WHITE PAPER

200G and Raman Technologies for Long-Haul Data Center Interconnect

200G and Raman are key enablers to help content delivery network operators maximize fiber capacity and extend all-optical reach to minimize the need for regeneration in long-haul, high-capacity data center networks.

Need for High Capacity in Optical Backbone Networks

The insatiable demand for more bandwidth in optical backbone networks is fueled not only by increases in the number of users, the access methods and rates, but also the increased importance of data centers, cloud and the number of services (such as mobile, social media, and video in general).

One of the data widely used in the industry is the one produced in Cisco's Visual Networking Index (VNI). Annual global IP traffic is expected to surpass the zettabyte (1021 bytes or 1000 exabytes) threshold in 2016, and will reach 2.3 zettabytes by 2020. This figure corresponds to a growth of global IP traffic at a Compound Annual Growth Rate (CAGR) of 22% from 2015 to 2020, and will have increased nearly 100-fold from 2005 to 2020.

Prefix	Symbol	Power of ten	
yotta	Y	10^{24}	
zetta	Z	10^{21}	Global IP traffic (per year)
exa	E	10^{18}	
peta	P	10^{15}	
tera	T	10^{12}	Fiber rate (Tbit/s)
giga	G	10^{9}	Channel rate (Gbit/s)
mega	M	10^{6}	
kilo	k	10^{3}	

Figure 1: Capacity scale.

Globally, IP video traffic will be 82% of all consumer Internet traffic by 2020, up from 70% in 2015. Within this IP video traffic, Ultra High Definition (UHD) video traffic will grow from 2% in 2015 to 16% in 2020. By 2020, wired devices will account for 34% (down from 52% in 2015) of IP traffic, while Wi-Fi and mobile devices will account for 66% of IP traffic.

The advent of new players whose bandwidth needs are strongly increasing and add to those from traditional telecoms service providers drives not only traffic capacity but traffic pattern as well. In a traditional telecom network traffic flows from the user to the network central office and back – this is commonly referred to as north-south traffic – while most traffic in a data center network is generated by machine-to-machine traffic between data centers – termed east-west traffic. This east-west DCI traffic represents now a very predominant part of all traffic compared with the north-south traffic. The requirements of the optical backbone networks supporting east-west traffic significantly differ from those for traditional telecom operators with higher capacity per fiber, longer optical data paths and fewer sites where access to the traffic is required.

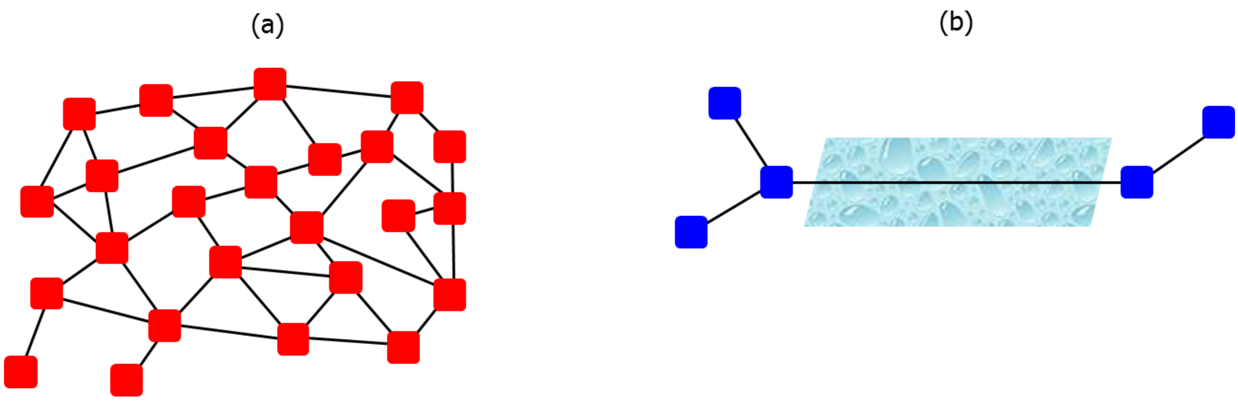

Figure 2: (a) Traditional telecom service provider network with multiple sites and meshed configuration, (b) Typical international content delivery network with fewer sites and wet segment(s).

In the recent years we have seen an evolution of optical backbone networks, with some of them clearly designed and optimized for long-haul data center interconnects. Also important to note is that some new subsea cable systems now directly terminate in inland data centers with the objective of making more easily available the huge amount of data stored in these termination points.

