$$

Hence, total loss;

$$32 = 22.84 + \text{M}$$
$$\text{M} = 32 - 22.84 = 9.16\text{dB (margin for OLT - ONU1 pair)}$$

Assuming the lowest OLT Tx power (3dBm) for class C+ optics is adopted, OLT Tx power becomes 3dBm; hence, equation 1 becomes:

$$3 - (\text{ONU1 Rx}) = 22.84 + \text{M}$$
$$\text{ONU1 Rx} = -29\text{dBm}$$

The network is divided into two segments for ease of presentation, segment A consist of ONU 1 to ONU 32 while segment B covered ONU 33 to ONU 59. Figure 3 is a block diagram showing Segment A

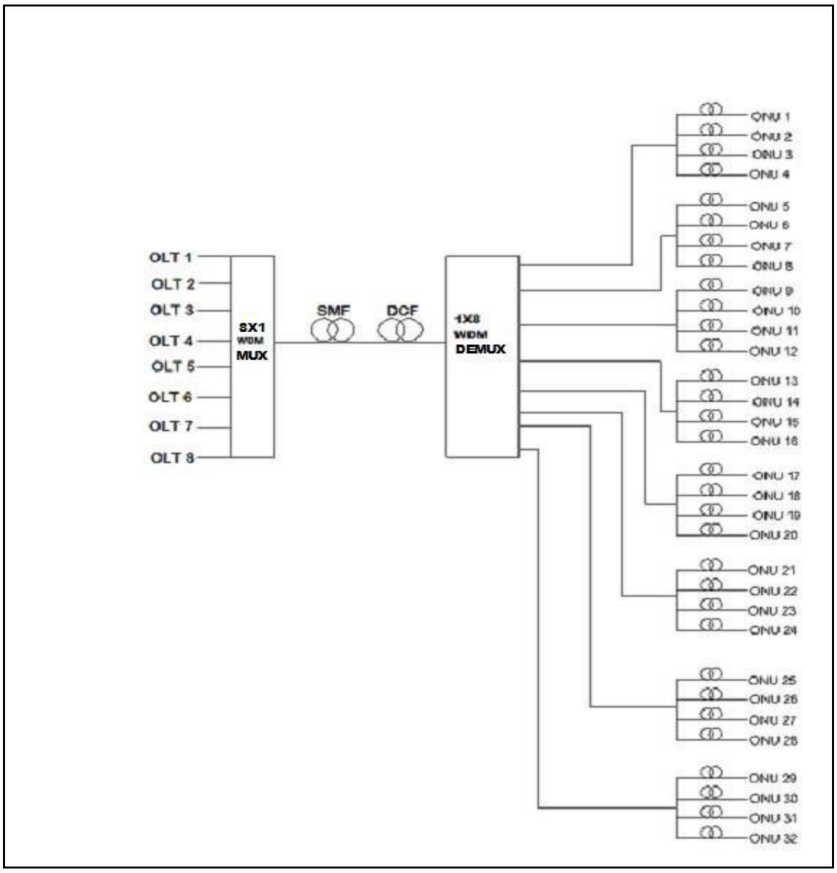

Fig.3: Block diagram of segment A of the network

Table 4: Downstream Power Budget

S/N	OLT TX (dBm)	ONU RX (dBm)	FIBRE LTH (km)	ATTN (dB/km)	FIBRE ATTN (dB/km)	DCF LTH (km)	ATTN (dB/km)	DCF ATTN (dB/km)	WDM MUX LOSS (dB)	WDM DEMUX LOSS (dB)	SPT. LOSS (dB)	CONNT. LOSS (dB)	SPL. LOSS (dB)	MARGIN (dB)
eNB1	3	-29	6.2	0.25	1.55	0.4	0.6	0.24	3.5	3.5	6.8	7	0.3	9.11
eNB2	3	-29	12.6	0.25	3.15	0.4	0.6	0.24	3.5	3.5	6.8	7	0.3	7.51
eNB3	3	-29	10.4	0.25	2.6	0.4	0.6	0.24	3.5	3.5	6.8	7	0.3	8.06
eNB4	3	-29	14.9	0.25	3.725	0.4	0.6	0.24	3.5	3.5	6.8	7	0.3	6.935
eNB5	3	-29	12.5	0.25	3.125	0.4	0.6	0.24	3.5	3.5	6.8	7	0.3	7.535
eNB6	3	-29	14.5	0.25	3.625	0.4	0.6	0.24	3.5	3.5	6.8	7	0.3	7.035
eNB7	3	-29	18.6	0.25	4.65	0.4	0.6	0.24	3.5	3.5	6.8	7	0.3	6.01
eNB8	3	-29	28.5	0.25	7.125	0.4	0.6	0.24	3.5	3.5	6.8	7	0.3	3.535
eNB9	3	-29	10.8	0.25	2.7	0.4	0.6	0.24	3.5	3.5	6.8	7	0.3	7.96
eNB10	3	-29	19.1	0.25	4.775	0.4	0.6	0.24	3.5	3.5	6.8	7	0.3	5.885
eNB11	3	-29	10.7	0.25	2.675	0.4	0.6	0.24	3.5	3.5	6.8	7	0.3	7.985
eNB12	3	-29	12.1	0.25	3.025	0.4	0.6	0.24	3.5	3.5	6.8	7	0.3	7.635
eNB13	3	-29	11.3	0.25	2.825	0.4	0.6	0.24	3.5	3.5	6.8	7	0.3	7.835
