Society for Science and Education
United Kingdom

TNC Transactions on Networks and Communications

Volume 4, Issue 6
ISSN: 2054 -7420

Non Regenerative Fiber Backbone Power Loss Budget

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ABSTRACT

The most important stage in the design of a Wavelength Division Multiplexing (WDM) fiber optic system is about the choice of the correct optical transmitter, and receiver combination. This depends on the signal to be transmitted over the channel. By adopting the WDM two (2) signals at two (2) different wavelengths of 1310nm and 1550nm, can conveniently be carried on the same fiber. The WDM fiber link can carry 32,256 channels and the throughput too is high (>=2.5Gbps). Many television channels can be accommodated. The amplification along the fiber backhaul remains a bottleneck due to the non-linearity effects that could be additive. In order to minimize the non-linearity effect of the amplifiers, non-regenerative solutions are nowadays used.

This paper develops a power loss budget for an optical sparse WDM long haul without inserting any regenerator along the transmission line. The study gives details of establishing a 200 km fiber optic link, operating at 2.5Gbps and supporting a digital signal of Synchronous Transport Signal-48/ Synchronous Transport Module 16 (STS-48/STM-16), where the link is assumed to carry 8 (WDM). In the dimensioning, the optical interfaces were chosen in agreement with the ITU-TG 654 applicable values. The system power deficit was not satisfactory in the first attempt, and so the Erbium Doped-Fiber Amplifiers (EDFAs) were inserted at the light source, and a preamplifier at the optical detector side. The system power deficit was still negative but not much. The transmitting system should have a positive value of the system power deficit so that the link budget can be suggested for the required transmission. Finally the change of the detector sensitivity gave the best estimation in the design process for the required link budget.

Keywords: Fiber power loss budget, Optical interfaces, Power deficit,

1 Introduction

Optical communication [1-2] have shown great advantage in the last decade. Optical waves present relatively lossless properties and high bandwidth. However, they are subjected to some limitations such as scattering, dispersion and bending losses in fiber media [2]. Fiber optic sensors [2-4] are used to measure the power loss at any point of the fiber link.

In measuring the optical wave, authors in [5] proposed the analysis of the scattering loss by quantifying the slope of light dispersion using a least square algorithm. An optical wave slope detection system for a finite spatial resolution in a cavity ring that produced a high frequency response was also proposed in [6]. The system made use of refraction of a narrow light beam at the air-water interfaces, which allowed the

DOI: 10.14738/tnc.46.2535
Publication Date: 03rd December 2016
URL: http://dx.doi.org/10.14738/tnc.46.2535

analysis of short gravity-capillary waves. The accuracy of the model was much related to the speed. In [7], the fiber lossless was investigated using an interferometers [8]. Meanwhile, in [9], the insertion loss was conducted.

This paper proposes a theoretical power loss budget for an optical sparse WDM long haul in assuming concept of a non-regenerative signal solution along the transmission line. The link shall carry 8 Wavelength Division Multiplexing operating at 2.5Gbps and supporting a digital signal of STS-48/STM-16 each [10-11]. A fiber optic link without any repeaters along the link was suggested in [12] and limited by some measures of verification like field measurement to confirm the hypotheses. Researchers at University of California [13] have proved transmission over 1000 miles, but the fiber power budget was not disclosed. In their research the authors were much interested in the evaluation of cross-talk, and hence the efficiency of the error correction algorithm. The rest of the paper is structured as follows. The next section of the paper, section II, depicts the fiber link system. Section III presents the method of selecting the correct optical transmitter, and receiver combination. Section IV discusses the obtained results. The conclusion, Section V, closes the paper by suggesting the domain of application of this contribution.

2 The link budget

The link power budget (ΔL) is the difference between the power launched into the fiber and the sensitivity (minimum amount of power required) of the receiver connected through the fiber optic cable [10].

