30 Gbaud Opto-Electronics and Raman Technologies for New Subsea Optical Communications

30 Gbaud opto-electronics and Raman technologies have quickly become the new standards for terrestrial backbone networks. Today, the different subsea market segments take benefit from these new technologies as well.

Introduction

Fueled by the traffic explosion driven by developments in video and internet, the demand for bandwidth has become insatiable.

As illustrated by Figure 1, the rate of traffic growth has been doubling approximately every 18 months since 2000, a trend which is predicted to continue, by several different sources, at least for the next several years.

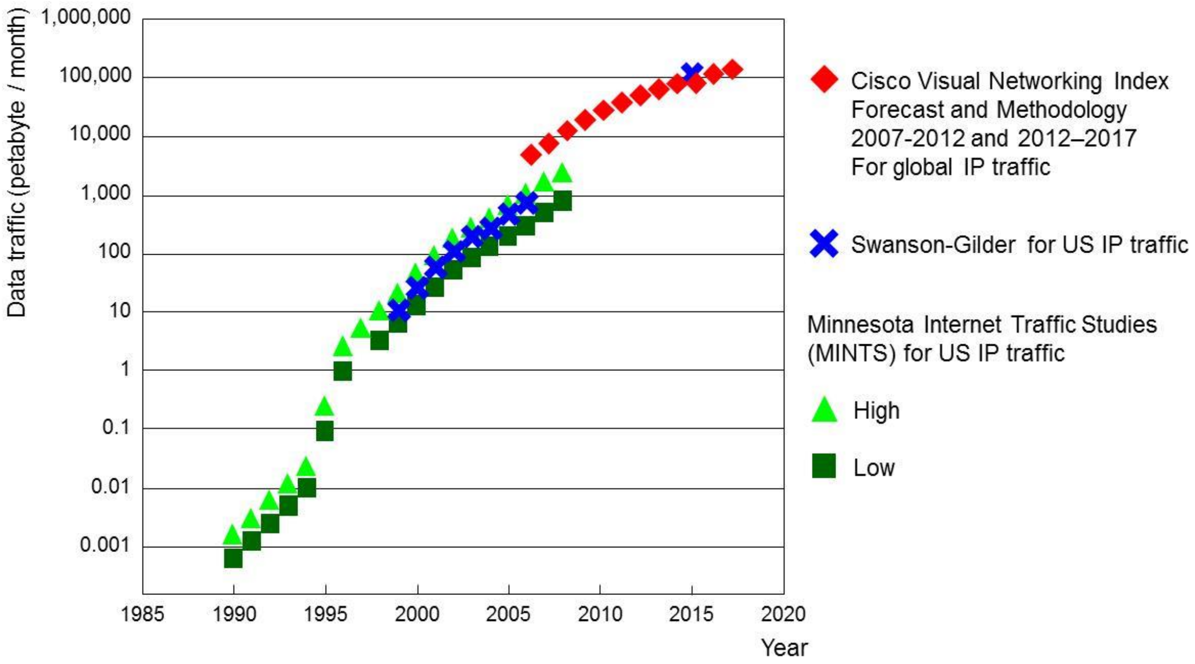

Figure 1: Data traffic as a function of time showing traffic doubling approximately every 18 months.

To satisfy this sustained demand, 100G channel rate with digital coherent detection – enabled by 30 Gbaud opto-electronics – emerged around 2011. With a 10-fold capacity increase over 10G technology, excellent capacity and reach performance and significant price erosion to come, 100G is the dominant line rate today with a bright future for the next years.

Figure 2 shows the global revenues for 10G, 40G, 100G and 100G+ DWDM line cards as a function of time. Since 2014, 100G has become the predominant channel rate while the 40G channel rate is continuously decreasing and remains below 10G line card revenues.

