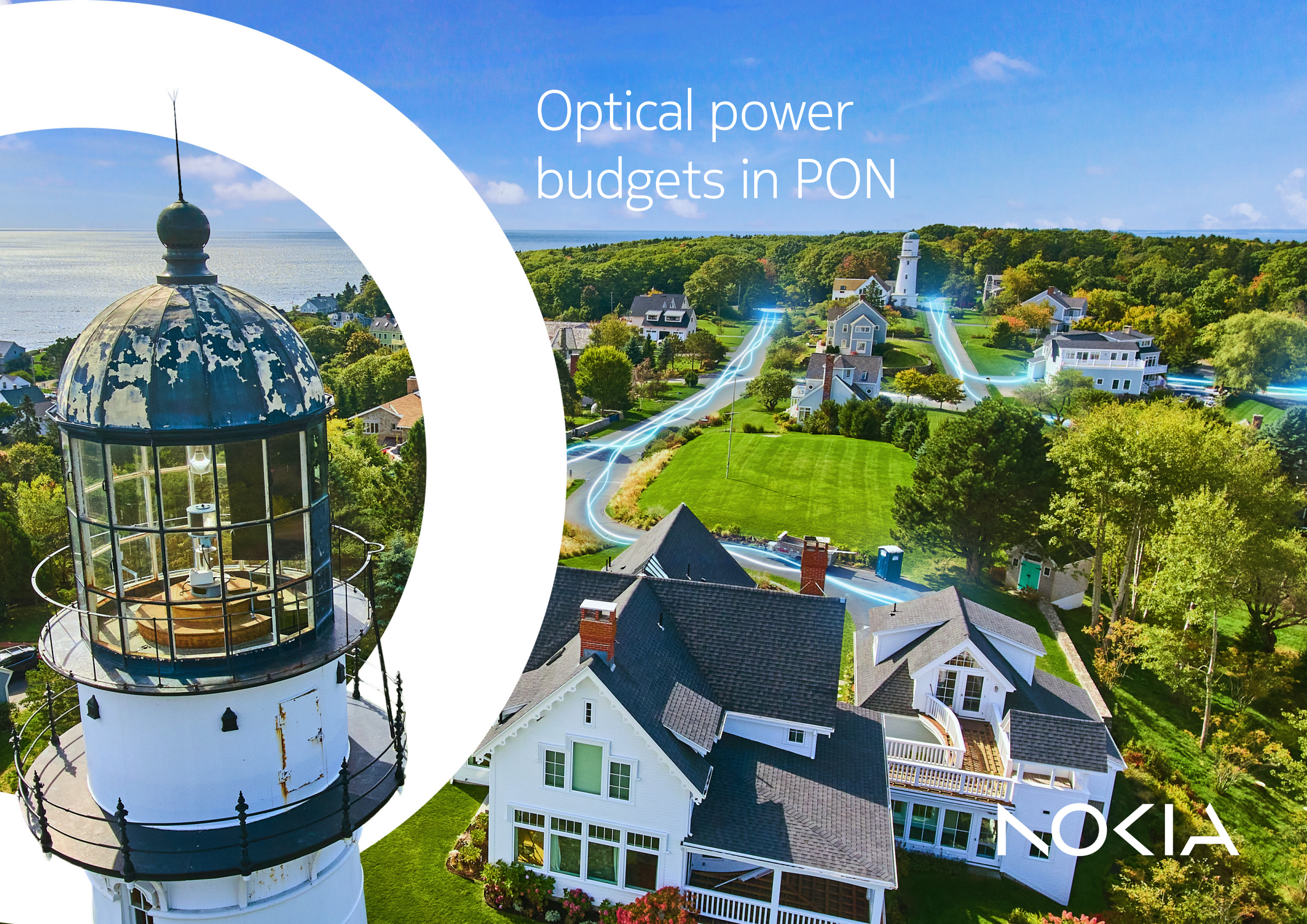




Optical power budgets in PON

NOKIA

In Passive Optical Networks (PONs), the power of the optical signal is attenuated (weakened) as it travels through the fiber network, due to scattering, absorption, and other losses. The signal attenuation depends on various factors, such as traveling distance, fiber bands, optical cable characteristics, splitters, splices, connectors, etc.

