Designing a Fiber Network

Planning Link-Loss Budgets Using Statistics

As new technical personnel enter the passive optical network field, one of the most confusing issues is the matter of calculating signal losses. Here's a primer.

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The scramble to expand broadband service offerings has begun. Carriers are turning to passive optical network (PON) architectures as a primary strategy to retain and grow their customer bases. A challenge carriers face as they design and deploy optical fiber deeper into their access networks is the cost associated with traditional outside plant fiber deployment. Many of these carriers have turned to fiber optic cable, fiber optic connectors, optical splitters and wavelength division multiplexing (WDM) devices to reduce installation costs and deployment time.

Throughout an optical network, however, designers must "budget" for signal losses. The light signal is attenuated by connectors, splitters, and the fiber optic cable itself – the links in a chain that brings data from a point of presence to the customer.

When service providers first started to overbuild their networks with fiber in the mid 1990s, the use of maximum loss values specified by equipment and component suppliers was a generally accepted approach for planning these "link-loss" budgets. It was soon realized, however, that the components performed significantly better than the specified maximum loss values.

The end result was that end-to-end power would exceed the specified dynamic range of the equipment, causing problems in the network. To fix these problems, technicians were forced to actually increase the loss of the system with optical attenuators or some alternate attenuation-inducing device. This reduced the speed of deployment and increased costs for these network builds.

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In the early 2000s, service providers began overbuilding using PON architectures. In an effort to increase speed of deployment and reduce installation costs, carriers deploying PON architectures have increased the use of fiber optic components in the outside plant (OSP) network. The perceived attenuation increase associated with this increase in optical components has reignited the debate as to which link-loss calculation method is most effective when planning PON link-loss budgets.

Due to the lessons learned with network planning in the 90s, many equipment providers and carriers turned to statistical models to predict the probability of being within the acceptable margin for network equipment – neither too much light, nor too little. This paper will discuss three different methods of link-loss budget calculations:

1. Using maximum loss values
2. Statistical analysis (mean + 3σ)
3. Monte Carlo simulations

Modeling the Network

The reference model – the example – used for the analysis in this article is

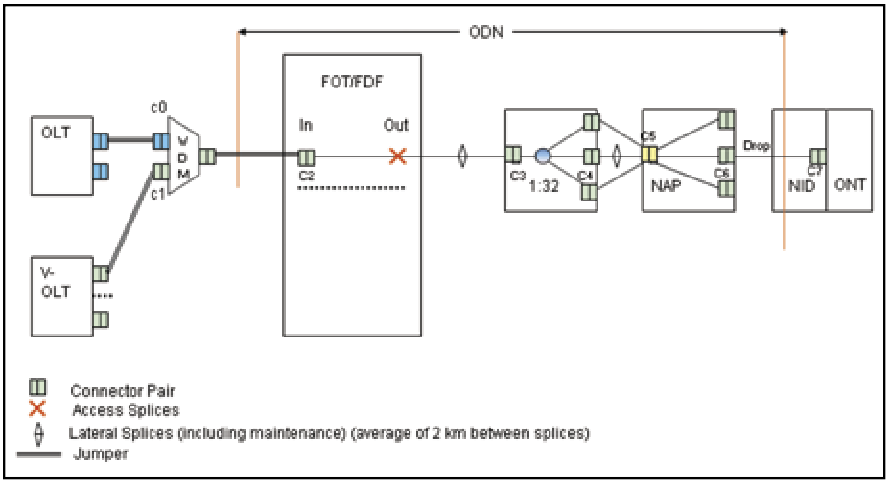


Figure 1 – The network example, or "Reference Model" used for analysis.

shown in Figure 1. The reference network consists of a total of 35,000 feet (about 10 km) of cabled single-mode fiber from the central office to the customer. Among the assumptions made for this network model were:

- The connector type for all components is SC APC.
- The OLT and video-OLT signals are consolidated via a WDM device located on the equipment side of the frame.
- The FDF located in the central office is an interconnect arrangement.
- There is a central office access splice in the vault and field fusion splices occur every 2 km.
- A 1x32 planar splitter with SC APC connectors is used at the transition between feeder and distribution.
- A network access point (NAP) is equipped with multi-terminal connector on the central office side and an SC APC connector on the customer side.
- The connection from NAP to NID (network interface device) uses an outside plant drop cable terminated with an environmentally hardened connector on each end.