eNB14	3	-29	11.9	0.25	2.975	0.4	0.6	0.24	3.5	3.5	6.8	7	0.3	7.685
eNB15	3	-29	16.9	0.25	4.225	0.4	0.6	0.24	3.5	3.5	6.8	7	0.3	6.435
eNB16	3	-29	9.8	0.25	2.45	0.4	0.6	0.24	3.5	3.5	6.8	7	0.3	8.21
eNB17	3	-29	23.8	0.25	5.95	0.4	0.6	0.24	3.5	3.5	6.8	7	0.3	4.71
eNB18	3	-29	12.9	0.25	3.225	0.4	0.6	0.24	3.5	3.5	6.8	7	0.3	7.435
eNB19	3	-29	10.8	0.25	2.7	0.4	0.6	0.24	3.5	3.5	6.8	7	0.3	7.96
eNB20	3	-29	9.6	0.25	2.4	0.4	0.6	0.24	3.5	3.5	6.8	7	0.3	8.26
eNB21	3	-29	8.6	0.25	2.15	0.4	0.6	0.24	3.5	3.5	6.8	7	0.3	8.51
eNB22	3	-29	11.9	0.25	2.975	0.4	0.6	0.24	3.5	3.5	6.8	7	0.3	7.685
eNB23	3	-29	13.7	0.25	3.425	0.4	0.6	0.24	3.5	3.5	6.8	7	0.3	7.235
eNB24	3	-29	21.3	0.25	5.325	0.4	0.6	0.24	3.5	3.5	6.8	7	0.3	5.335
eNB25	3	-29	8.8	0.25	2.2	0.4	0.6	0.24	3.5	3.5	6.8	7	0.3	8.46
eNB26	3	-29	12.6	0.25	3.15	0.4	0.6	0.24	3.5	3.5	6.8	7	0.3	7.51
eNB27	3	-29	9.6	0.25	2.4	0.4	0.6	0.24	3.5	3.5	6.8	7	0.3	8.26
eNB28	3	-29	16	0.25	4	0.4	0.6	0.24	3.5	3.5	6.8	7	0.3	6.66
eNB29	3	-29	28.3	0.25	7.075	0.4	0.6	0.24	3.5	3.5	6.8	7	0.3	3.585
eNB30	3	-29	28.9	0.25	7.225	0.4	0.6	0.24	3.5	3.5	6.8	7	0.3	3.435
eNB31	3	-29	21.8	0.25	5.45	0.4	0.6	0.24	3.5	3.5	6.8	7	0.3	5.21
eNB32	3	-29	25.2	0.25	6.3	0.4	0.6	0.24	3.5	3.5	6.8	7	0.3	4.36
eNB33	3	-29	5.35	0.25	1.3375	0.4	0.6	0.24	3.5	3.5	6.8	7	0.3	9.3225
eNB34	3	-29	7.4	0.25	1.85	0.4	0.6	0.24	3.5	3.5	6.8	7	0.3	8.81
eNB35	3	-29	19.1	0.25	4.775	0.4	0.6	0.24	3.5	3.5	6.8	7	0.3	5.885
eNB36	3	-29	13.1	0.25	3.275	0.4	0.6	0.24	3.5	3.5	6.8	7	0.3	7.385
eNB37	3	-29	13.5	0.25	3.375	0.4	0.6	0.24	3.5	3.5	6.8	7	0.3	7.285
eNB38	3	-29	7.9	0.25	1.975	0.4	0.6	0.24	3.5	3.5	6.8	7	0.3	8.685
eNB39	3	-29	13.9	0.25	3.475	0.4	0.6	0.24	3.5	3.5	6.8	7	0.3	7.185
eNB40	3	-29	12.6	0.25	3.15	0.4	0.6	0.24	3.5	3.5	6.8	7	0.3	7.51

