Complimentary Fiber and Active Equipment Technologies that Deliver Extended Reach for High Data Rate Transmission in Long-Haul Networks

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Authors: Ian Davis (Corning Incorporated) and Bertrand Clesca (Xtera)

Introduction

Installation of new, high data rate backbone networks continues apace as a key driver for economic advancement in developing regions of the world. Providing a reliable infrastructure for the movement of large volumes of telecoms data are as important for the economic development of a country as road network is for transporting physical goods. Without higher capacity networks in the backbone, subscribers will remain unable to access the sorts of data-rich applications, e.g., YouTube and Skype that subscribers in Europe and North America now take for granted.

Many of the regions that are investing most heavily today in high performance backbones share common challenges in geography and population density. Large cities are separated by extensive areas of sparsely inhabited land, perhaps mountain or desert, making physical access difficult, even dangerous (Figure 1). Network operators will prefer to avoid locating amplification sites in these remote regions due to the costs of building, powering, maintaining and providing security for these stations. However, as the demand for higher capacity pushes data rates upward, this can reduce the reach of networks, curtailing design flexibility to connect large population centers whilst avoiding inaccessible amplification sites in between. Options to extend reach and improve the flexibility of network design can be achieved through selection of advanced fiber and active equipment. The most important fiber attribute that delivers improved network design capability is low loss.

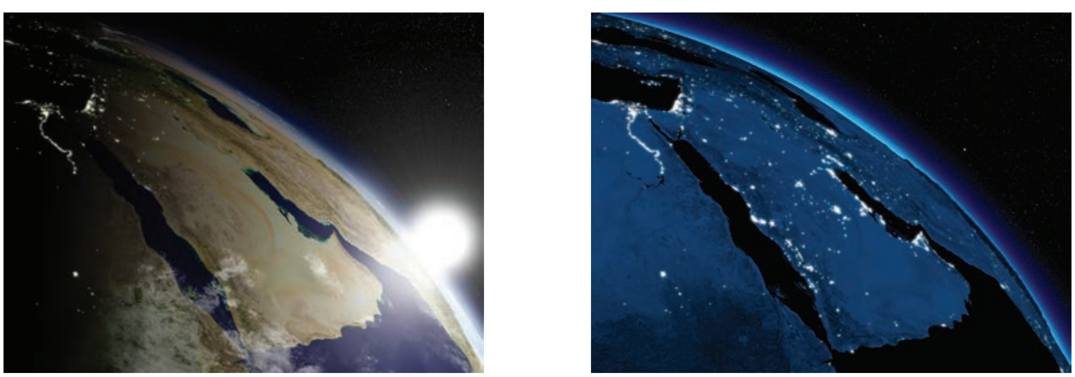

Figure 1. The dispersed population of the middle-east can be clearly identified in the “light-map” of the region.

How High Data Rates Challenge Optical Signal to Noise Ratio (OSNR)

Transmission technology has evolved to the point where 100 Gb/s deployments are now routinely reported and 400 Gb/s are beginning to be installed. These advances help deliver the capacity needed to provide advanced applications and services but also present challenges to network owners. The effects of attenuation (loss) and noise accumulation introduce a limit on transmission distance once the signal can no longer be reliably detected and errors begin to be introduced (Figure 2). This is referred to as the OSNR limit. As advanced modulation formats are used to pack more data into a channel, higher OSNR becomes necessary to achieve reliable detection.

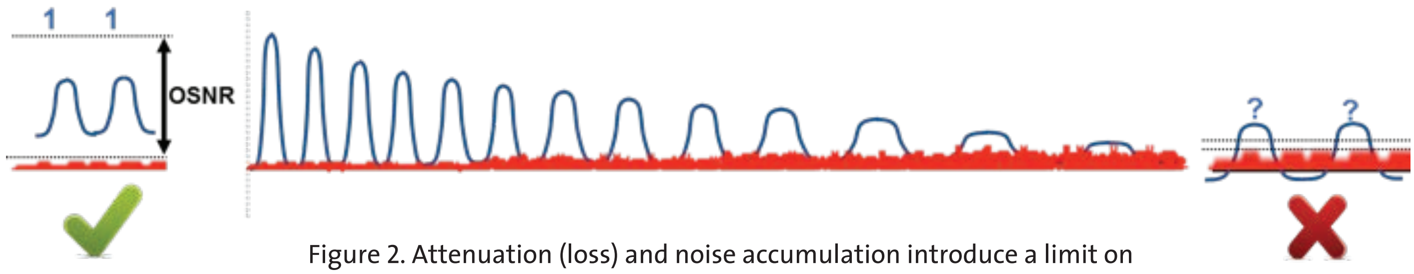

Figure 2. Attenuation (loss) and noise accumulation introduce a limit on transmission distance once the signal can no longer be reliably detected.