	Mean loss per unit	SD per unit	Max per unit
	dB	dB	dB
Optical Component			
SCAPC Connector (mated pair)	0.15	0.1	0.50
Optical Cable loss @ 1310 nm	0.32	0.0	0.35
Optical Cable loss @ 1550 nm	0.22	0.0	0.25
1x32 Optical Splitter	15.80	0.3	17.00
WDM	1.40	0.1	1.70
Fusion Splice (ribbon)	0.06	0.0	0.13

Table 1 – Losses expected in each component of the reference network.

Upstream Data	**loss (dB)**
Transmission Budget @1310nm	**28.0**
Downstream Data	
Transmission Budget @1490nm	**28.0**
Video	
Transmission Budget @1550nm	**26.2**

Table 2 – Allowable loss for each wavelength that the reference network is required to transmit.

The Data

Before discussing the recommended methods of statistical analysis and simulation for predicting link-loss probabilities, the consolidated loss data for each component in the network must be compiled. To do that, you must list manufacturing distribution data for each component with the objective of determining average loss, maximum loss and how likely a specific loss might be (in terms of the standard deviation for each component).

Table 1 is a summary of the optical components and associated values that will be used in this analysis.

After the link-losses have been calculated, all values will be compared to the requirements shown in Table 2 to determine whether each link passes or fails.

Using Maximum Loss Values

Using maximum loss values is a good way to get a "first-pass" idea of what the link-loss will be for a given network. This method is typically used when you do not have a lot of information on the components in the network. Using the "max" values in Table 1, you can calculate a link-loss budget for the reference network. The results are shown in Table 3.

In addition to the individual component losses calculated, it should also be noted that 2 dB of planning margin has been added to the link-loss budget to account for the potential need for future service offerings and the aging of the outside plant network.

Table 3 shows that the "maximum" optical loss for this link is 29.12 dB (1260-1360 nm range) and 28.05 dB (1480-1575 nm range). Comparing these values with the parameters in Table 2 shows that the link would fail the upstream/downstream budget requirements and the video requirements.

Using Statistical Loss Values

While a max value analysis provides a rough-cut evaluation of the suitability of a link, a statistical modeling approach to modeling link-loss budgets can help determine the impact of component loss variability in the link.

The suggested modeling method of "mean + 3 sigma" will be used. That is, we will look at the distribution of possible losses in the various network components. Three "sigmas" or three standard deviations from the mean (or average) encompasses about 99.7 percent of all expected loss values in any one component, assuming the distribution is not skewed – that is, that the distribution is "normal."

In link-loss calculations, one often assumes that the loss components are from an approximately normally distributed population.

If that assumption is justified, then about 68 percent of the values are within one standard deviation of the mean, about 95 percent of the values are within two standard deviations, and about 99.7 percent lie within three standard deviations. This is known as the "68-95-99.7 rule," or "the empirical rule."

Link Loss Model				
	Max loss per unit dB	Quantity /length	Max loss Total dB	
CO video coupler				
OLT-WDM Connector SCAPC	0.50	2	1.00	
WDM 1260-1360 nm	1.70	1	1.70	
VOLT-WDM Connector	0.50	2	1.00	
WDM 1480-1575 nm	1.70	1	1.70	
Central Office loss				
SCAPC Connector (mated pair)	0.50	1	0.50	
Access splice	0.130	1	0.13	
Splitters Loss				
LCP splitter w/Pigtail Conn (1x32)	17.00	1	17.00	
SCAPC Connector	0.50	2	1.00	
Fiber Facilities				
1260-1360 nm in dB / km	0.35	10.7km	3.75	
Lateral splices	0.130	6	0.78	
Maintenance splices	0.130	2	0.26	
1480-1575 nm in dB / km	0.250	10.7km	2.68	
Lateral splices	0.130	6	0.78	
Maintenance splices	0.130	2	0.26	
Subscriber Drop				
SCAPC Connector NAP (mated pair)	0.50	1	0.50	
ONT access connector	0.50	1	0.50	
Other				
Cable Plant Aging	2.00	1	2.00	
			Max loss Total (dB)	
Link Loss (1260-1360 nm) dB			**29.12**	
Link Loss (1480-1575 nm) dB			**28.05**	

Table 3 – Calculated maximum losses.