eNB41	3	-29	11.7	0.25	2.925	0.4	0.6	0.24	3.5	3.5	6.8	7	0.3	7.735
eNB42	3	-29	7	0.25	1.75	0.4	0.6	0.24	3.5	3.5	6.8	7	0.3	8.91
eNB43	3	-29	22.6	0.25	5.65	0.4	0.6	0.24	3.5	3.5	6.8	7	0.3	5.01
eNB44	3	-29	10.6	0.25	2.65	0.4	0.6	0.24	3.5	3.5	6.8	7	0.3	8.01
eNB45	3	-29	15	0.25	3.75	0.4	0.6	0.24	3.5	3.5	6.8	7	0.3	6.91
eNB46	3	-29	21.8	0.25	5.45	0.4	0.6	0.24	3.5	3.5	6.8	7	0.3	5.21
eNB47	3	-29	23.3	0.25	5.825	0.4	0.6	0.24	3.5	3.5	6.8	7	0.3	4.835
eNB48	3	-29	16.8	0.25	4.2	0.4	0.6	0.24	3.5	3.5	6.8	7	0.3	6.46
eNB49	3	-29	9.2	0.25	2.3	0.4	0.6	0.24	3.5	3.5	6.8	7	0.3	8.36
eNB50	3	-29	10.3	0.25	2.575	0.4	0.6	0.24	3.5	3.5	6.8	7	0.3	8.085
eNB51	3	-29	14.3	0.25	3.575	0.4	0.6	0.24	3.5	3.5	6.8	7	0.3	7.085
eNB52	3	-29	9	0.25	2.25	0.4	0.6	0.24	3.5	3.5	6.8	7	0.3	8.41
eNB53	3	-29	8.6	0.25	2.15	0.4	0.6	0.24	3.5	3.5	6.8	7	0.3	8.51
eNB54	3	-29	30.2	0.25	7.55	0.4	0.6	0.24	3.5	3.5	6.8	7	0.3	3.11
eNB55	3	-29	11	0.25	2.75	0.4	0.6	0.24	3.5	3.5	6.8	7	0.3	7.91
eNB56	3	-29	11.9	0.25	2.975	0.4	0.6	0.24	3.5	3.5	6.8	7	0.3	7.685
eNB57	3	-29	14.6	0.25	3.65	0.4	0.6	0.24	3.5	3.5	6.8	7	0.3	7.01
eNB58	3	-29	10.9	0.25	2.725	0.4	0.6	0.24	3.5	3.5	6.8	7	0.3	7.935
eNB59	3	-29	6.6	0.25	1.65	0.4	0.6	0.24	3.5	3.5	6.8	7	0.3	9.01

1.3 Calculating For Upstream Power Budget

Calculating for upstream, equation 2 is adopted:

$$\begin{aligned}&\text{ONU Tx - OLT Rx} = \text{atten x fibre length}\\&+ \text{atten x DCF length} + \text{WDM mux loss}\\&+ \text{WDM demux loss} + \text{combiner loss}\\&+ \text{connector losses} + \text{splice losses} + \text{Margin} \qquad (2)\end{aligned}$$

In this case, eNBs (ONUs) are transmitting and the power splitter is replaced by combiners. Attenuation coefficient at 1310nm window is used and it is 0.3dB/km. A worst case OLT Rx (-30dBm) for class C+ optics is adopted.

