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Choosing the Right Fiber for a Long Haul Route

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Selecting the best optical fiber for a given long haul route is not a simple decision. Over the expected lifetime of a fiber, transmission technology and electronics will likely change and be upgraded several times. As a result, optical cables are often deployed with several fiber types in the same cable. This strategy can help ensure that the most options possible are available as the network evolves.

One of the most important considerations in the fiber specification process is the fact that optical signals may need to be amplified and switched along the long haul route. The costly transmission equipment required for these operations is stored in huts that are typically spaced at regular intervals of about 75 km along the route.

The farther apart the huts are spaced, the fewer that are needed along the route, but the greater the complexity of reconstituting the optical signal. That's where choosing the right fiber can make a big difference.

To simplify the fiber selection process, the industry offers several fiber types that can provide added performance beyond traditional ITU-T G.652D single-mode fibers.

These fiber types fall into a few basic categories:

1. ITU-T G.652D fibers with improved attenuation performance
2. ITU-T G.655 fibers with low chromatic dispersion
3. ITU-T G.656 fibers with medium chromatic dispersion

Let's look at each of the parameters involved to understand how they affect optical fiber selection in a long haul link.

Amplification

Signals travel down an optical fiber as pulses of light, which inherently degrade over distance due to attenuation, or signal loss. The weaker the signal gets, the harder it is to detect; when the signal falls below the level of background noise in the system, the information is lost. Thus, the signal must be amplified prior to reaching this noise floor for continued propagation.

Typically, optical fibers designed for high-performance long haul networks have approximately 0.25 dB/km attenuation, and current transmission equipment has about a 22 dB dynamic range, resulting in a possible transmission distance of about 88 km. Factor in splice losses, excess cable length and system margins, and you arrive at the traditional 75 km between huts.

There are three technologies commonly used to amplify optical systems. The simplest is called regeneration. Here, the optical signal is converted into an electrical signal and then processed, boosted and retransmitted; this is often referred to as optical-electrical-optical, or OEO, conversion. Its main advantage is that the optical signal is reprocessed and any distortions that occur during transmission are removed.

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The second method uses erbium doped fiber amplifiers. These contain about 20 meters of optical fiber doped with erbium, a rare earth element, combined with a pump laser. When the optical power is transmitted through the device, the signal is boosted about 22 dB and can be sent to the next hut along the optical link. These devices amplify optical signals from about 1535 to 1625 nm, which are the wavelengths that constitute the C and L bands used in optical systems.

The third amplification method, called Raman amplification, works by pumping the transmission fiber at a wavelength of about 80 nm less than the transmission wavelength. The system can be pumped from either the transceiver end or the receiver end. Raman amplifications can be used to amplify light at any wavelength.

Switching

Another application that may be necessary at the hut is switching, which allows access to optical signals that may be needed at intermediate locations along the route. The simplest way to switch an optical signal is to convert the signal from optical to electrical, access what information is needed, add any additional information to the data stream, and then convert the signal back to optical and send it down the remainder of the fiber.

In a DWDM system, the optical fibers in the data stream consist of many wavelengths. Using a traditional switch, all of these wavelengths must be converted to electrical signals prior to processing the data at any wavelength. The cost of accessing individual data streams increases as more wavelengths are added to a fiber.

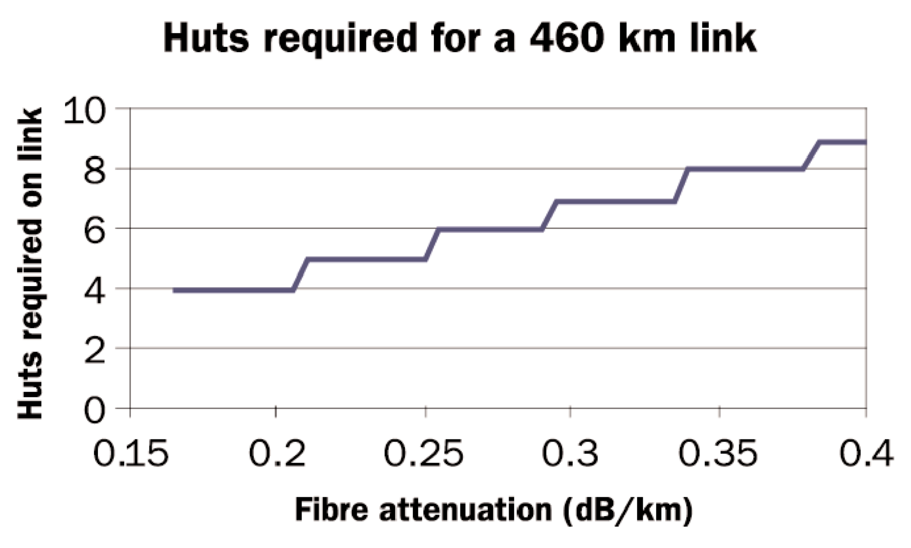
Fortunately, individual wavelengths can be selected, added or removed to a data stream through the use of reconfigurable optical add drop multiplexers (ROADMs) without impacting the rest of the data stream.