During the design of a network, it is important that optical power loss is properly calculated to ensure that there is sufficient signal strength at the receiver so that incoming signals can be correctly deciphered.

This paper describes the basic concepts of optical power budget in passive optical networks.



Basic concepts of optical power

What is optical power?

Optical power is energy transmitted in the form of photons over a period of time. In a fiber system, the optical power is created in a transmitter laser. Once emitted, the optical power is transmitted through the fiber to the other end. At the receiver, the photons strike a photodiode which converts the optical power back into a small current proportional to the power.

How is optical power measured?

Power is normally measured in Watts. However, to help in dealing with very large and very small numbers, we use dBm (decibel-milliwatt) which is a logarithmic value expressing the power as a ratio to a fixed amount of light (i.e., 1 mW). It's easy to remember: 0 dBm = 1 mW.

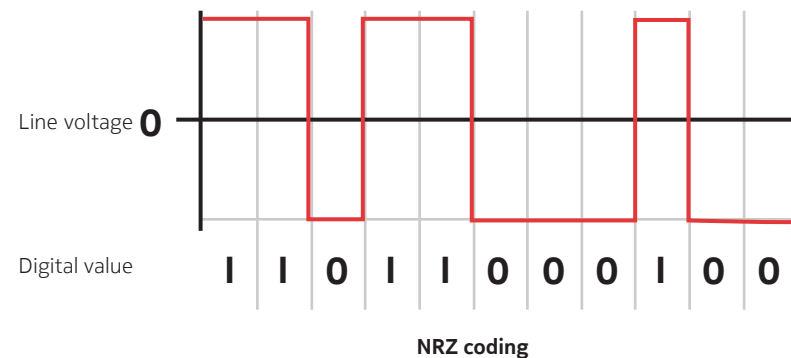
When measuring the difference between two power levels, we use dB (decibel). The power is attenuated by a certain number of dBs as it travels through each segment of fiber, connector, and splitter in the PON network. A few easy numbers to remember are:

- +3dBs is 2x the power. So, a loss of 3dBs is a loss of half the power.
- + 10dBs is 10x the power. A loss of 10dBs is a loss of 90% of the power (i.e., 1/10th remains).

Using optical power modulation to carry information

A communications signal is carried over the fiber by varying, or modulating, the level of optical power. The simplest form of digital modulation is to turn the laser on and off. More complicated modulation techniques use multiple power levels in combination with different phases to encode more information.

In PON, we use binary **Non-Return-to-Zero (NRZ) modulation**. In NRZ there is high level and low level to represent digital information (1s and 0s) but there is no neutral state between the bit intervals. NRZ is a very efficient technique that can use simple components and has a high reliability.



Mitigating the effect of noise on optical signals

There is always background noise causing the receiver to occasionally mistake a 0 for a 1 and vice versa, especially on low-power signals. We aim to deliver virtually error-free signals; that is to say with less than one error per trillion (10^{12}) bits of information sent.

To achieve this, we use Forward Error Correction (FEC) which adds a little bit of overhead information to help the receiver detect and correct errors. The result is that we can deliver a near-perfect signal to the end user. This technique allows us to receive signals in the order of 3 to 4 dB lower than without it. PON standards specify levels assuming the use of FEC. Only GPON allows a mode of operation that does not have FEC on, but this mode is rarely used.

Elements of an optical power design

The loss elements of a fiber access network

A PON network consists of a transmitter and a receiver at each end and a sequence of passive elements that attenuate the optical signal as the light goes through them.

The passive elements to be factored in include:

Fiber

Splicers and
connectors

Splitters

Filter and
coexistence
elements

Maintenance

The optical budget is defined as the difference between the minimum launch power and the minimum acceptable receive power minus a reserve called the Optical Power Penalty (OPP), which is a margin to account for imperfections in the transmission (to be described later).