Nomenclature

λ: $Operating\ wavelenght$
r: $core\ radius$
P_{in}: Transmitter Power
P_{out}: Receiver Sensitivity Power
ΔL: Link Power Budget
ΔD: System Power Deficit
Tl: Total Link Losses
L: Fiber length
b: fiber attenuation per km
Sp_L: Splice loss
N_{Sp}: number of Splices
Co_L: Connector loss
N_{Co}: number of Connectors
M: safety margin
In_L: Insertion Loss
CD_L: Chromatic dispersion loss
ΔCD: Chromatic dipersion $accumulation$
MBL: Macro bend loss
a the shape of the refraction index
n_1 Index of refraction of the core
n_2 Indexes of refraction of the cladding
Δn the relative refractive index difference between the core and the cladding
B: Data rate
c: speed of light in vacuum

The basic link power budget is computed by the relation (1):

$$\Delta L = [P_{in}\ [dBm]] - [P_{out}\ [dBm]] \tag{1}$$

The System Power Deficit is expressed as in (2):

$$\Delta D = \left[\Delta L[dBm]\right] - Tl[dB] \tag{2}$$

The Total link losses are calculated as in (3):

$$TL\,[dB] = [b * [dB/km] * L[km]\,] + [N_{Sp} * Sp_L[dB]\,] + [N_{Co} * Co_L[dB]] + M[dB] \tag{3}$$

The insertion loss comes as in (4):

$$In_L[dB] = 1.5 * \log_2 n \tag{4}$$

where n is the number of ports (channels, either input to a multiplexer or output from a demultiplexer).

Chromatic dispersion loss ($\mathrm{CD_L}$) is computed by (5)

$$\mathrm{CD_L} = \Delta\mathrm{CD} * L \tag{5}$$

The macro bend loss (MBL) relative to path profile curvature at a radius R is expressed by (6):

$$MBL = 10\,logR * \frac{a+2}{2a} * \frac{r}{R\Delta n} \tag{6}$$

where r is the radius of the core, a the shape factor of the refraction index, R the curvature of the bend, Δn the relative refractive index difference between the core and the cladding.

The fiber loss at the critical curvature of the bend R_c is important for the design engineer. The critical radius R_c is given as in (8):

$$R_c = \frac{3 * n_1^2 * \lambda}{4\pi\left(n_1^2 - n_2^2\right)^{3/2}} \tag{7}$$

where n_1 and n_2 are the indexes of refraction of the core and the cladding respectively, λ the operating wavelength.

3 Methodology

An optical WDM link system [2] is considered as a case in multi-input and multi-output (MIMO) antennae configuration.

Two types of fiber optics medium are assumed such as the Plastics fiber ~~a~~nd the Glass fiber. Point to point measurement in a single local loop with an Optical Time-Domain Reflectometer (OTDR) could be considered. The optical interface will consist of the photonics integrated circuits (PIC) at the detector interface while assuming a transmission over a typical sparse wavelength division multiplexing channel.

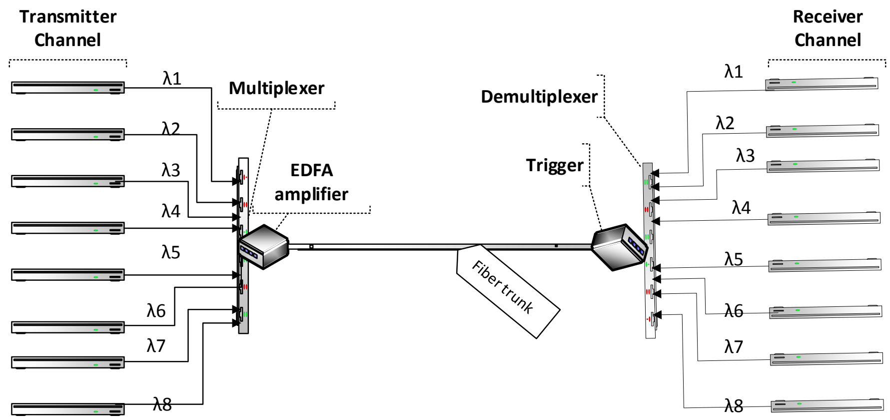

Figure 1: Wavelength Division multiplexing link.

