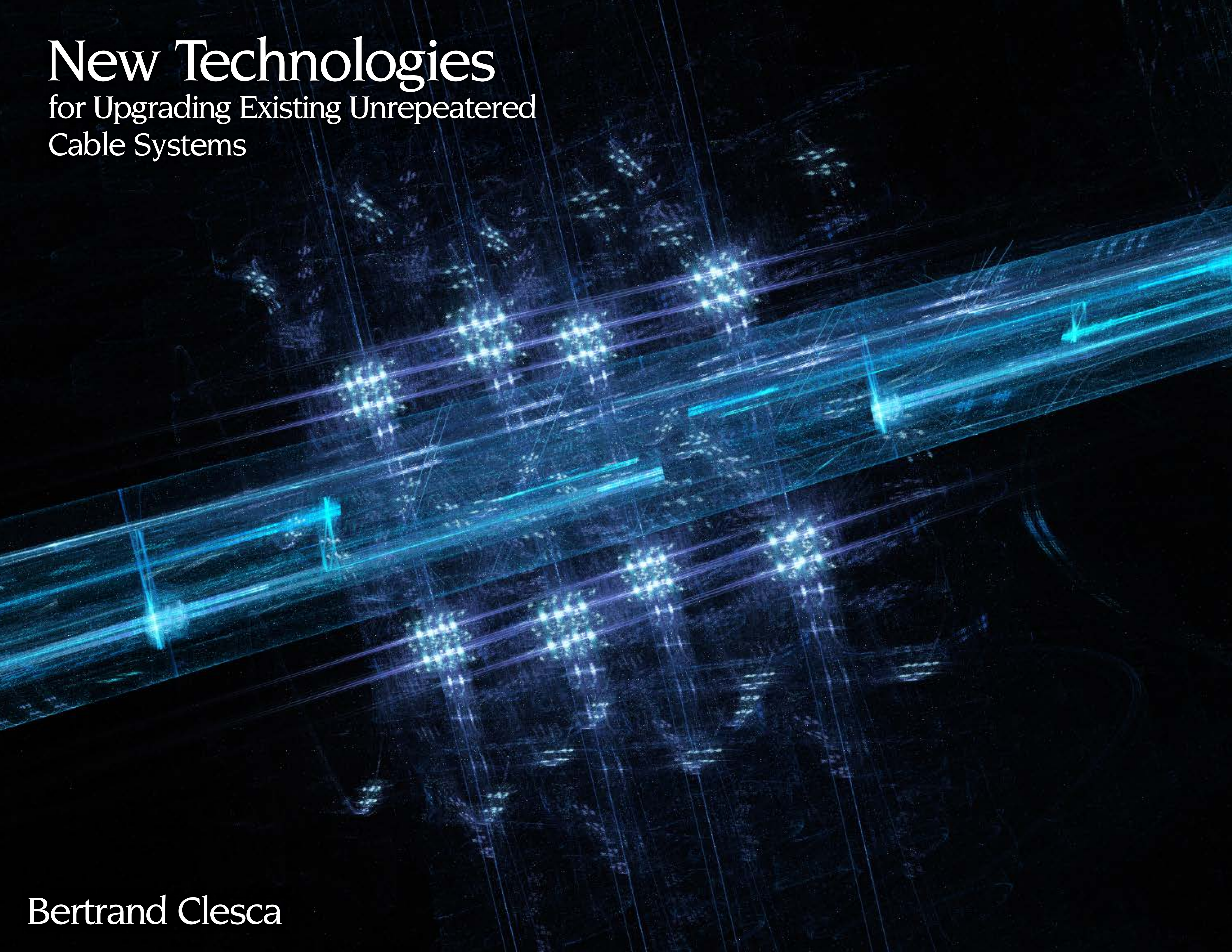


New Technologies
for Upgrading Existing Unrepeatered Cable Systems

Bertrand Clesca

Along with long-distance repeatered submarine cable systems, shorter distance unrepeatered cable systems are part of the worldwide subsea transmission infrastructure transporting the IP traffic across the globe. Unrepeatered subsea cable systems refer to submarine links with nothing under water but the optical cable, with active equipment – namely the Submarine Line Terminal Equipment (SLTE) – being located in the cable landing stations. The unrepeatered system category was extended to systems with submerged Remote Optically Pumped Amplifiers (ROPAs) jointed to the cable some distance away (typically 80 to 150 km) from the landing sites. The rationale for this definition extension is that ROPAs do not require electrical power – so no electrical Power Feed Equipment (PFE) needed in the cable landing station – and that there is no requirement for a copper-based power conductor in the cable.

Recent publications have reported increased unrepeatered distances with for instance 150 x 100G channel unrepeatered transmission over 410 km, 1 x 100G over 627 km and 1 x 10G over 645 km. These demonstrations were carried out with commercially-available STLE and high-end line fibers offering ultra-low attenuation and very large effective area. These advanced line fibers are available, at the expense of higher cost compared with more standard fibers, for new builds that can achieve this Capacity – Reach performance in commercial service.

Because unrepeatered cable systems are loss-limited systems, there is a strong coupling between the link fiber capacity and reach performance: when one is increased, the other one is reduced. Every technical innovation that improves one characteristic has an impact (generally positive) on the other one as described in the following section. This article describes the different ways the recent innovations can be used for upgrading existing unrepeatered cable systems.

Why Upgrading Existing Unrepeatered Cable Systems?

There are two main reasons that lead to the need for a system upgrade. One reason is the increase in cable loss over time, due to for instance multiple cable repairs, which reduces the system margin or does not allow the system to operate error free. When several cable repairs are located along a small cable length, it may make sense to replace this cable length by a new piece of cable. But in the case these multiple cable repairs are distributed over a long cable length, this may not be a practical and/or economically viable approach. The second reason is the need for increasing the cable capacity by increasing the channel rate or count. The objective here is to play first at the cable landing station by upgrading or replacing the existing SLTE using newer optical transport technologies. If the SLTE (or dry) upgrade is not enough to reach the desired capacity performance, wet upgrade can be contemplated as discussed at the end of this article.