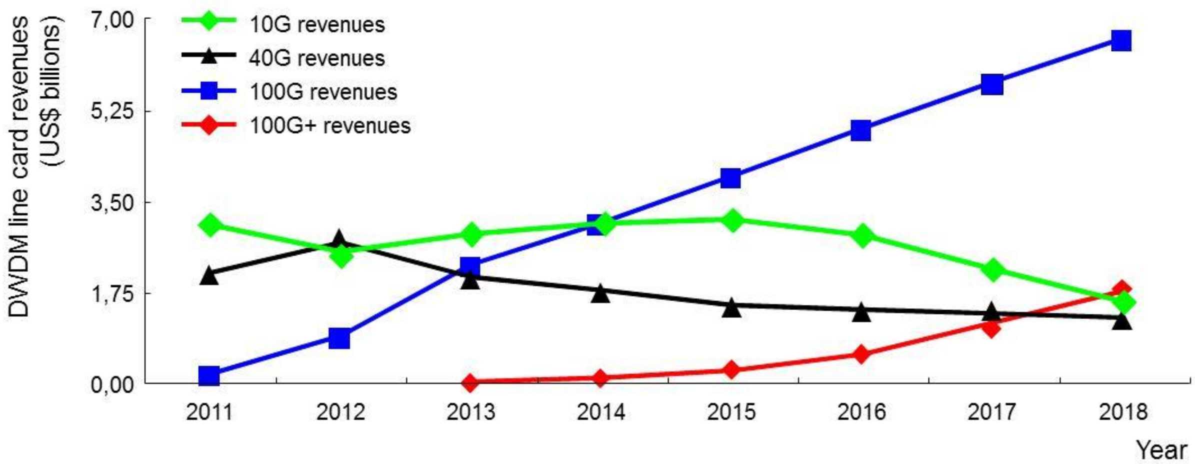

Figure 2: History and forecast for 10G, 40G, 100G and 100+G DWDM line card revenues (After Ovum).

Historically, the first deployments of 100G technology happened in high-capacity terrestrial backbone networks and were driven by the constrained line capacity offered by 10G technology (typically 80 x 10G, i.e. a total of 800 Gbit/s per fiber pair). Another source of limitation, found in aged fiber plants, was Polarization Mode Dispersion (PMD) which could impose an upper limit on the reach for direct detection at 10G. 100G technology was simultaneously deployed in the existing optical transmission infrastructure of developed countries and in new networks of emerging countries. In the latter case, operators took the opportunity to skip 10G and jump directly to 100G rate in the new builds in order to benefit from the lower cost per transported bit enabled by 100G technology.

The Xtera Communications strategy is, and has always been, to maximize both spectral efficiency and spectrum width without compromising on the reach performance, regardless of fiber type or vintage. The foundation of this strategy relies on the Wise Raman™ amplification solution and 30 Gbaud opto-electronics. Combining a 100 nm wide spectrum and 400G channels built on a 16QAM modulation format, both technologies being field proven, leads to a capacity of 64 Tbit/s per fiber pair over a reach that exceeds 1,500 km in terrestrial network conditions.

But… what about submarine communications? What does this technical evolution in terrestrial networks mean to technologies for submarine cable systems? How are the different subsea market segments (unrepeatered, upgrades of existing repeatered links, new builds of repeatered links) impacted?

Unrepeatered Market Segment & 100G

First Applications

Shortly after its advent in terrestrial network, the 100G channel rate was part of proposals for new unrepeatered subsea cable systems where the optical fiber could be selected for optimizing both the linear attenuation and the effective area. Recent deployments of new cable systems, like the one of Tamares Telecom in 2012 between Israel and Cyprus (Figure 3), enable the reach of very high end-of-life capacity such as 7 Tbit/s, even on distances as long as 350 km. This capacity figure is expressed per fiber pairs (the cable capacity being obtained by multiplying this 7 Tbit/s figure by the number of fiber pairs) and is achieved with only active transmission equipment at each end of the cable system (no active equipment under water).