Mean + 3 sigma

This method uses two basic statistical variables to determine loss budget probability:

1. Mean (average)
2. Standard Deviation, sigma (σ)

Both of these variables can be obtained from the various vendors who supply the components in the network. Once these variables are input into the model, the link-loss budget will be calculated using statistical analysis. The

Link Loss Model					
	Mean loss per unit dB	SD per unit dB	Mean + 3xSigma dB	Quantity /length	Max loss Total Stat dB
CO video coupler					
OLT-WDM Connector	0.15	0.1	0.597	2	0.597
WDM 1260-1360 nm	1.40	0.1	1.640	1	1.640
OLT-WDM Connector	0.15	0.1	0.597	2	0.597
WDM 1480-1575 nm	1.40	0.1	1.640	1	1.640
Central Office loss					
SCAPC Connector (mated pair)	0.15	0.1	0.360	1	0.360
Access splice	0.060	0.0	0.126	1	0.126
Splitters Loss					
LCP splitter w/Pigtail Conn (1x32)	15.80	0.3	16.580	1	16.580
SCAPC Connector	0.15	0.1	0.597	2	0.597
Fiber facility					
Span (km)				**10.7**	
Span (Miles and Ft))			**6.646**	**35,094**	
1260-1360 nm in dB / km	0.32	0.0	3.522	10.7	3.522
Lateral splices	0.060	0.0	0.507	6	0.507
Maintenance splices	0.060	0.0	0.205	2	0.205
1480-1575 nm in dB / km	0.220	0.0	2.452	10.7	2.452
Lateral splices	0.060	0.0	0.507	6	0.507
Maintenance splices	0.060	0.0	0.205	2	0.205
Subscriber Drop					
SCAPC Connector NAP (mated pair)	0.15	0.1	0.360	1	0.360
ONT access connector	0.15	0.1	0.360	1	0.360
Other					
Planning Margin + Cable Plt Aging	2.00	0.00	2.000	1	2.000
					Max loss (dB) Total stat
Link Loss (1260-1360 nm) dB					**26.85**
Link Loss (1480-1575 nm) dB					**25.78**

Table 4 – Results of the "mean+3 sigma" calculations.

Loss Method	Max loss (dB) Total max	Max loss (dB) Total mean +3std
Link Loss (1260-1360 nm) dB	**29.12**	**26.85**
Link Loss (1480-1575 nm) dB	**28.05**	**25.78**

Table 5 – Using a "mean + 3 sigma" statistical approach instead of a max loss approach you estimate a +2 dB difference in optical power.

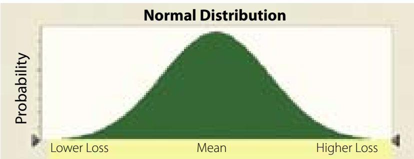


Figure 2 – A "normal" distribution. In our example, each component is assumed to have some finite chance of deviating from the average loss value, but the chance follows a normal pattern centered on the mean. This example could be for the SC APC connector loss distribution.

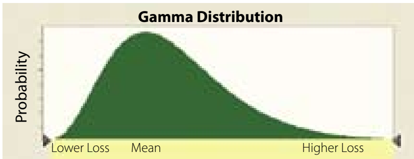


Figure 3 – SC APC connector loss distribution using actual vendor data. The actual loss data is not normal; it is skewed.

model then determines the probability bands for the link. The model will use mean+3σ to determine the max loss value of each component in the network.

To begin the statistical modeling, the mean and standard deviations for each component were input into the model. The next step was to apply three standard deviations (positive and negative) to the mean to reach a 99.7 percent confidence level in the loss value used for each component.

Note: to calculate the combined standard deviation of two or more components the following formula was used in Excel:

= SQRT(number of components * Std Dev ^2)

Using the data, we can calculate the statistical probability of operating within a specified link-loss budget. The inputs and results are shown in Table 4.

Table 4 shows the link-loss results using a mean+3 sigma approach. It shows that the optical loss for this link is 26.85 dB (1260-1360 nm range) and 25.78 dB (1480-1575 nm range). Comparing these values with the parameters in Table 2 shows that the link would pass the upstream/downstream budget requirements and the video requirements.

A comparison of the first two methods is shown in Table 5.

Using Monte Carlo Simulations

Another method for calculating link loss budget is to use Monte Carlo simulations to show the probability and range of optical loss for a given network.