Advanced Interface Cards

The need for higher capacity over longer distances in optical transmission systems has rekindled the interest in coherent detection. One approach to increase the data throughput is to maximize the spectral efficiency, measured in bit/s/Hz. Until the advent of 100G systems around 2010, most optical transmission systems use binary modulation formats with direct (non-coherent) detection and achieve spectral efficiencies of 0.8 bit/s/Hz. Higher spectral efficiencies call for more advanced modulation schemes that encode the information to be transmitted along several axes: amplitude, phase, polarization. Recovery of the information symbols at the receiver requires the more complex (polarization alignment, carrier synchronization), but also higher sensitivity, coherent detection.

More stringent Optical Signal-to-Noise Ratio (OSNR) requirements, as imposed by higher channel rates, are the drivers for stronger Forward Error Correction (FEC) codes. Like with repeated cable systems, and driven by the higher OSNR figure required by 100G and beyond channel rate, soft-decision FEC have been used in unrepeatered systems since 2013, based on even more powerful encoding and decoding algorithms and soft decision mechanism.

Both coherent detection, including powerful digital signal processing, and FEC code enable to increase the capacity over given cable length and attenuation.

Adding Raman Pumping for Distributed Optical Amplification along the Cable

Distributed Raman optical amplification is a simple, field-proven way to instantaneously increase both capacity and system margin over the existing fiber plant. Raman amplification of an optical signal occurs when the signal is transmitted through an optically-pumped material with a frequency which falls within the Raman scattering spectrum of the pump source [3]. The signal photon triggers the stimulated emission of a photon at the signal wavelength, which is in phase with, and propagates in the same direction as, the original signal photon, and so leads to Raman gain. Practically speaking, the optical pump wavelength (launched from the cable landing station equipment) is in the range of 1420 to 1500 nm in order provide optical amplification around 1560 nm where line fiber attenuation is minimal (Figure 1).