The reach of a network is a trade-off with the spacing of intermediate amplifier sites on the path. Designing links with shorter spans (i.e., distance between amplifiers) allows reach to be increased (see Figure 3). This may be desirable, but regeneration of a multi-wavelength optical signal is by far the most expensive component of a network and is to be avoided as far as possible. The shortcoming of this approach is evident when the network crosses desert, tundra or other remote regions – operators are forced to build power and maintain many inaccessible amplification sites.

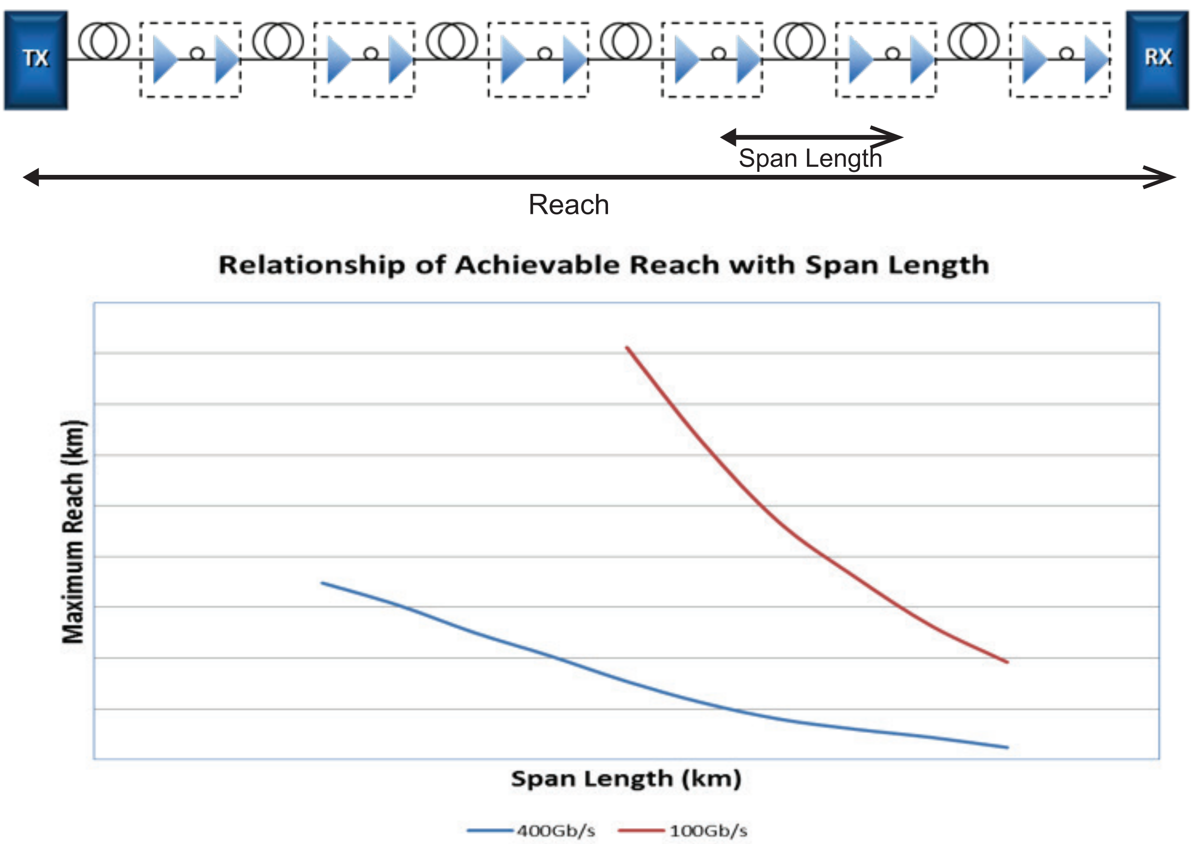

Figure 3. Achieving long reach without intermediate regeneration requires more frequent amplifier sites. This can force amplification sites in remote regions. Planning for 400 Gb/s requires even more frequent amplification.