The optical power design needs to ensure that the sum of the losses in the network is less than the available optical budget. Stated mathematically:

$$[\text{Sum of all losses} + \text{Mtce margin}] < = [\text{Min Transmit Power (dBm)} - \text{Min Receive Power (dBm)} - \text{OPP}]$$

We will now describe each of the above elements of the optical power design.

Fiber loss

An optical fiber keeps most of the optical power inside and moving forward by having a different refractive index between the core and the cladding which reflects the light inside. Nevertheless, the channel is not perfect and small amounts of power escape, reflect, or get absorbed by the fiber. The result is that there is an amount of loss for every kilometer of fiber.

Furthermore, this loss is different for different wavelengths. PON transmitters use different wavelengths for the upstream and downstream traffic; therefore, the outside plant design must consider the wavelength with the highest loss.

One further observation can be about the chromatic dispersion curve. This phenomenon leads to an additional loss which is included in the Optical Power Penalty and will be described later. Note that the dispersion is generally worse where the loss is better.

Splicer and connector loss

Splicers are used to connect one spool of fiber to another when deploying over a long distance.

- Fusion splicers use an arc to effectively weld two fibers together. The loss is very low.
- Mechanical splicers physically attach two fibers together, but the fiber loss is higher.

Connectors are designed to give the flexibility of attaching different fibers as needed. They are usually in a fiber patch panel in the central office (CO) near the Optical Line Terminal (OLT), in the field to interface between the feeder and distribution fibers, or at the terminal box near the home to attach distribution fibers to drop fibers. While they provide flexibility, the loss is significant so their quantity should be limited.