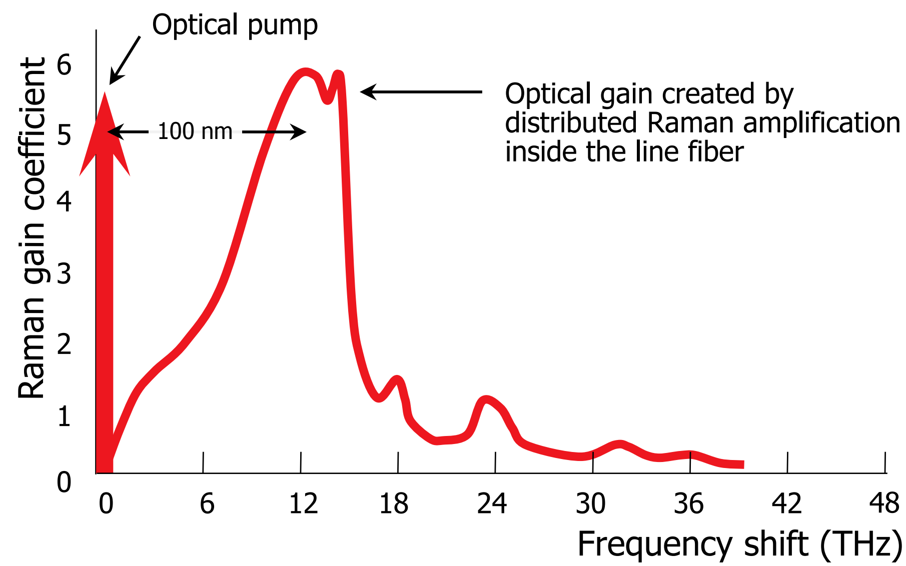
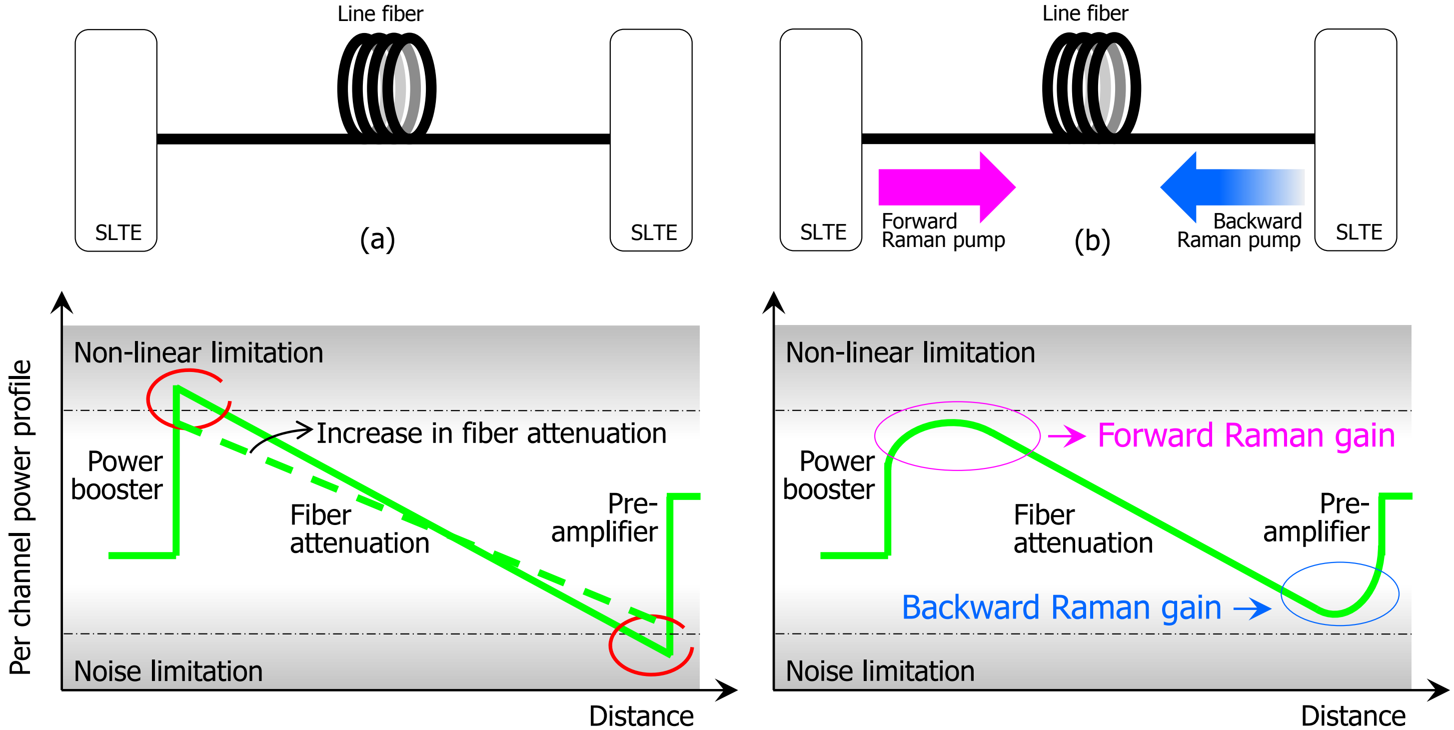