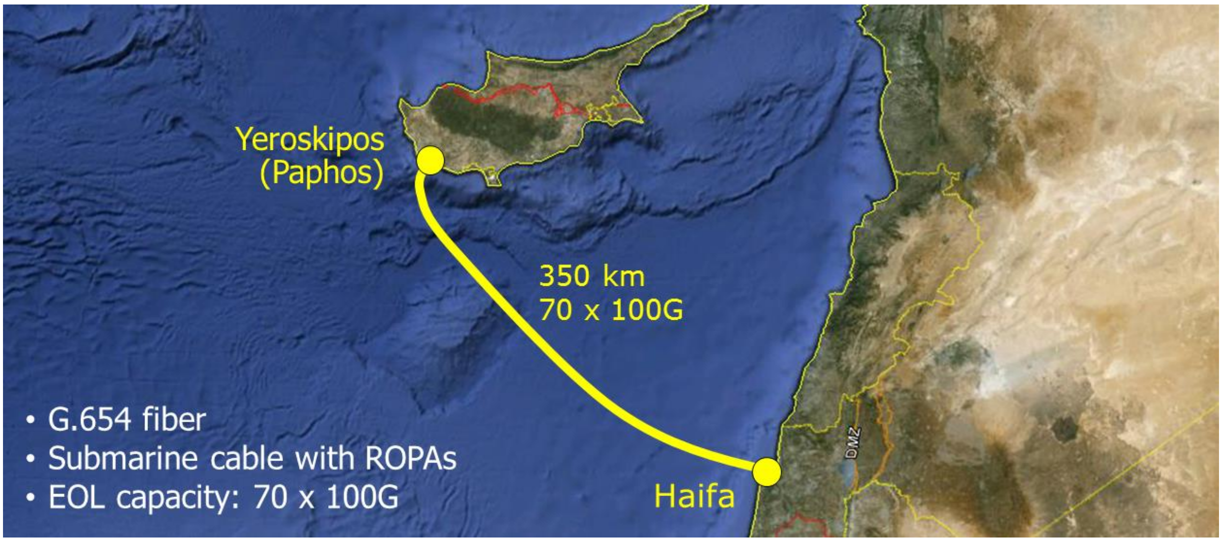

Figure 3: Commercial 350 km unrepeatered subsea cable system with 70 x 100G design capacity per fiber pair.

Subsea fiber infrastructures that were deployed more than 10 years ago are also capable of being upgraded to 100G. A very good example is the ARCOS ring in the Caribbean that was put in service in 2001: the 22 unrepeatered segments of this subsea network are now capable of multi-terabit capacity per fiber pair even on the longest unrepeatered legs (up to 380 km).

Both examples demonstrate the reality of the 100G line rate for achieving high capacity in unrepeatered submarine cable systems (both old and new). Actually, it is the combination of 100G and Raman optical amplification technologies that enables this Capacity – Reach performance level.

Pushing the Envelope

Studies focusing on furthering the reach and capacity of unrepeatered links did not stop with the commercial achievements mentioned above. Recent demonstrations with commercially-available transmission products and Corning's line fibers have set the bar at an impressively high level.

In a first step, the maximum unrepeatered transmission for very high cross-sectional capacity was assessed. With only the line fiber inside the cable, 150 x 100G channels were transmitted over an unrepeatered cable length of 334 km.

Using Remote Optically Pumped Amplifiers (ROPAs) in the cable, the same line capacity of 15 Tbit/s was transported over an unrepeatered cable length of 390 km. A ROPA is a sub-system that is typically placed 100 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. By nature, the ROPA is a fully passive sub-system that requires no remote electrical power feeding from the cable end. In Xtera's implementation, 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; there is no fiber in the cable wasted for the sole purpose of optical pump transport from terminal end to ROPA.