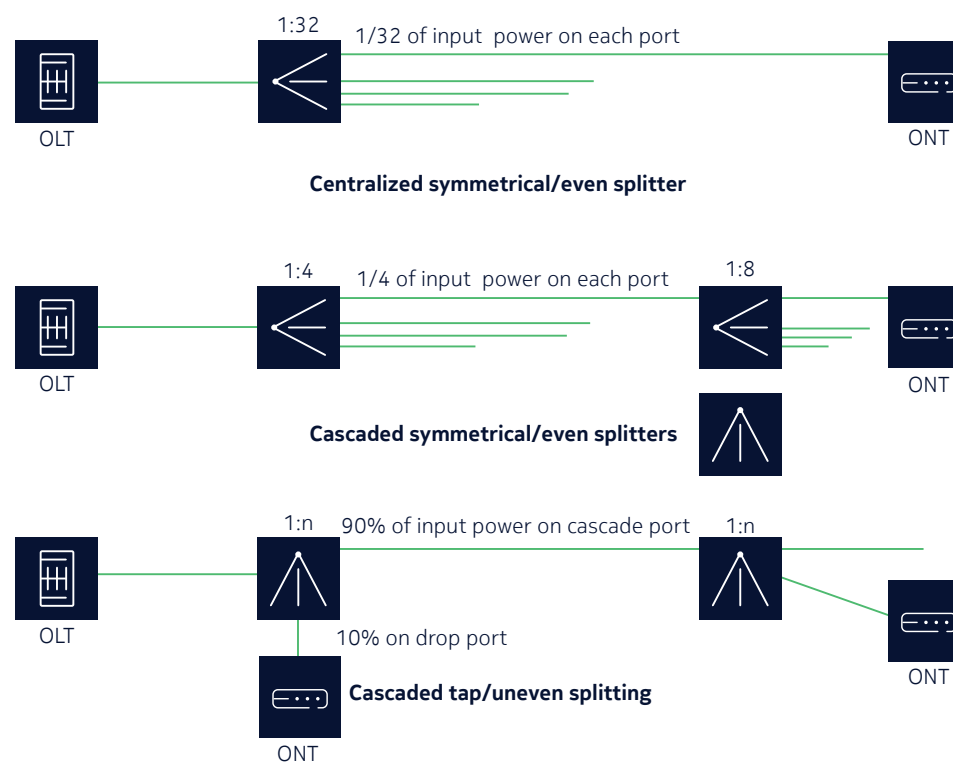
Splitter loss

Optical splitters essentially take a stream of light and split it between N ports, leaving a certain amount of optical power on each port. There are two types of splitters: symmetrical and tap splitters with other words even and uneven spitters. Symmetrical splitters will have an equal amount of optical power in each port (so, for a 1:N split, there will be 1/Nth the amount of power on each port). In a symmetrical 1:2 splitter, there is a 3dB reduction on each of the output ports. Each successive 1:2 split further reduces the signal by 3dB. So, for 1:4 split, the loss is 6dB; for 1:8 split it is 9 dB, etc. Symmetrical (or even) splitters can be used in centralized or cascaded configurations.

In the case of tap (or uneven) splitters, output ports have different amounts of optical power. One port that brings the signal to the next splitter will have higher power, and the rest of the optical budget is left for the drop port.

Independently of the type of splitter used, the total optical budget must be calculated for the ONT with the highest loss (usually the furthest user).

The loss is experienced both in upstream and downstream directions.



Optical filters and coexistence elements

Whenever multiple wavelengths are combined (or separated) on a single fiber, a filter is involved which has a small amount of loss.

To combine upstream and downstream wavelengths on a fiber, a filter is included inside the optical transceiver. This loss is factored in by the transceiver vendor and does not need to be included in the outside plant (OSP) optical budget.

To combine two different generations of PON on the same fiber, a coexistence element is needed. There are two cases:

- If there are two separate transceivers, then the loss of the coexistence element is external and needs to be included in the OSP optical budget.
- In the case of Multi-PON modules (combo modules), multiple generations of PON are included in the same transceiver. In this case, the filter loss is part of the transceiver loss and does not need to be included in the OSP optical budget. Special optical classes are defined for this.