Figure 1: Raman gain inside the line fiber.

Distributed optical Raman amplification results in lower per channel power inside the fiber (leading to lower fiber nonlinearities) and higher OSNR compared to a fiber link made of discrete Erbium-Doped Fiber Amplifiers (EDFAs). Figure 2a shows an unrepeatered cable system with no distributed optical amplification. At the beginning of life, the fiber attenuation is depicted by the dashed green line; EDFA amplifiers enable to launch the signal wavelengths into the line fiber at a per channel power level lower than the upper limit set by fiber nonlinearities, and to recover the signals before they are too severely corrupted by optical noise. When the fiber attenuation increases over the system lifetime (solid line), an increase in the signal launched power can hit



the fiber nonlinearities threshold; also per channel power can go under the lower optical noise limit. A very efficient way to recover from this situation is to turn some parts of the line fiber into amplification media as shown in Figure 2b. This is achieved with Raman pump wavelengths launched from the received end (backward pumping) and/ or from the transmit end (forward pumping); Raman effect will create distributed optical amplification inside the line fiber as shown in Figure 2b.

Figure 2: a) Per channel power as a function of the transmission distance in an unrepeatered cable system with only discrete amplification at the SLTE level at beginning (dashed green line) and mid (solid green line) life of the cable system, and b) Per channel power as a function of the transmission distance with forward and backward distributed Raman amplification inside the line fiber.

Starting from a baseline where the SLTE is equipped with only EDFA amplifier at both transmit and receive sides, and assuming 100G coherent interfaces with 15% overhead SD-FEC and a target OSNR of 13.5 dB / 0.1 nm, backward Raman pumping offers the equivalent of up to 9 dB of extra cable attenuation; adding forward Raman pumping can offer another extra cable attenuation of up to 10 dB [4]. The exact figures depend on the line fiber type and linear attenuation but distributed Raman amplification is clearly a simple and very effective way to breathe new life in existing subsea cable system that becomes loss-limited over time.

Adding Remote Optically Pumped Amplifier

A Remote Optically Pumped Amplifier (ROPA) is a very simple sub-system that is typically placed 80 to 150 km ahead of the receive end. This sub-system is based on a few passive optical components that are placed inside an enclosure jointed to the cable (Figure 3). By nature, the ROPA is a fully passive sub-system that requires no remote electrical power feeding from the cable end.