These devices simplify access to data along a route, but this comes at a cost: signals travel further without being regenerated when ROADMs are deployed, and this can result in greater distortion. Thus, the selection of ROADM technology often results in more stringent performance demands placed on the optical fibers.

Now we'll turn our attention to the two parameters that have the greatest impact on long haul optical signals: attenuation and dispersion.

Optical Attenuation

As mentioned, optical signals undergo signal loss as it propagates through optical fibers. To help us understand typical loss, let's consider a link of 460 km using standard G.652D fiber with an attenuation of 0.4 dB/km as specified by the ITU-T G.652D standard. The average splice loss is assumed to be around 0.1 dB per splice and cables have an average length of 10 km along the route.



Reducing system attenuation can increase the maximum distance between huts.

Traditional fiber slack management used along the route results in approximately 5 percent excess length. Using these inputs, along with a 1 dB power margin and a 22 dB dynamic range for the amplifiers, we can calculate that nine huts would be needed along the route using conventional G.652D fiber.

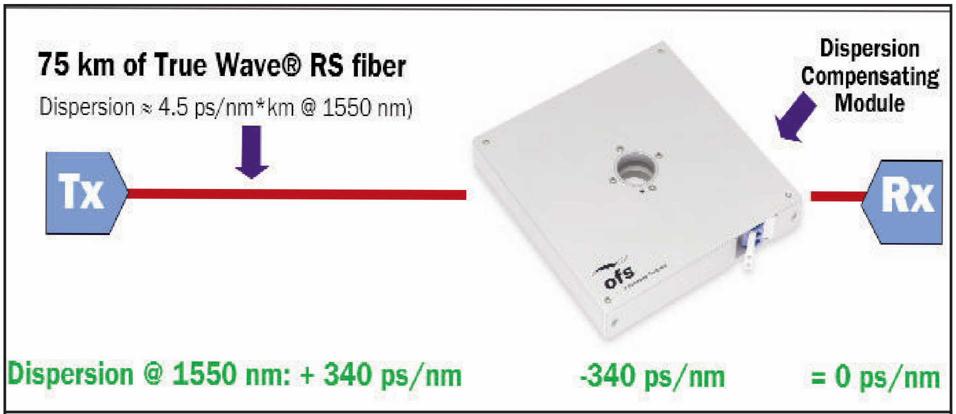
Lowering the attenuation can increase the maximum distance between huts. The number of huts required is found by dividing the length of the route by the maximum hut spacing and rounding up (obviously, you can not have a fractional hut in a real route - a hut is either there or it is not).

The graph on this page shows that the number of huts drops as the attenuation drops. For example, if the attenuation is less than 0.20 dB/km, only four huts are required to support this route. For practical purposes, attenuations less than 0.165 dB/km are not currently available and even for this ultra low attenuation there is no significant system advantage over low loss fiber with 0.20 dB/km for the route considered.

When evaluating system attenuation there are a few practical considerations that should be taken into account. It is unlikely that all parameters end up at a maximum attenuation, so if specification limits are used when determining an optical link the estimate will be very conservative. In real systems, the distributions for the attenuation parameters are an important consideration; median attenuation values are often a better predictor of what will be observed in the deployed link.