ONU1 Tx - OLT Rx pair calculation is as shown;

$$\begin{aligned}&\text{Fibre length} = (4.8 + 1.4)\ \text{km} = 6.2\text{km}\\&\text{Attenuation per length} = 0.3 \text{ x } 6.2 = 1.86\text{dB/km}\\&\text{Loss due to DCF, atten x DCF length} = 0.6 \text{ x } 0.4\text{km}\\&= 0.24\text{dB/km}\\&\text{Loss due to connection} = 4 + 0.5 + 0.5 + 2 = 7\text{dB}\\&\text{Loss due to splicing (3 possible splicing)} = 0.1\text{x } 3 = 0.3\text{dB}\end{aligned}$$

Insertion loss due to WDM mux =3.5dB

Insertion loss due to WDM demux = 3.5dB

Insertion loss due to 4 x 1 Combiner = 6.8dB

Margin = unknown (varies)

From equation 2,

$$\begin{aligned}&\text{ONU1 Tx - OLT Rx} = (1.86\text{dB/km} + 0.24\text{dB/km}\\&+ 3.5\text{dB} + 3.5\text{dB} + 6.8\text{dB} + 7\text{dB} + 0.3\text{dB} + \text{M})\\&\text{ONU1 Tx - OLT Rx} = (23.2 + \text{M})\end{aligned}$$

If a total loss of 32 is adopted because class C+ optics is considered, M =32-23.2 = 8.8dB

Assuming worst probable OLT Rx (sensitivity) for class C+ optics is adopted, OLT Rx power becomes -30dBm.

$$\begin{aligned}&\text{ONU1 Tx - (-30dBm)} = 32\text{dB}\,(23.2 + 8.8)\\&\text{ONU1 Tx} = 2\text{dBm}\end{aligned}$$

The method for calculating the losses, margin, and ONU Tx for every ONU Tx - OLT Rx pair, as detailed earlier, is reiterated for all 59 ONU Tx - OLT Rx pairs utilizing a spreadsheet. The outcomes of this process are displayed in Table 5. The margin is employed to ensure uniform losses across all 59 OLT – ONU pairs.

The margin is adjusted individually in each instance to uphold consistent loss levels across the entire range of OLT – ONU pairs. This adjustment is essential for maintaining a uniform ONU Tx for each pair. The margin values span a range from 1.60 dB to 9.055 dB.