The energy, necessary for creating optical amplification, is brought to the ROPA by optical pump waves launched into the line fiber from the terminal equipment. Actually this is the residual pump power that has not be consumed to build Raman distributed gain inside the line fiber that is used to pump the ROPA. As we are in a small-signal regime in the backward pumping scheme, 5 to 10 mW of pump power is

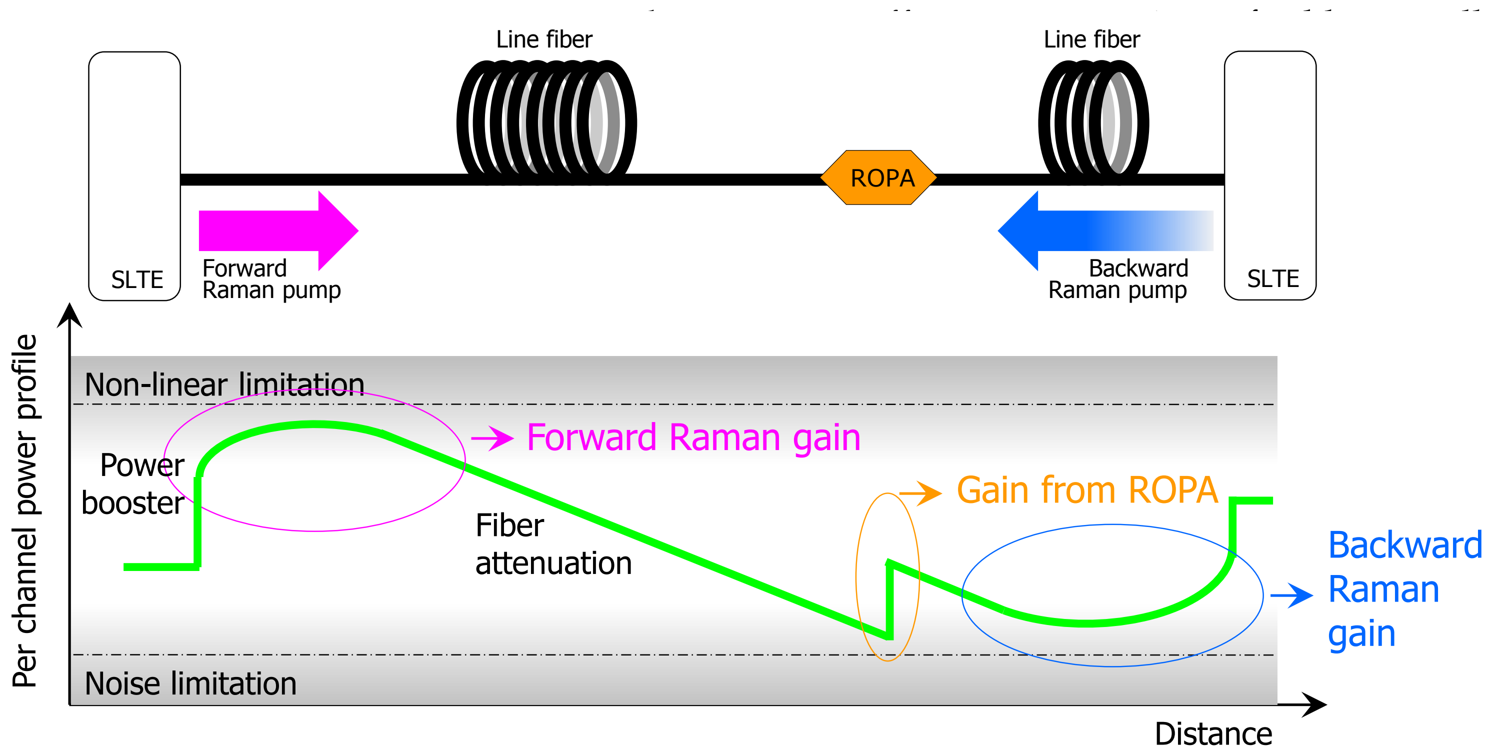
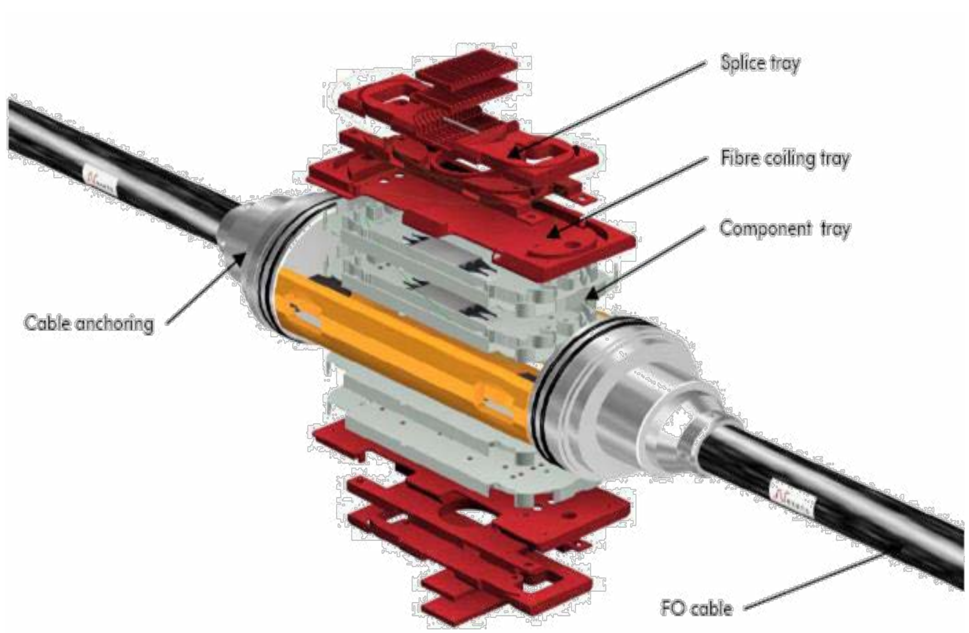