The second consideration is the stability of the attenuation over time. Low water peak (LWP) and zero water peak (ZWP) fibers were developed to maintain attenuation performance over time. The optical fiber must be properly passivated to assure long term stability over its life.

When deploying new fiber types, one should consider that each aging environment is slightly different and long term attenuation stability may not be observed for all installations.



Dispersion in a system can be corrected by inserting an element, such as a dispersion compensating module, that has the inverse dispersion.

A third consideration is average splice loss. With a splice occurring every 10 km one can expect about 46 splices along the 460 km route. This is approximately 4.6 dB of loss for 0.1 dB splices.

Using fiber with lower average splice loss (such as OFS AllWave® fiber, with an average splice loss of less than 0.05 dB/splice when using core aligned splicers) can cut this splice loss term in half and add more than 2 dB to the system margin.

Dispersion

As pulses travel down an optical link they tend to disperse. There are two types of dispersion that need to be considered: polarization mode dispersion (PMD) and chromatic dispersion (CD). PMD is a random dispersion and thus complex to compensate; chromatic dispersion is deterministic and simpler to compensate.

Many new transmission formats have been developed in recent years to make systems more tolerant of these parameters, and it is likely that over a 30-year deployment many transmission formats may be deployed on an optical link. Comparing sensitivity to dispersion, it is best to consider the simplest transmission format: Non Return to Zero.

PMD is often a hidden problem in optical fiber, because the parameter is difficult to measure and only challenges systems at high transmission speeds. For example, consider a link that is currently used at 2.5 Gb/s and is now targeted for 10 or 40 Gb/s deployment. High PMD fibers may perform perfectly well at the slower speeds, while costly regeneration is required at higher speeds.

The ITU-T G.652D specifies a PMD link design value of 0.20 ps/sqrt (km) for cabled optical fiber. This value supports 10 Gb/s transmission over a 1000 km distance, but at 40 Gb/s this same link design value will support less than 100 km. Since it is likely that 40 Gb/s will be deployed over this 40 km link, using cable with a link design value less than 0.09 ps/sqrt (km) is recommended.

> ***Over a 30-year deployment, many transmission formats may be deployed on an optical link.***

Chromatic dispersion is another important consideration in optical systems. This parameter is a result of wavelengths traveling at different speeds, causing pulses to spread as they propagate though an optical link. Fortunately, the dispersion can be corrected by inserting an element, such as a dispersion compensating module, that has the inverse dispersion.

Different optical fiber types have different chromatic dispersion maps. Optimal system performance is achieved when the dispersion compensating module is matched with the optical fiber being used. If the dispersion compensating module is not properly matched, the dispersion penalty is increased and the number of WDM channels that can be deployed is limited.

Each fiber type has its own advantages and disadvantages in this area. For example, G.652D fiber has the highest chromatic dispersion but it also has the largest effective area. G.655 has the lowest chromatic dispersion, which can result in lower system costs for transmission speeds less than or equal to 10 Gb/s; but at 40 Gb/s there is not enough dispersion to prevent some non-linear effects. G.656 fibers offer a trade-off between G.652 and G.655 fibers.

Composite Cables

Multiple fiber types are often deployed in the same cable to help ensure that there will be fibers optimized for every transmission strategy that may be used throughout the 30-year expected life of the cable.

When deploying an optical cable, the first rule to consider is that all optical fibers in the link are useable and add value. For example, if a fiber with an attenuation of 0.18 dB/km is deployed with a fiber having 0.25 dB/km attenuation, five huts would be required for the higher attenuation fiber and four for the lower attenuation fiber.

If only four huts are used, the higher attenuation fiber is unavailable for transmission, and if five huts are used the lower attenuation fiber provides little benefit. A more useful composite cable would be a G.652D fiber paired with a G.656 fiber, where each fiber may be deployed with a different transmission strategy that takes greatest advantage of the fiber dispersion map now and in the future.

Conclusion

Selecting fiber for long haul links can be a difficult choice. There are many fiber types available, as well as a number of performance attributes within each category. Composite cables with different attributes are often deployed in these networks as it is often desirable not to have only one fiber alternative.

When deploying composite cables it is important to look at the overall system requirements and choose fiber types that provide the most flexibility for both today's deployment as well as tomorrow's

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