In a second step, Xtera carried out more investigations to assess the maximal transmission distance for a few 100G channels. Recent results published at OFC 2014, and using latest generation ultra-low loss fiber and advanced architecture for ROPAs, have made significant steps forward, enabling an impressive increase in reach performance: four 100G channels were transmitted over 523 km and one 100G channel over 557 km. The single-channel demonstration leads to the significant combination of 100G channel bridging a loss of 90 dB. This [Cable Loss x Capacity] metric has to be compared with the 2004 state-of-the-art technology offering 10G on 77 dB. The latest result represents a 23 dB increase in the [Cable Loss x Capacity] metric over 10 years, which is slightly more than what is commonly named Moore's law!

Table 1 summarizes the results of these recent unrepeatered transmission demonstrations.

Distance (km)	Cable loss (dB)	Capacity	Fiber type	ROPA
334	55.4	150 x 100G	SMF-28 ULL	No
390	64.3	150 x 100G	SMF-28 ULL	Yes
523	84.8	4 x 100G	Vascade® EX2000	Yes
557	90.2	1 x 100G	Vascade® EX2000	Yes

Table 1: Results of recent unrepeatered transmission demonstrations by Xtera with Corning's fibers. (ROPA: Remote Optically Pumped Amplifier).

Repeatered Upgrade Market Segment & 100G

First Applications

The first commercial deployment of 100G technology on existing repeatered submarine cable systems happened in the Mediterranean Sea in the first quarter of 2012. A dark fiber pair was illuminated with 100G channels between Alexandria, Egypt and Mazara del Vallo, Sicily, Italy. It is remarkable that for this type of regional network combining land and subsea sections (as depicted in Figure 4), the very same equipment (including the same 100G interface cards) is deployed for the terrestrial backhaul networks (about 2,500 km between the Mazara del Vallo cable landing station and the Milan PoP across Italy, about 500 km across Egypt) and the submarine link. Common spare units, training and management system considerably simplify the operation of such networks.

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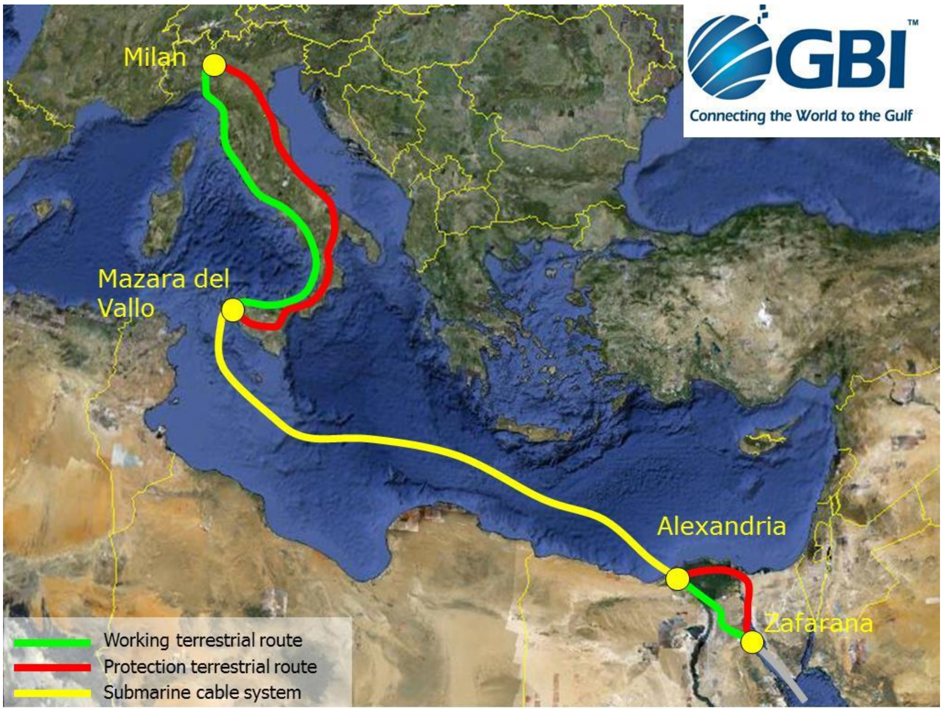

Figure 4: First commercial deployment of 100G technology on existing repeatered submarine cable systems.