To increase span length a network designer must add more fiber without degrading OSNR at the end of the link. Two complimentary options exist.

1) Deploy ultra-low-loss fiber. The OSNR threshold is reached after completion of a longer distance.
2) Introduce advanced amplification techniques that boost the signal power without exceeding the threshold for non-linear distortion.

As Figure 3 illustrates, with migration to 400 Gb/s in mind, preserving OSNR becomes an increasingly important concern.

Ultra-Low-Loss Single-mode Fiber

Ultra-low-loss technology refers to fiber types that are capable of delivering ≥3dB additional optical power over a 100 km span compared to conventional G.652.D single-mode fiber. Corning introduced ultra-low-loss technology in an ITU-T Recommendation G.652 compliant product in 2007. This marked the launch of SMF-28® ULL optical fiber. This product addresses the desire of network owners to increase OSNR for high speed transmission whilst maintaining G.652 compliance throughout their installations. An early adopter of SMF-28® ULL optical fiber was du[1] in the UAE who derived clear-cut savings from the decision to install this product in their Pan-Emirates, high-capacity network. Use of ultra-low-loss fiber allowed un-repeatered transmission across links between three major cities that would each have required remote amplification sites had conventional fiber with higher loss been selected.

In laboratory simulations, deploying SMF-28® ULL optical fiber for operation at 100 Gb/s has been shown to extend reach by 36 percent compared to the same configuration using standard G.652.D optical fiber[2] and up to 3000 km reach at 100 Gb/s has also been demonstrated in 24 x 125 km spans using only Erbium-Doped Fiber Amplifiers (EDFAs)[3].

Amplification Technologies

At the end of the 1980s and beginning of the 1990s, both EDFA and Raman optical amplification technologies were in competition. Having the right mix of optical performance and optical pump requirements needed at the time, EDFA won with the first deployments in commercial networks, both terrestrial and submarine, around the mid-1990s. EDFAs were particularly well suited to the transmission of multiple wavelengths, each carrying a bit-rate ranging from 2.5 to 40 Gb/s and the typical count of wavelengths amplified simultaneously was 64.

Today EDFAs are used to transport multiple wavelengths at 100 Gb/s in the backbone network. With high-quality fiber installed (e.g., new builds with SMF-28 ULL optical fiber), practical distances of about 2,000 km could be achieved assuming uniform span lengths and allowing sufficient margin for future cable repairs.

EDFA amplification technology however limits the [Capacity x Reach] performance in a number of ways:

- The optical spectrum is limited to a maximum of 38 nm. Packing more wavelengths means narrower spacing and stronger inter-carrier optical impairments inside the optical fiber.
- EDFAs represent “hot spots” that boost the signal’s power periodically along the optical links. Such a power profile is conducive to non-linearities within the line fiber at the beginning of each span. Although very effective in compensating for linear degradations (e.g., chromatic dispersion and PMD), the digital signal processing of today’s 100 Gb/s coherent receiver is not yet effective in compensating for non-linear degradations.
- EDFA noise generation is not optimal, resulting in a significant noise accumulation along the optical path with multiple in-line amplifiers.

Raman amplification is an effective technology to overcome these limitations:

- Raman-based optical amplifiers offer up to 100 nm bandwidth (such amplifiers were deployed by Xtera as early as 2004). Wider spectrum means more wavelengths than can fit into the amplifier spectrum for higher line capacity.
- Superior noise performance of Raman-based optical amplifiers leads to higher OSNR performance at the output end of the optical path. Reducing the amount of optical noise generated by a string of optical amplifiers is critical for increasing the span length and/or the unregenerated reach.
- Distributed Raman amplification within the line fiber results in a lower peak-to-peak power excursion along the optical path, avoiding “hot spots” inside the line fiber and reducing the effect of nonlinearities.

Figure 4 provides the evolution of the per channel optical power along a link made of several spans and in-line amplifiers, based on EDFA or Raman technologies. The net result is a lower peak-to-peak power excursion along the optical path in the Raman-based link compared to the EDFA chain, keeping the optical signal away from noise and nonlinear impairments.