A single-mode fiber (9/125μm) in the 1550nm band is considered noting that 1550 nm is the point of minimum loss for single-mode fiber accordingly to the ITU-T G.654 reference. The channel spacing of the ITU grid with 200 GHz spacing is assumed in order to avoid the problem with four-wave mixing.

The long distance makes fiber attenuation the dominant loss. The fiber loss in reference ITU-T Rec. G.654, with respect to the selected operating band is about 0.25dB/km for fiber attenuation including splice losses and 20ps/km/nm for chromatic dispersion accumulation. In spite of the chromatic dispersion's effect that is significant for frequencies above 1Gbps and in particular for the narrowed margins, in this work, such consideration will not be made. The chromatic dispersion loss is normally evaluated in order to account for the span loss when including the dispersion compensation units along the long haul at the various predefined spans. It should be noted the spans are calculated in such way to accommodate the dispersion penalty and with a view that the light source could not comfortably reach the optical receiver.

4 Results and discussions

In order to compute and establish the link budget the following steps are used with references to the published specifications.

Firstly, the Optical interfaces (transmitter power and the receiver sensitivity) are selected.

Since the link is a long haul at high speed, it requires a laser light source. The signal may go through two connector pairs in patch panel at each end with an insertion of 0.5dB per connector plus 2 connectors for the WDM.

With the help of ITU-T G.957, page 7, Reference 2, which provides the maximum power to be launched, this is +3dBm and the minimum launched power of -2dBm, for a Bit Error Rate of $\mathrm{BER} = 1 * 10^{-10}$ and a receiver threshold of -28dBm.

The optical Interfaces are given in Table: 1.

Table 1: Optical interface

Optical transmitter	-2dBm to + 3dBm
Optical receiver	-28dBm with $BER = 1 * 10^{-10}$

The second step consists of establishing the link power budget.

In order to have a reliable link, a 5% of the assumed cable length is added so that the cable loss value can accommodate losses due to the cable slack. At each optical interface of the WDM, 8 wavelength are expected, then their insertion loss incurred are:

$$Insertion\ Loss = 1.5 * \log_2 n$$

with $n = 8$ number of wavelength

The insertion for each interface is about 4.5dB.

The filter insertion (multiplexer output, and demultiplexer input) loss is $1.5 * \log_2 n = 1.5$ dB,

with $n = 2$

The total loss for eight channel WDM equipment including filters is the total sum of all the insertion loss given as:

$$Insertion\ loss = \ 4.5\text{dB} \ + 4.5\text{dB} + \ 1.5\text{dB} \ = \ 10.5\ \text{dB}$$

The chromatic dispersion loss (CDL)

$$CDL = 200km * 20\text{ps/km/nm}) = 4000\text{ps.nm}$$

The chromatic dispersion loss is evaluated to make sure that the dispersion tolerance is met when including the dispersion compensation units along the long-haul at each span to accommodate the various nonlinearity effects introduced by the amplifiers.

The macrobend loss relative to the critical radius bend is obtained by substituting (7) into (6),

$$MBL = 1.30 \sim 1\ dB$$

If $n_{_1} = 1.6$, and $n_{_2} = 1.2$ respectively to glass fiber

It comes that an approximated macrobend loss of 1dB will be incurred.

The link power budget is a balance sheet that shows the details of the different involved devices in the link. It reveals the power loss due to the connectors, the splices and the device. The most important thing for a designer is the value of the system power deficit. It indicates whether the sustained power is appropriate for the link. The link budget is always presented in a table form as in Table: 2.