Table 5: Upstream Power Budget

S/N	ONU TX (dBm)	OLT RX (dBm)	FIBRE LTH (km)	ATTN (dB/km)	FIBRE ATTN (dB/km)	DCF LTH (km)	ATTN (dB/km)	DCF ATTN (dB/km)	WDM MUX LOSS (dB)	WDM DEMUX LOSS (dB)	SP.T LOSS (dB)	CONNT. LOSS (dB)	SPL. LOSS (dB)	MARGIN (dB)
eNB1	2	-30	6.2	0.3	1.86	0.4	0.6	0.24	3.5	3.5	6.8	7	0.3	8.8
eNB2	2	-30	12.6	0.3	3.78	0.4	0.6	0.24	3.5	3.5	6.8	7	0.3	6.88
eNB3	2	-30	10.4	0.3	3.12	0.4	0.6	0.24	3.5	3.5	6.8	7	0.3	7.54
eNB4	2	-30	14.9	0.3	4.47	0.4	0.6	0.24	3.5	3.5	6.8	7	0.3	6.19
eNB5	2	-30	12.5	0.3	3.75	0.4	0.6	0.24	3.5	3.5	6.8	7	0.3	6.91
eNB6	2	-30	14.5	0.3	4.35	0.4	0.6	0.24	3.5	3.5	6.8	7	0.3	6.31
eNB7	2	-30	18.6	0.3	5.58	0.4	0.6	0.24	3.5	3.5	6.8	7	0.3	5.08
eNB8	2	-30	28.5	0.3	8.55	0.4	0.6	0.24	3.5	3.5	6.8	7	0.3	2.11
eNB9	2	-30	10.8	0.3	3.24	0.4	0.6	0.24	3.5	3.5	6.8	7	0.3	7.42
eNB10	2	-30	19.1	0.3	5.73	0.4	0.6	0.24	3.5	3.5	6.8	7	0.3	4.93
eNB11	2	-30	10.7	0.3	3.21	0.4	0.6	0.24	3.5	3.5	6.8	7	0.3	7.45
eNB12	2	-30	12.1	0.3	3.63	0.4	0.6	0.24	3.5	3.5	6.8	7	0.3	7.03
eNB13	2	-30	11.3	0.3	3.39	0.4	0.6	0.24	3.5	3.5	6.8	7	0.3	7.27
eNB14	2	-30	11.9	0.3	3.57	0.4	0.6	0.24	3.5	3.5	6.8	7	0.3	7.09
eNB15	2	-30	16.9	0.3	5.07	0.4	0.6	0.24	3.5	3.5	6.8	7	0.3	5.59
eNB16	2	-30	9.8	0.3	2.94	0.4	0.6	0.24	3.5	3.5	6.8	7	0.3	7.72
eNB17	2	-30	23.8	0.3	7.14	0.4	0.6	0.24	3.5	3.5	6.8	7	0.3	3.52
eNB18	2	-30	12.9	0.3	3.87	0.4	0.6	0.24	3.5	3.5	6.8	7	0.3	6.79
eNB19	2	-30	10.8	0.3	3.24	0.4	0.6	0.24	3.5	3.5	6.8	7	0.3	7.42
eNB20	2	-30	9.6	0.3	2.88	0.4	0.6	0.24	3.5	3.5	6.8	7	0.3	7.78
eNB21	2	-30	8.6	0.3	2.58	0.4	0.6	0.24	3.5	3.5	6.8	7	0.3	8.08
eNB22	2	-30	11.9	0.3	3.57	0.4	0.6	0.24	3.5	3.5	6.8	7	0.3	7.09
eNB23	2	-30	13.7	0.3	4.11	0.4	0.6	0.24	3.5	3.5	6.8	7	0.3	6.55
eNB24	2	-30	21.3	0.3	6.39	0.4	0.6	0.24	3.5	3.5	6.8	7	0.3	4.27
eNB25	2	-30	8.8	0.3	2.64	0.4	0.6	0.24	3.5	3.5	6.8	7	0.3	8.02
eNB26	2	-30	12.6	0.3	3.78	0.4	0.6	0.24	3.5	3.5	6.8	7	0.3	6.88
eNB27	2	-30	9.6	0.3	2.88	0.4	0.6	0.24	3.5	3.5	6.8	7	0.3	7.78
eNB28	2	-30	16	0.3	4.8	0.4	0.6	0.24	3.5	3.5	6.8	7	0.3	5.86
eNB29	2	-30	28.3	0.3	8.49	0.4	0.6	0.24	3.5	3.5	6.8	7	0.3	2.17
eNB30	2	-30	28.9	0.3	8.67	0.4	0.6	0.24	3.5	3.5	6.8	7	0.3	1.99
eNB31	2	-30	21.8	0.3	6.54	0.4	0.6	0.24	3.5	3.5	6.8	7	0.3	4.12
eNB32	2	-30	25.2	0.3	7.56	0.4	0.6	0.24	3.5	3.5	6.8	7	0.3	3.1
eNB33	2	-30	5.35	0.3	1.605	0.4	0.6	0.24	3.5	3.5	6.8	7	0.3	9.055
eNB34	2	-30	7.4	0.3	2.22	0.4	0.6	0.24	3.5	3.5	6.8	7	0.3	8.44
eNB35	2	-30	19.1	0.3	5.73	0.4	0.6	0.24	3.5	3.5	6.8	7	0.3	4.93
eNB36	2	-30	13.1	0.3	3.93	0.4	0.6	0.24	3.5	3.5	6.8	7	0.3	6.73
eNB37	2	-30	13.5	0.3	4.05	0.4	0.6	0.24	3.5	3.5	6.8	7	0.3	6.61
eNB38	2	-30	7.9	0.3	2.37	0.4	0.6	0.24	3.5	3.5	6.8	7	0.3	8.29
eNB39	2	-30	13.9	0.3	4.17	0.4	0.6	0.24	3.5	3.5	6.8	7	0.3	6.49
eNB40	2	-30	12.6	0.3	3.78	0.4	0.6	0.24	3.5	3.5	6.8	7	0.3	6.88