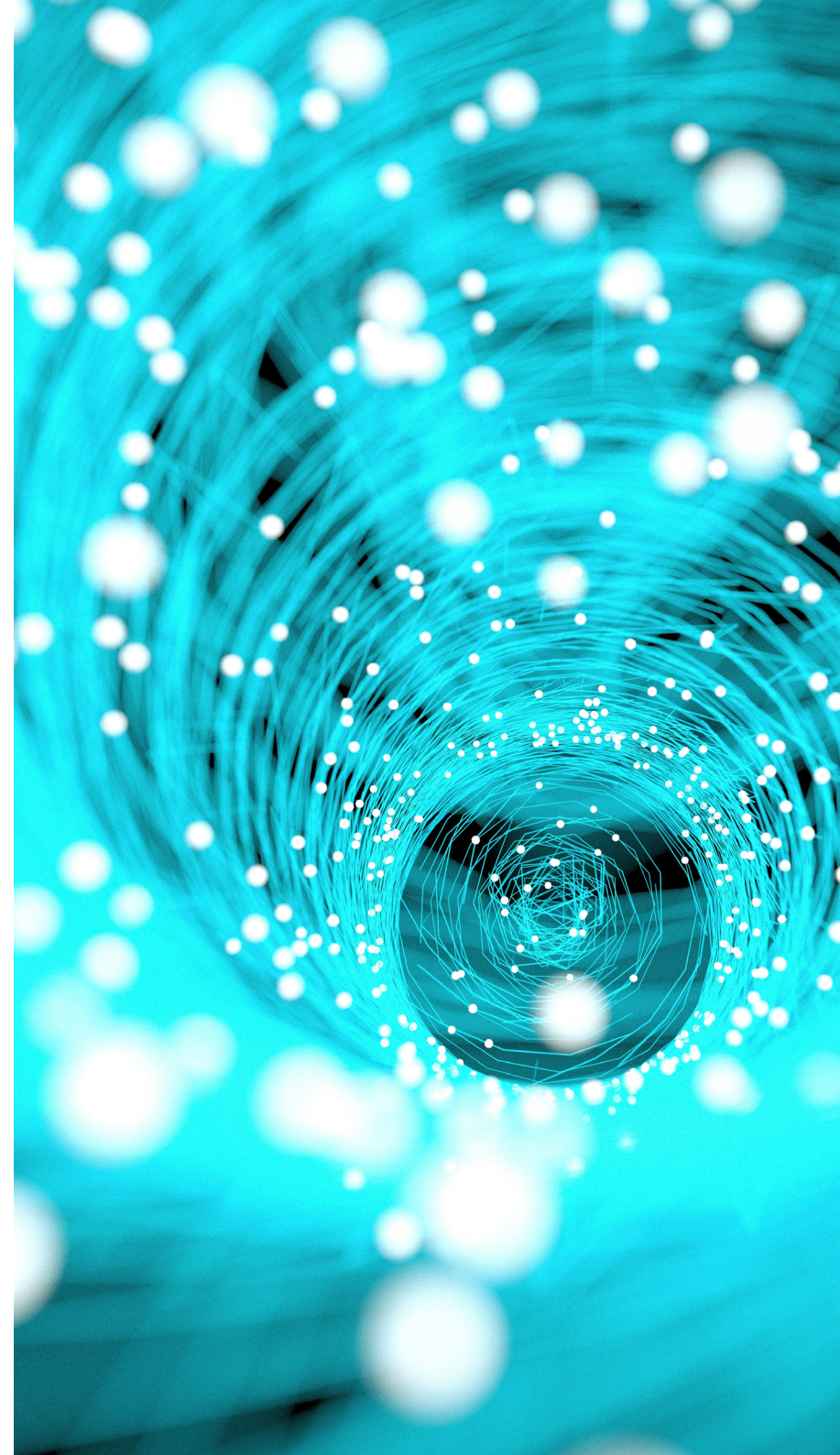
Maintenance margin

Over the life of an optical distribution network (ODN), it should be anticipated that there would be future losses associated with additional splices for fiber repairs or possibly an unforeseen future connector. A buffer of 1 or 2 dBs is often added to account for unforeseen losses.

Optical power penalty

There are some distortions in the transmission that may have a negative impact on the signal. This is accounted for by allocating a small buffer called the Optical Power Penalty (OPP) into the optical budget.

The primary cause of distortion is chromatic dispersion which means that light travels at slightly different speeds depending on the wavelength. Any optical signal occupies a wavelength width that is greater than zero, which means that part of the signal will arrive at the other end before the rest of it. This adds a bit of blur to the information. The OPP for each PON is specified in the standard and is in the order of 1 or 2 dB.



Optical loss budgets defined for different PON technologies

In PON networks, transceivers and receivers in the OLT and ONT use optics with classes defined by PON standards. For each optical class, there is a minimum and maximum value, defining the sensitivity range in which the optic can function. For example, if a transceiver transmits the light with too much power, it would “blind” the ONT; and if it transmits the light with insufficient power, the receiver would not detect it.