Table 2: Link Budget 1

Link budget 1			
Items or parameters			Value
Light source output (SLM)			= +3dBm
Receiver Sensitivity (PIN Diode)			= -28dBm
Link Power Budget			= **31dBm**
Link Loss Budget			
Fiber Optic Cable (ITU-TG 654 Fiber, λ=1550nm)			
Attenuation at 200km +5% Length added for slack	210	Loss / km : 0.25dB	= 52.5 dB
WDM loss+ filter loss			
Insertion Loss			= 10.5 dB
Macrobend Loss			= 1 dB

Patch Panels/connectors			
Quantity	6	Loss/patch: 0.5 dB	= 3 dB
Total link loss			= **67dB**
Safety Margin			= 3 dB
Total Losses	Total Link Loss +Safety Margin		=.**70dB**
Power at Receiver:			= - 70.dB
System Power deficit			= - 39dB

Link Budget 1 in the Table 2 shows that the System Power deficit is negative. The next approach consists of incorporating a power amplifier with the light source and a preamplifier at the far-end. The amplifiers are assumed to be made of the Erbium-Doped Fiber Amplifier (EDFA) technology, which implies a 1550-nm operation with +17dBm gain. The new link budget is given in the Table: 3.

Table 3: Link Budget 2

Link budget 2			
Items or parameters			Value
Light source output (SLM) + EDFA Amplifier			= +20dBm
Receiver Sensitivity (PIN Diode) + EDFA Preamplifier gain			= -45dBm
Link Power Budget			= **65 dBm**
Link Loss Budget			
Fiber Optic Cable (ITU-TG 654 Fiber, λ=1550nm)			
Attenuation at 200km +5% Length added for slack	210	Loss / km : 0.25dB	= 52.5 dB
WDM loss+ filter loss			
Insertion Loss			= 10.5 dB
Macrobend Loss			= 1 dB
Patch Panels/connectors			
Quantity	6	Loss/patch: 0.5 dB	= 3 dB
Total link loss			= **67dB**
Safety Margin			= 3 dB
Total Losses	Total Link Loss +Safety Margin		=.**70dB**
Power at Receiver:			= - 70dB
System Power deficit			= **- 5dB**

The system power deficit is still negative. This shows an unfavorable transmission even when the maximum margin is included. In this case, it will be advisable to change the light detector by an ALCATEL APD diode receiver with threshold (-33dBm, BER $1*10^{-10}$) and can operate at the same bandwidth. However, the optical interface amplifiers will remain. The only thing is that, it is expensive. The new link budget is then given in Table: 4.

Table 4: Link Budget 3

Link budget 3			
Items or parameters			Value
Light source output (SLM)			= +20dBm
Receiver Sensitivity	APD Alcatel diode		= -50dBm
Link Power Budget			= **70dBm**
Link Loss Budget			
Fiber Optic Cable (ITU-TG 654 Fiber, λ=1550nm)			
Attenuation at 200km +5% Length added for slack	**210**	Loss / km : 0.25dB	= 52.5 dB
WDM loss+ filter loss			
Insertion Loss			= 10.5 dB
Macrobend Loss			= 1 dB
Patch Panels/connectors			
Quantity	**6**	Loss/patch: 0.5 dB	= 3 dB
Total link loss			= **67dB**
Safety Margin			= 3 dB
Total Losses	Total Link Loss +Safety Margin		=.**70dB**
Power at Receiver:			= - 70.dB
System Power deficit			= 0.0dB

The System Power deficit is now zero. The transmission can be effected since a 3dB safety margin was reserved. In practice the safety margin is in the range of 3 to 10dB. It should be noted that the lower bound of the margin was considered. The Fiber requirement and the signal requirement are given in Table 5 for a simulation and an eventual field measurement.

5 Conclusion

The design of fiber link is quite different from setting up a wired line. A non-regenerative long haul is much convenient with an EDFA optical transmitter due to its non-accumulated dispersion loss, and further provides sufficient gain to reach a comfortable receiver threshold. The paper shows the theoretical power budget of establishing a fiber optic link without any repeaters along the link. Non regenerative fiber links may find applications in submarine and offshore surveillance.

Table 5: Fiber cable and signal requirement

Digital Signal Parameters:STS-48/STM16	
Data rate	2.5Gbps
Bit Error Rate (BER)	1x10^{-10}··
DC Coupling (Power supply)	+5V

Fiber optic requirement	
Transmission Distance	200km
Optical Wavelength	1550 nm
Optical connectors	ST pigtail
Fiber type	Glass 9/125μm
Fiber length	210 km

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