eNB41	2	-30	11.7	0.3	3.51	0.4	0.6	0.24	3.5	3.5	6.8	7	0.3	7.15
eNB42	2	-30	7	0.3	2.1	0.4	0.6	0.24	3.5	3.5	6.8	7	0.3	8.56
eNB43	2	-30	22.6	0.3	6.78	0.4	0.6	0.24	3.5	3.5	6.8	7	0.3	3.88
eNB44	2	-30	10.6	0.3	3.18	0.4	0.6	0.24	3.5	3.5	6.8	7	0.3	7.48
eNB45	2	-30	15	0.3	4.5	0.4	0.6	0.24	3.5	3.5	6.8	7	0.3	6.16
eNB46	2	-30	21.8	0.3	6.54	0.4	0.6	0.24	3.5	3.5	6.8	7	0.3	4.12
eNB47	2	-30	23.3	0.3	6.99	0.4	0.6	0.24	3.5	3.5	6.8	7	0.3	3.67
eNB48	2	-30	16.8	0.3	5.04	0.4	0.6	0.24	3.5	3.5	6.8	7	0.3	5.62
eNB49	2	-30	9.2	0.3	2.76	0.4	0.6	0.24	3.5	3.5	6.8	7	0.3	7.9
eNB50	2	-30	10.3	0.3	3.09	0.4	0.6	0.24	3.5	3.5	6.8	7	0.3	7.57
eNB51	2	-30	14.3	0.3	4.29	0.4	0.6	0.24	3.5	3.5	6.8	7	0.3	6.37
eNB52	2	-30	9	0.3	2.7	0.4	0.6	0.24	3.5	3.5	6.8	7	0.3	7.96
eNB53	2	-30	8.6	0.3	2.58	0.4	0.6	0.24	3.5	3.5	6.8	7	0.3	8.08
eNB54	2	-30	30.2	0.3	9.06	0.4	0.6	0.24	3.5	3.5	6.8	7	0.3	1.6
eNB55	2	-30	11	0.3	3.3	0.4	0.6	0.24	3.5	3.5	6.8	7	0.3	7.36
eNB56	2	-30	11.9	0.3	3.57	0.4	0.6	0.24	3.5	3.5	6.8	7	0.3	7.09
eNB57	2	-30	14.6	0.3	4.38	0.4	0.6	0.24	3.5	3.5	6.8	7	0.3	6.28
eNB58	2	-30	10.9	0.3	3.27	0.4	0.6	0.24	3.5	3.5	6.8	7	0.3	7.39
eNB59	2	-30	6.6	0.3	1.98	0.4	0.6	0.24	3.5	3.5	6.8	7	0.3	8.68

2 RESULTS AND DISCUSSION

2.1 Downstream Power Budget Analysis

The margin is adjusted individually in each instance to uphold consistent loss levels across the entire range of OLT – ONU pairs. This adjustment is essential for maintaining a uniform ONU Tx for each pair. The margin values span a range from 1.60 dB to 9.055 dB.