Figure 3: ROPA enclosure for subsea applications (Courtesy of Nexans).



ROPA located before the receive end.

Starting from the same baseline as above, a receive ROPA offers the equivalent of up to 11 dB of extra cable attenuation. Here again, the exact figure depends on the line fiber type and linear attenuation. The addition of a ROPA to an existing subsea cable systems requires a few days of marine operations and is quite similar to a cable repair process (recovery of the cable and jointing a

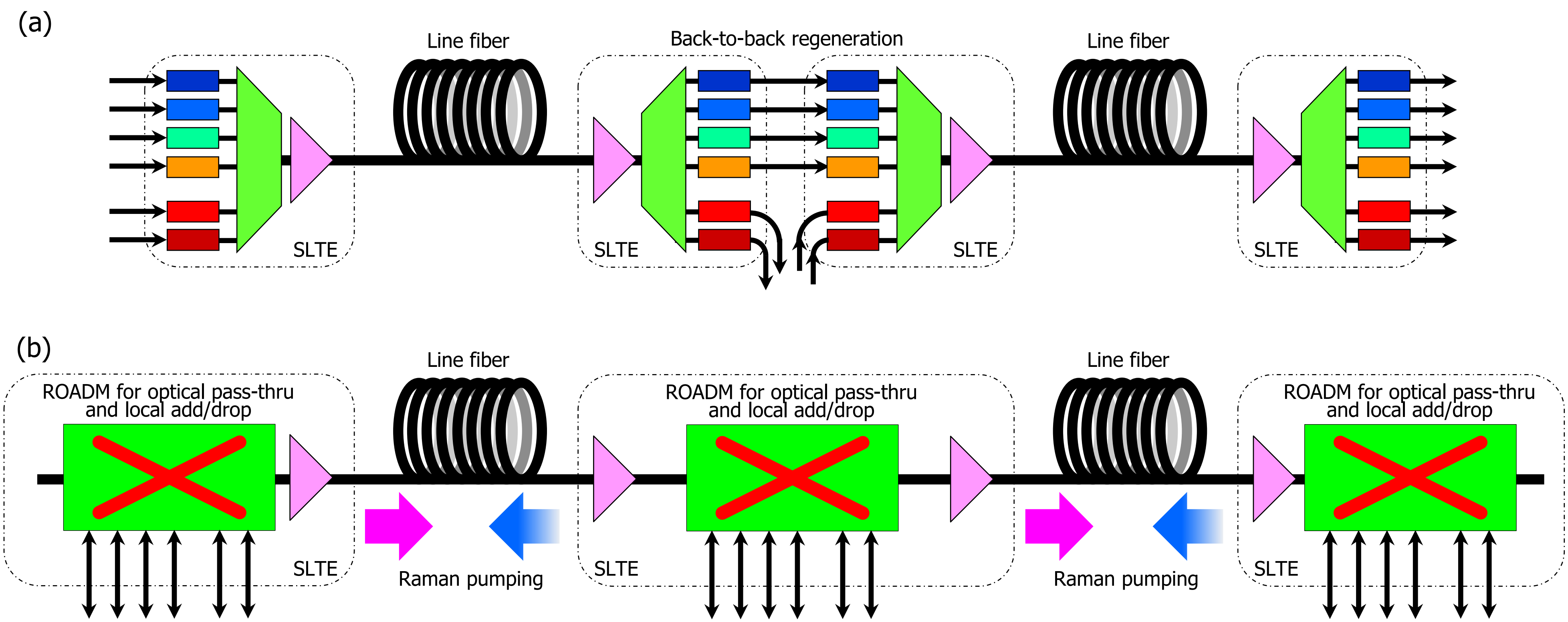
technologies can be used for modifying the configuration of the subsea network based on unrepeatered cable systems. Two examples will be briefly discussed here.

The first example of unrepeatered system configuration upgrade can be found in festoon network. With previous optical transport technologies, festoon networks were usually made of cascaded single-span segments, with back-to-back regeneration in cable landing stations for pass-thru traffic as depicted in Figure 5a.

Figure 5: a) Traditional festoon network configuration with back-to-back regeneration in cable landing stations for pass-thru traffic, and b) New festoon network configuration enabled by more advanced optical amplification technology with ROADM optical switch offering optical pass-thru for the express traffic.

Implementing Raman pump source modules at the SLTE levels not only offers extra margins for single-span transmission but also enables express wavelengths to propagate beyond a single span. This opens the path for new SLTE architecture based on Reconfigurable Optical Add Drop Multiplexers (ROADMs in Figure 5b) where express wavelengths are passed thru and local wavelengths are added/ dropped for local traffic purposes. By doing this, the cost per transported bit for express wavelength is greatly reduced and the global operation of the network is simplified as ROADMs can be remotely reconfigured via the network management system.

The extra margins provided by distributed Raman amplification can be used to modify the configuration and reach of existing unrepeatered cable systems. Figure 6 represents the example of an unrepeatered system connecting A to B, originally deployed with only EDFA amplifiers within the SLTE equipment (Figure 6a).