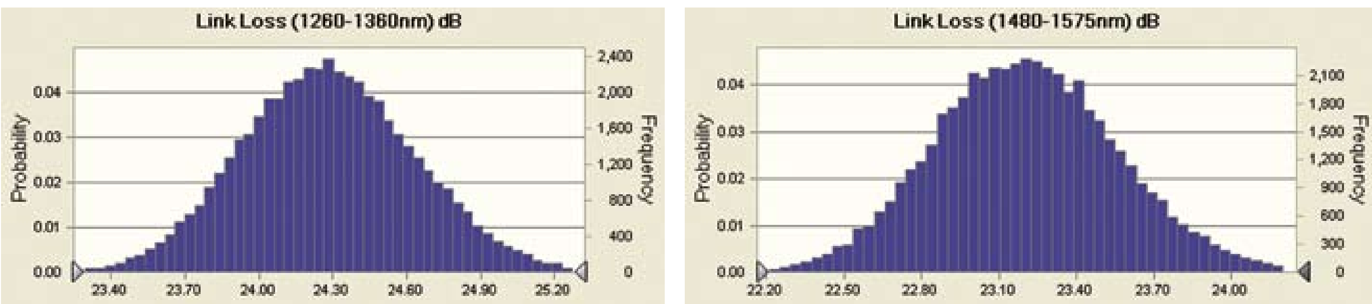
Monte Carlo methods are a widely used class of computational algorithms for simulating the behavior of various physical and mathematical systems. They are distinguished from other simulation methods by being nondeterministic in some manner – usually by using random numbers – as opposed to deterministic algorithms.

Though the mean+3σ approach is a more accurate representative analysis of link-loss than a max value analysis, it still has one major flaw … it assumes every variable has a normal distribution. In the real world this is probably not the case. The difference in distributions can be explained by looking at one of the variables in the example network – the optical connector.

In the mean+3σ approach, the loss is assumed to be a normal distribution, so using a mean of 0.15 dB and a standard deviation of 0.07 dB yields the graph shown in Figure 2. This shows that there is a symmetrical distribution of loss around the mean of 0.15 dB.

Analyzing the actual data yields the distribution represented in Figure 3. This shows that the loss is not symmetrical around the mean of 0.15 dB, and that most of the loss is skewed to the lower loss region.

To complete the Monte Carlo sim-



Figures 4 and 5 – Monte Carlo output.

	Max loss (dB)	Max loss (dB)	Max loss (dB)
	Total	Total	Total
Loss Method	max	mean +3std	Monte Carlo
Link Loss (1260-1360 nm) dB	**29.12**	**26.85**	**25.98**
Link Loss (1480-1575 nm) dB	**28.05**	**25.78**	**24.74**

Table 6 – A final comparison of all three methods.

ulation, the variables shown in Table 4 will be set up using the actual loss distributions from the manufacturers. After the variables were set up in the model, 50,000 trials were simulated on this 35,000 ft link. Usually, the calculation is done in a basic statistical software package. The results are shown in Figures 4 and 5.

The results, after 50,000 simulations, show that the optical loss for this link is 25.98 dB (1260-1360 nm range) and 24.74 dB (1480-1575 nm range). Comparing these values with the parameters in Table 2 shows that the link would pass the upstream/downstream budget requirements and the video requirements.

Table 6 illustrates that as the network planner gets better information, a more accurate link-loss budget can be calculated. The difference between the max method and the Monte Carlo method is over 3 dB … and that is a very big difference when it comes to network performance.

Conclusion

Link-loss planning is a critical step in determining the current and future quality of service a network will provide. Planning to the component supplier's specified maximum loss provides a high level of confidence that the required transmission budget will not be exceeded, but the difference between maximum loss and actual component loss could create the opposite problem – a calculated link loss that is well above the necessary transmission budget.

Additionally, this approach may also impact quality of service and network operating costs due to the need to attenuate the network in order to fall within the required transmission budget.

The optical equipment and carrier market learned in the mid 1990s about the importance of link-loss planning. The statistical analysis models that have resulted from those experiences have allowed for more efficient network planning and tighter control over operating costs. Furthermore, these models have proven network link-loss can be calculated to a probability that reaches the six 9's level, or to $3/100{,}0000^{th}$ of one percent.

Network planners may find mean + 3σ or Monte Carlo simulations useful when evaluating network extensions or service opportunities that are on the fringe when max value analysis is applied. **BBP**

About the Authors

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