(i) OLT Tx for all the eNBs has value of 3dBm

(ii) Receiver sensitivity for all the 59 eNBs in the network is -29dBm

(iii) Attenuation coefficient in downstream is 0.25dB/km

(iv) DCF attenuation coefficient is 0.6dB/km

(v) OLT – eNB1 pair has fibre length of 6.2km

(vi) OLT – eNB1 pair has fibre attenuation of 1.55dB/km

(vii) OLT – eNB1 pair has dispersion compensation fibre (DCF) of length 0.4km

(viii) OLT – eNB1 pair has DCF attenuation of 0.24dB/km

(ix) WDM mux used has insertion loss of 3.5dB

(x) WDM demux used has insertion loss of 3.5dB

(xi) Losses accrued due to connection is 7dB

(xii) Losses accrued due to spicing is 0.3dB

(xiii) Margin of 9.11dB was used to maintain fixed OLT Tx and ONU Rx.

The same methodology was applied to derive the aforementioned parameters (items i to xiii) for all OLT – ONU pairs within the network. Across all pairs, the margin was employed to ensure a consistent OLT Tx and ONU Rx, despite variations in fibre lengths and attenuations. Figure 4 illustrates a graphical representation of the results obtained from downstream power budget. The result shows fibre lengths, fibre attenuations, and varying margin values for all 59 eNBs serving as ONUs within the network. It is noteworthy that eNBs with longer fibre cable lengths exhibit correspondingly higher levels of fibre attenuation but lower margin values. For instance, eNB54, which boasts the longest fibre cable length of 30.2km, demonstrates a fibre attenuation of 7.55dB and a margin of 3.11dB. Conversely, eNB33, with the shortest fibre cable length of 5.35km, exhibits a fibre attenuation of 1.34dB and a margin of 9.32dB. This pattern is consistent across all 59 eNBs within the network, as evident in Figure 4.

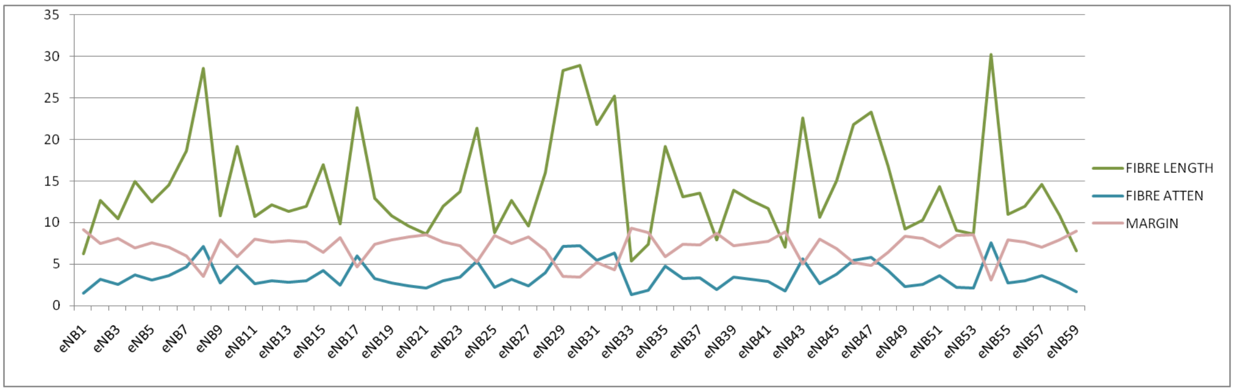

Fig.4: Downstream power budget graphic representation

2.2 Upstream Power Budget Analysis

In the upstream transmission, each eNB transmits data to the OLT located at the exchange/switch, while the OLT, in turn, receives data from each ONU. This section focuses on the findings of the upstream power budget analysis. The calculations in Table 5 were performed using Equation 2. The ONUs are configured with a transmit power of 2dBm, whereas the OLT receiver sensitivity is set at -30dBm. For the ONU1 Tx – OLT Rx pair, the following parameters were determined in accordance with the data provided in Table 5.