Upgrades are Possible on the Different Generations of Submarine Cable Systems

Since the first deployment in 2012, the 100G upgrades of existing repeatered cable systems gained a lot of momentum. 100G upgrades have been executed for the different generations of cable systems with obviously differences in the resulting total capacity per fiber pair. Taking a look at the first generation optically amplified cable systems that were originally designed for single-channel operation with one 2.5 or 5G wavelength, applying 100G and Wavelength Division Multiplexing (WDM) technologies at the terminal level allows an up to 100-fold capacity increase. The more recent the cable system generation is, the smaller the relative capacity increase is with respect to the original design capacity but the higher the absolute potential capacity is. This has been made possible using a combination of advanced modulation schemes, coherent technology, soft-decision forward error correction, and further digital signal processing.

Subsea cable systems are designed to last for at least 25 years. Before the upgrade concept was generalized, some of them were phased out due to their old terminal equipment technology as their operation expenses were high with respect to the offered capacity. Upgrades with 100G breathe new life into existing cable systems – even very old ones – and significantly expand their operational lifetime. Continued effort to improve transmission technologies is happening at the interface card level to increase further total capacity per fiber pair and maximize the value of subsea cable assets.

Repeatered New Builds Market Segment & 100G

What Can Be Achieved for Submarine New Builds?

Evolution of Line Card Technology

In the past few years, technologies for submarine line terminal equipment have experienced tremendous progress with the channel rate evolving from 10G to 20G, then 40G and, today, 100G. Figure 5 illustrates the technical evolution of 100G channel cards with respect to the different types of repeatered subsea cable systems by length (regional, transatlantic and transpacific). For regional cable systems (typically up to 3,000 km), terrestrial 100G channel cards relying on Polarization Multiplexing – Quadrature Phase Shift Keying (PM-QPSK) modulation format can be used.

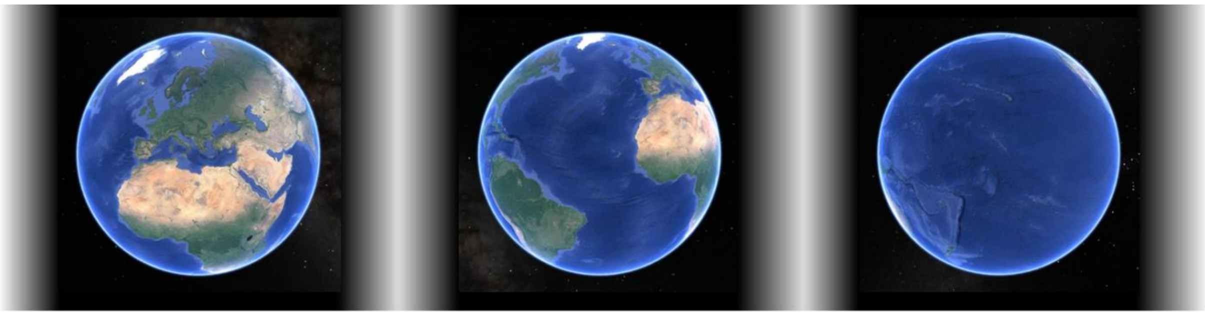

Figure 5: Evolution of line card technology for 100G and beyond 100G channel rate to address regional, transatlantic and transpacific applications.

For transatlantic cable systems (typically up to 7,000 km), an improved variant of terrestrial 100G channel cards, with the introduction of bit interleaving, was developed to enhance reach performance.

For longer applications (like transpacific cable systems with transmission distances up to 11,000 km), further improvements are brought along the lines listed on the right hand of Figure 5, with the objective to offer a flexible 100G and beyond line card suitable for both long-haul terrestrial and subsea networks.