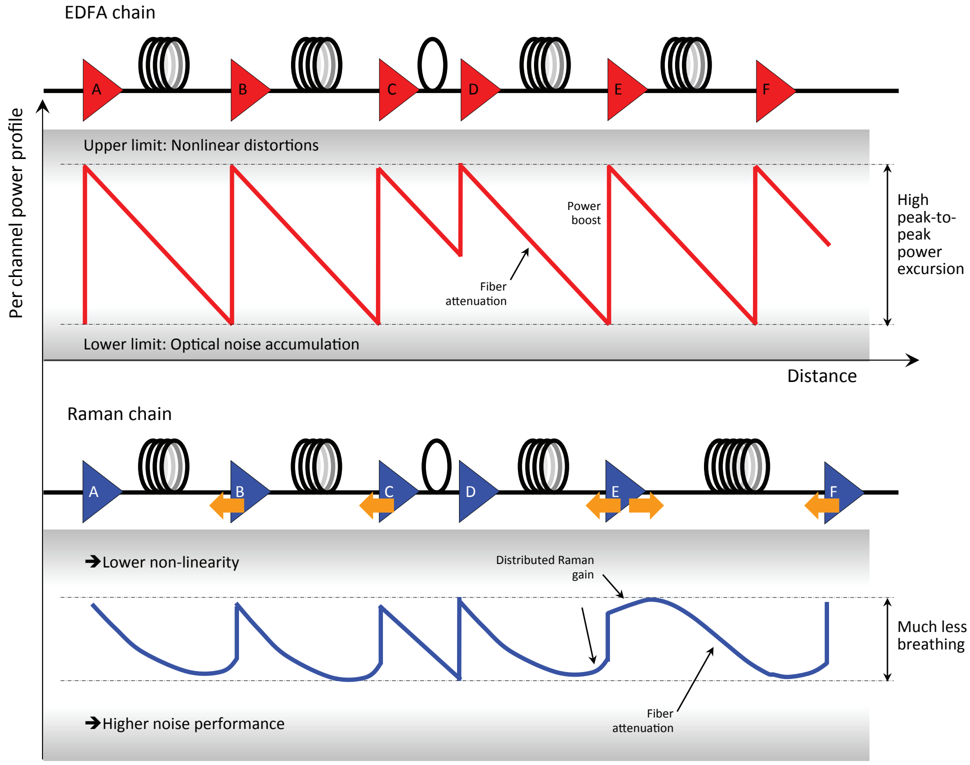

Figure 4. Typical per channel optical power profile as a function of the transmission distance in chains of EDFA and Raman amplifiers.

Raman amplification is recognized by the industry as a key future-proof technology to efficiently support 100 and 100+ Gb/s long-haul optical networking. Based on an extensive patent portfolio and a continuous R&D effort over 15 years, Xtera's Raman technology extends beyond just the device itself. Backed by unrivalled field and operational experience for more than 10 years, built on field-proven photonic design and optical configurations, and supported by efficient control loops and automation, Xtera's Raman technology offers both high performance and operational excellence. This allows the seamless integration of Raman amplification into optical networks.

Raman amplification effectively turns the optical fiber into a distributed amplifier. Instead of being a purely passive transmission medium, some portions of the optical spans can provide the optical carriers with optical gain. Raman amplification and ultra-low loss fiber both address the same goal - to minimize the attenuation experienced by the optical signals along the transmission path.

Figure 5 shows the benefits of using a combination of SMF-28 ULL optical fiber and Xtera's Raman amplification over a single span between two network elements.