(i) All the 59 eNBs (ONU) has transmitter power of value 2dBm

(ii) Receiver sensitivity of the OLT in the network is -30dBm

(iii) Attenuation coefficient in upstream is 0.3dB/km

(iv) DCF attenuation coefficient is 0.6dB/km

(v) OLT – eNB1 pair has fibre length of 6.2km

(vi) OLT – eNB1 pair has fibre attenuation of 1.86dB/km

(vii) OLT – eNB1 pair has dispersion compensation fibre (DCF) of length 0.4km

(viii) OLT – eNB1 pair has DCF attenuation of 0.24dB/km

(ix) WDM mux used has insertion loss of 3.5dB

(x) WDM demux used has insertion loss of 3.5dB

(xi) Losses accrued due to connection is 7dB

(xii) Losses accrued due to spicing is 0.3dB

Margin of 8.8dB was used to maintain fixed OLT Rx and ONU Tx

The same procedure was applied to acquire the aforementioned parameters (items i to xiii) for all ONU – OLT pairs within the network. In all these pairs, a margin was implemented to maintain a consistent ONU Tx and OLT Rx, even when faced with varying fibre lengths and attenuations. Figure 5 illustrates a graphical representation of fibre lengths, fibre attenuations, and the varying margin values for all 59 eNBs serving as ONUs in the network. It is evident that eNBs with longer fibre cable lengths exhibit correspondingly higher levels of fibre attenuation but lower margin values. For instance, eNB54, which features the lengthiest fibre cable at 30.2km, displays a fibre attenuation of 9.06dB and a margin of 1.6dB. On the other hand, eNB33 with the shortest fibre cable length of 5.35km, demonstrates a fibre attenuation of 1.61dB and a margin of 9.06dB. This consistent pattern is observable across all 59 eNBs within the network, as depicted in Figure 5.

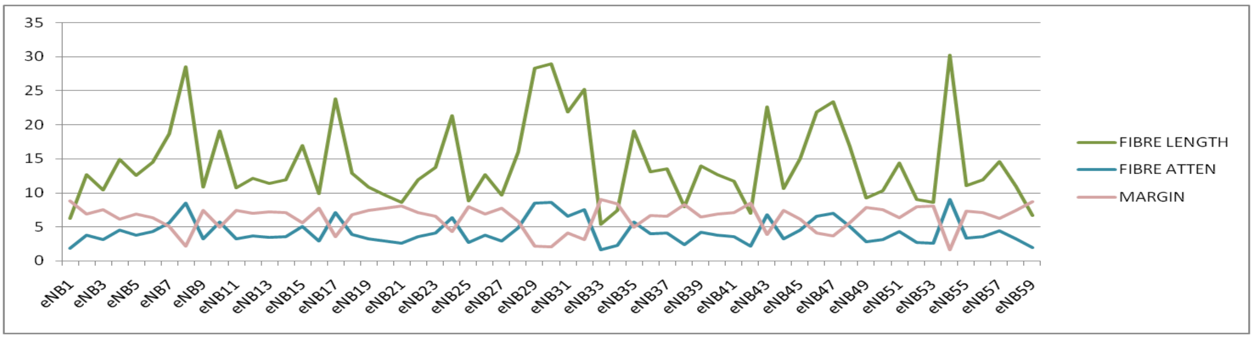

Fig.5: upstream power budget graph

III. CONCLUSION

This study focuses on attaining optimal power budget analysis for Passive Optical Networks (PON) utilized as backhaul deployment for mobile communication network. It achieves its cost-effectiveness because optimal splitter location was chosen by utilizing the coordinates obtained via computational optimal splitter coordinates from research carried out in [7]. The primary objective of this study is to establish an efficient power budgeting approach for PONs, taking into consideration the locations of eNodeBs of the mobile operator (SMILE). The research is conducted within the geographical area of Port-Harcourt city, located in Rivers State, Nigeria.

The investigation incorporates the coordinates of 60 SMILE eNBs to calculate the respective distances between the eNBs and the splitter. An algorithmic model in [7] was employed to determine the optimal location for the splitter, minimizing the distance between the splitter and the 60 eNBs. This approach is referred to as the automatic/systematic method. Power bedget calculation was carried out using spreadsheet for all eNBs. It was evident that eNBs with longer fibre cable lengths exhibit correspondingly higher levels of fibre attenuation but lower margin values. This consistent pattern was observed across all 59 eNBs within the network for both Upstream and Downstream transmissions. The Power Budget achieved in this research ensured that attenuation was greatly reduced and significant receiver sensitivity was achieved.

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