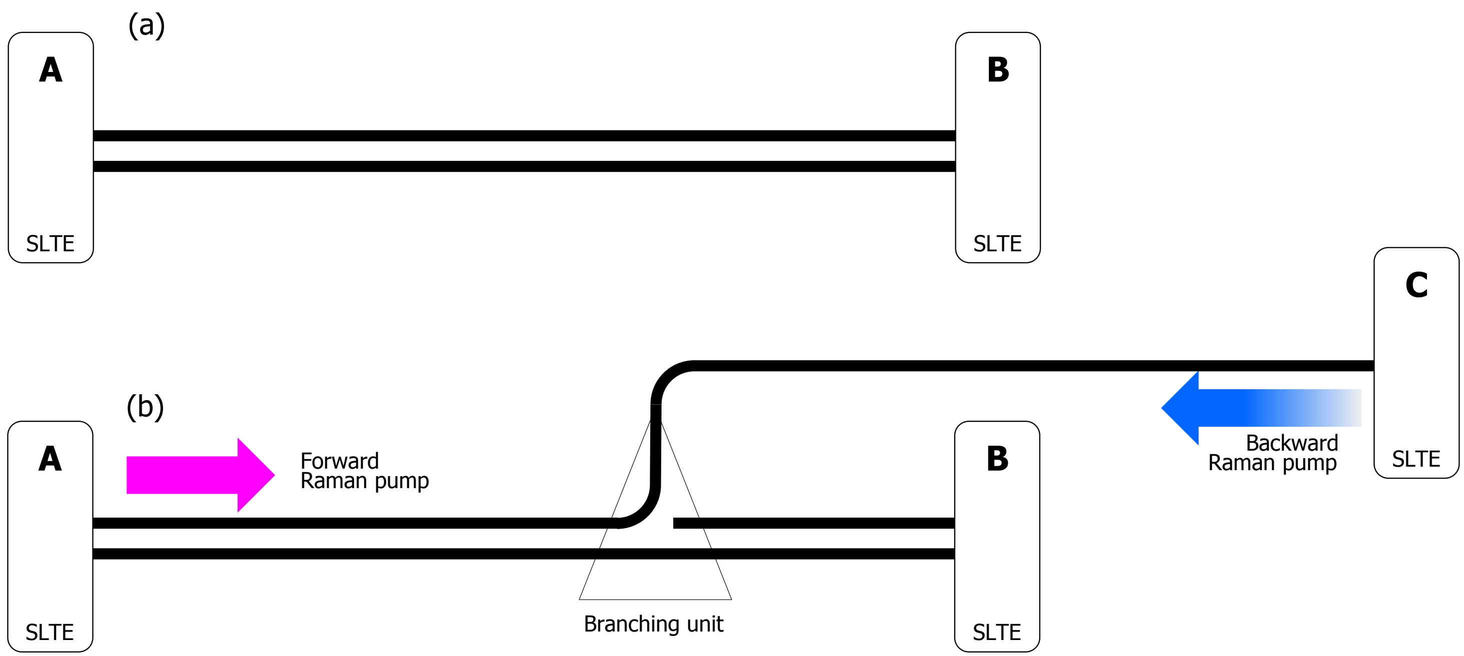


Figure 6: a) Originally deployed unrepeatered link between cable landing stations A and B, with EDFA amplifiers only, and b) Network extension enabled by distributed optical amplification technology, SLTE upgrade and wet plant upgrade.

At the expense of the insertion of a branching unit (assuming fiber pairs are free or can be freed up) and the upgrade of SLTE with Raman pump source modules to build distributed again inside the line fiber, a new network configuration can be implemented, enabling to reach a new landing site C that may be more distant from the site A than the site B is (Figure 6b).

Conclusion

Although the advanced of unrepeatered transport technologies are usually advertised through the announcement of transmission demonstrations over state-of-the-art fibers, these technologies can be deployed in many ways into existing unrepeatered cable systems. Taking into account wet plant upgrade and ROADM implementation inside cable landing stations, the tool box of subsea system designers is getting richer and richer for extending the lifetime and capabilities of existing unrepeatered cable systems.

Bertrand Clesca is Head of Global Marketing for Xtera and is based in Paris, France. Bertrand has over twenty five years of experience in the optical telecommunications industry, having held a number of research, engineering, marketing and sales positions in both small and large organizations.

Bertrand Clesca holds an MSC in Physics and Optical Engineering from Institut d'Optique Graduate School, Orsay (France), an MSC in Telecommunications from Telecom ParisTech (fka Ecole Nationale Supérieure des Télécommunications), Paris (France), and an MBA from Sciences Po (aka Institut d'Etudes Politiques), Paris (France).