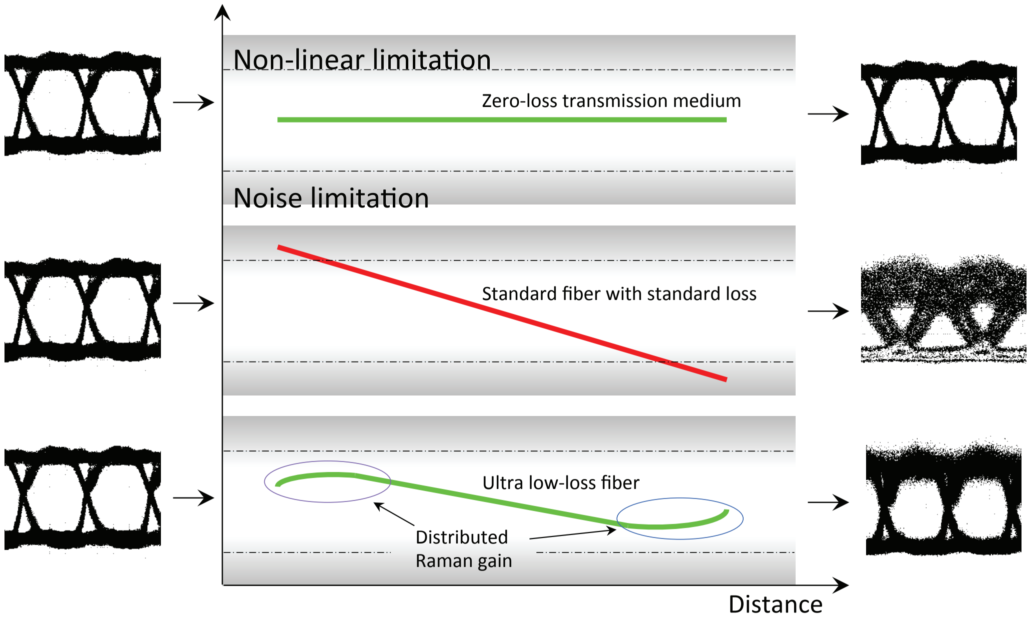

Figure 5. Advanced fiber and amplification technologies to minimize optical signal attenuation along the optical path.

100 Gb/s Transmission Over a Single-Span of 500 km

At the Optical Fiber Communication Conference (OFC) 2014, Corning and Xtera partnered in a demonstration of 100 Gb/s transmission over a single-span of 500 km[4] (Figure 6). This impressive performance was achieved by Corning's SMF-28 ULL optical fiber used together with Xtera's Wise Raman equipment. Through a combination of amplification techniques, including conventional erbium-doped amplification, forward and backward Raman amplification and Remote Optically Pumped Amplification (ROPA), 86 dB of loss between terminals was made available (including 3 dB of margin for repairs over the lifetime of the deployment) over a single span. Use of ultra-low-loss fiber ≤0.165 dB/km (typical) at 1550 nm allowed the single-span of 500 km to be built with <83 dB of loss (including splices). Compared to conventional single-mode optical fiber, SMF-28 ULL optical fiber generated around 15 dB lower loss over this span.

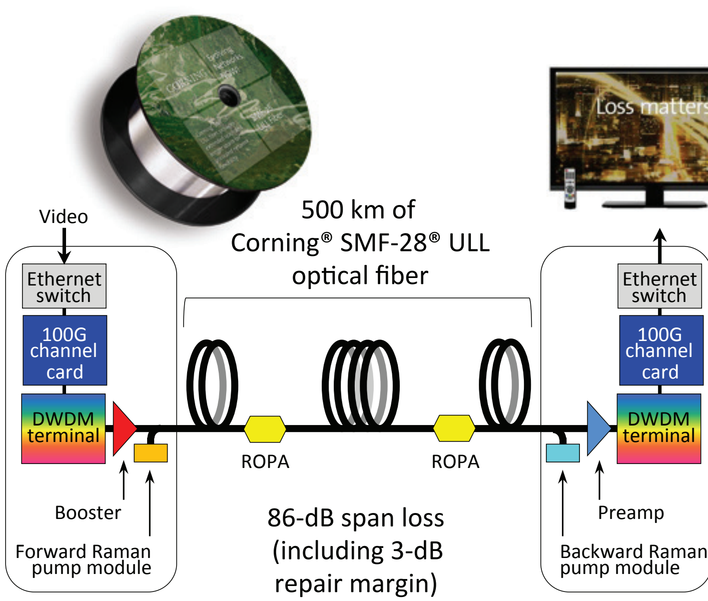

Figure 6. 100 Gb/s transmission over 500 km achieved by combining ultra-low loss fiber and advanced amplification technologies.

Conclusion

A combination of ultra-low-loss fiber and advanced amplification technology serve to extend reach and maximize network design flexibility for high capacity backbone networks.

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Corning Incorporated
www.corning.com/opticalfiber

One Riverfront Plaza
Corning, New York
USA

Phone: (607)248-2000
Email: cofic@corning.com