The following table shows the commonly used optical classes for PON technologies

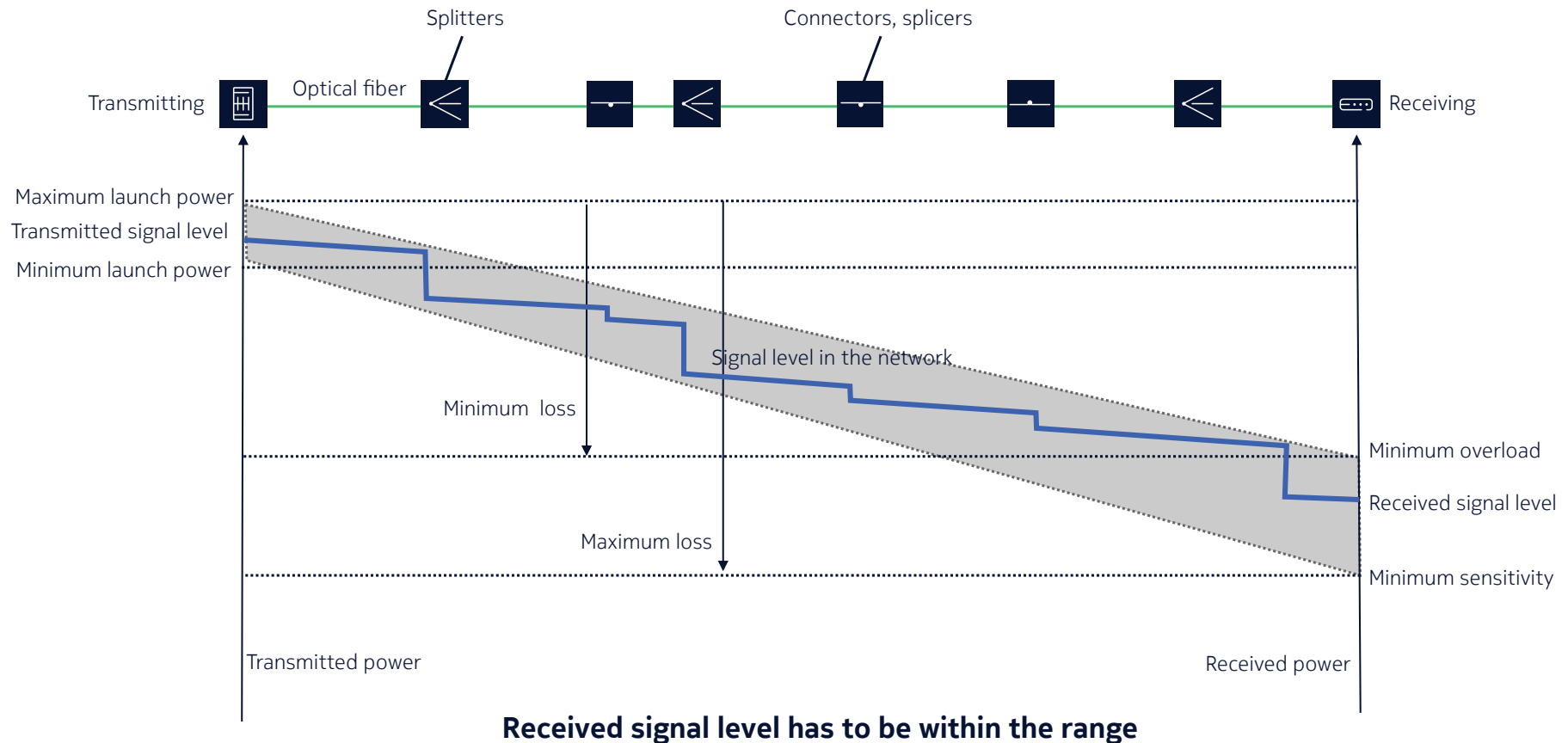
Optical class	B+	C+	D	N1	N2	E1	E2
Technologies	GPON XGS (MPM)	GPON, XGS (MPM) 25G, 50G	GPON, XGS (MPM)	XGS-PON, 25G, 50G	XGS-PON, 25G	XGS-PON, 25G	XGS-PON
Min. loss	13 dB	17 dB	20 dB	14 dB	16 dB	18 dB	20 dB
Max. loss	28 dB	32 dB	35 dB	29 dB	31 dB	33 dB	35 dB

These optical classes allow network operators to optimize the performance and reach of PON systems based on the specific requirements of their deployment scenarios. By selecting the appropriate optical class, operators can ensure reliable and efficient communication over the passive optical infrastructure.:



Optical budget calculation: typical example

When designing a fiber network, we have to make sure that the sum of losses in the passive network is within the limit that is allowed by the active components, the OLT and the ONT. We take the transmitter (TX) level, subtract respective receiver (RX) sensitivity and margins: the result is the optical budget. We have to stay within this budget with the sum of worst-case values of all optical losses between the TX and RX ports of the OLT and ONT. The optical losses depend on the eventual coexistence element, split ratio (e.g., 1:32), number of connectors, splicers, and the total length of the optical cable.



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