Raman Amplification for Innovation under Water

With the introduction of 100G channel rate in terrestrial networks, Raman optical amplification benefits (excellent noise performance, reduction of nonlinearities inside the line fiber) became clear and more needed than ever to efficiently enable long-haul optical networking with both high capacity and a minimal number of regeneration sites. As a result, Raman optical amplification is becoming ever more common in terrestrial backbones.

Regarding new builds of submarine cable systems, no significant technology progress had been made for at least 10 years at the wet plant level. To unleash the potential of new terminal technologies and access the wide spectrum offered by silica line fiber, one had to significantly improve the wet plant in order to enable more sophisticated technologies (like super channels and 16QAM) and offer higher capacity per fiber pair.

The major innovation in the wet plant in the past years is the introduction of Raman optical amplification. An article about the development and introduction of Raman-based repeaters was published in May 2013 issue of Submarine Telecoms Forum. The key differentiators that are accessible by using Raman amplification technology in a repeater are:

- The Raman effect can be used to create gain in the line fiber, thus attaining a noise figure that is inherently lower than that of a traditional Erbium-Doped Fiber Amplifier (EDFA);
- The Raman amplification can also be utilized to create gain outside the fixed window provided by classical EDFA amplifiers.

The former opens the gate to increasing the inter-repeater spans for some specific applications, while the latter can be used to widen the useable optical bandwidth in a system.

Figure 6: Raman optical amplification going under water.

Examples of Submarine New Builds

Given the maturity of the technology and the cost per 10G equivalent, all new builds are designed and implemented today with 100G channel rate. Furthermore, 100G and coherent detection simplifies the line design and maintenance with a unique type of line fiber all along the cable because chromatic dispersion management inside the cable is no longer needed.

On the repeater side, Raman amplification is a future proof technology that has been already demonstrated to maximize reach performances for higher channel rates, new modulation formats (e.g. 16QAM) and super channel approach. The better noise performance offered by Raman-based repeaters is an opportunity to increase the inter-repeater spacing for some specific applications like "thin" routes where connectivity matters more than capacity. A good example of such an application is provided by the developments of new subsea cable systems to connect small islands communities to the rest of the world with an optical telecommunication technology that offers higher capacity and lower latency than what was offered so far by satellite communications. Ongoing projects in the Pacific Ocean are excellent illustrations of how thin optical subsea cable systems can help network operators and service providers solve the digital divide for remote and/or small communities.

The enhanced spectral characteristics of Raman amplification offers the potential for widening the useable optical spectrum beyond 50 nm and offer higher capacity on fat routes like across the Atlantic Ocean or between Asia and Europe. Raman-based repeaters allow the building of new systems with, e.g., a capacity of 90 Tbit/s on six fiber pairs on busy routes.

Conclusion

100G channel rate, based on 30 Gbaud opto-electronics, is the new 10G in the sense that it is expected to have a long lifetime because of the excellent Cost – Capacity – Reach tradeoff it offers. 30 Gbaud opto-electronics technology leads not only to PM-QPSK modulation format as used in standard 100G channel implementation but also to 16QAM format for 400G channels and higher-rate channels formed by the combination of multiple 200G PM-16QAM subcarriers. At the same time, and in a way similar to what can be observed in terrestrial networks, Raman optical amplification is an instrumental technology to build efficient and high-performance 100G and beyond subsea cable systems.

Introducing Raman-based repeaters is also a key technical enabler for the convergence between terrestrial and submarine; common spectrum for dry and wet parts of the networks avoids capacity bottlenecks at the demarcation points. 30 Gbaud opto-electronics and Raman amplification technologies offer the possibility to unify terrestrial and submarine links in order to build end-to-end, PoP-to-PoP connectivity. ROADMs and OTN switches, implemented inside cable landing stations and PoPs, respectively, in addition to the associated control plane, are becoming crucial equipment to build a global network with high resiliency against multiple faults.

Maximizing Network Capacity, Reach and Value

Over land, under sea, worldwide

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