This need for high capacity between data centers is one of the causes for the advent of 200G carrier rate, especially when fiber resource is scarce. This is the case for Over-The-Top (OTT) players leasing only one fiber pair per terrestrial route or subsea cable system.

Metric for Long-Haul Data Center Interconnect

The traditional metric in optical transmission industry has been the cost per transported bit for the past decades. An obvious path to continuously decrease the cost per transported bit has been to increase the channel rate as history proves that the mature transponder cost provides significant savings in the cost per delivered bit. Increase in the channel rate may introduce, however, new limitations that can unfavorably impact the cost per transported bit over long distances. For instance, more stringent reach limitations can be faced when the channel rate is increased from 100G to 200G: both Optical Signal-to-Noise Ratio (OSNR) degradations and fiber nonlinearities significantly reduce (typically by a factor of four) the reach of 200G carriers in comparison with 100G performance. Long optical data path can be still achieved at 200G or higher carrier rate with conventional amplification technology but at the expense of putting in intermediate signal regeneration, which lead to higher capital and operational expenditures (see text box and Figure 3).

Regeneration Sites Drawbacks

Regeneration sites represent many drawbacks for network operators, such as: high power consumption, large space requirements and points of lower reliability. Beyond these OpEx issues, regeneration sites are also very costly when the network capacity grows because interface cards must be deployed for each new wavelength put in service (contrary to an amplification site where all of the waves present in the line share the cost of the amplifier).

Regeneration sites imply higher incremental cost and longer lead time when placing new capacity into service compared to an optically-amplified link design with no need for intermediate signal regeneration. The incremental cost for added capacity is all the higher that the data rate supported by the optical wavelengths is high. A way to minimize the lead time for activating new capacity is to pre-deploy extra hardware in the regeneration sites so that the needed optics is already in place; this requires a specific commercial model as the cost for this pre-deployed hardware must be supported by one of the parties.

For all these reasons, it is of the utmost importance to avoid or minimize the number of regeneration sites for long light paths in order to build a cost-effective optical network.

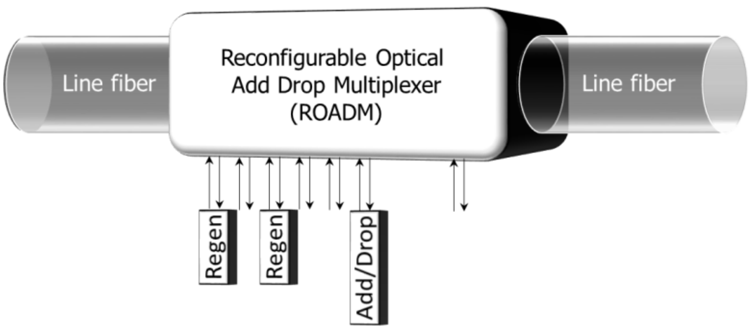

Figure 3: Typical two-degree node implementation with Reconfigurable Optical Add Drop Multiplexer (ROADM) to enable both local add/drop and off-line regeneration where needed. Limited optical reach imposes the deployment of regeneration cards on a per carrier basis at some intermediate sites.

A relevant metric that is widely accepted across the industry for ultra-long transport is the cost per transmitted bit per transport kilometer. This metric enables to better understand the actual cost of optical transport over long distances and compare more accurately different transmission technologies.

For instance, a given high-end transmission technology could look at first sight expensive over short distance but the cost per transmitted bit per transport kilometer over longer reach with no regeneration will reflect its highest cost-effectiveness for backbone applications.

Benefits from Raman for Maximizing Fiber Reach and Capacity

Optical Raman amplification offers a two-dimension benefit when compared with conventional optical Erbium-Doped Fiber Amplification (EDFA): longer all-optical, regen-free reach and wider optical spectrum.

Longer Reach

Optical transport equipment based on EDFA is not conducive to long transmission reach for 200G or higher carrier rates because of the discrete nature of EDFA amplifiers (they provide local optical gain, turning the amplifier sites into hot spots leading to fiber nonlinear impairments) and their intrinsic suboptimal noise performances (resulting in OSNR figures that can be unacceptable for proper detection of the signals).

Some "hero" terrestrial experiments with high-performance fibers (exhibiting ultra-low loss and very large effective area, i.e. not representative of the fiber plants presently buried in the ground) have been reported over ultra-long distances. However, in field conditions (with loss close to or larger than 0.25 dB/km, non-uniform span length, margins for repair, lumped losses caused by, e.g., bad connectors or imperfect fiber cut repairs, etc.), the practical reach for 200G carriers (based on 30 to 34 Gbaud optoelectronics components and PM-16QAM coherent approach) over EDFA links is limited to about 600 km.

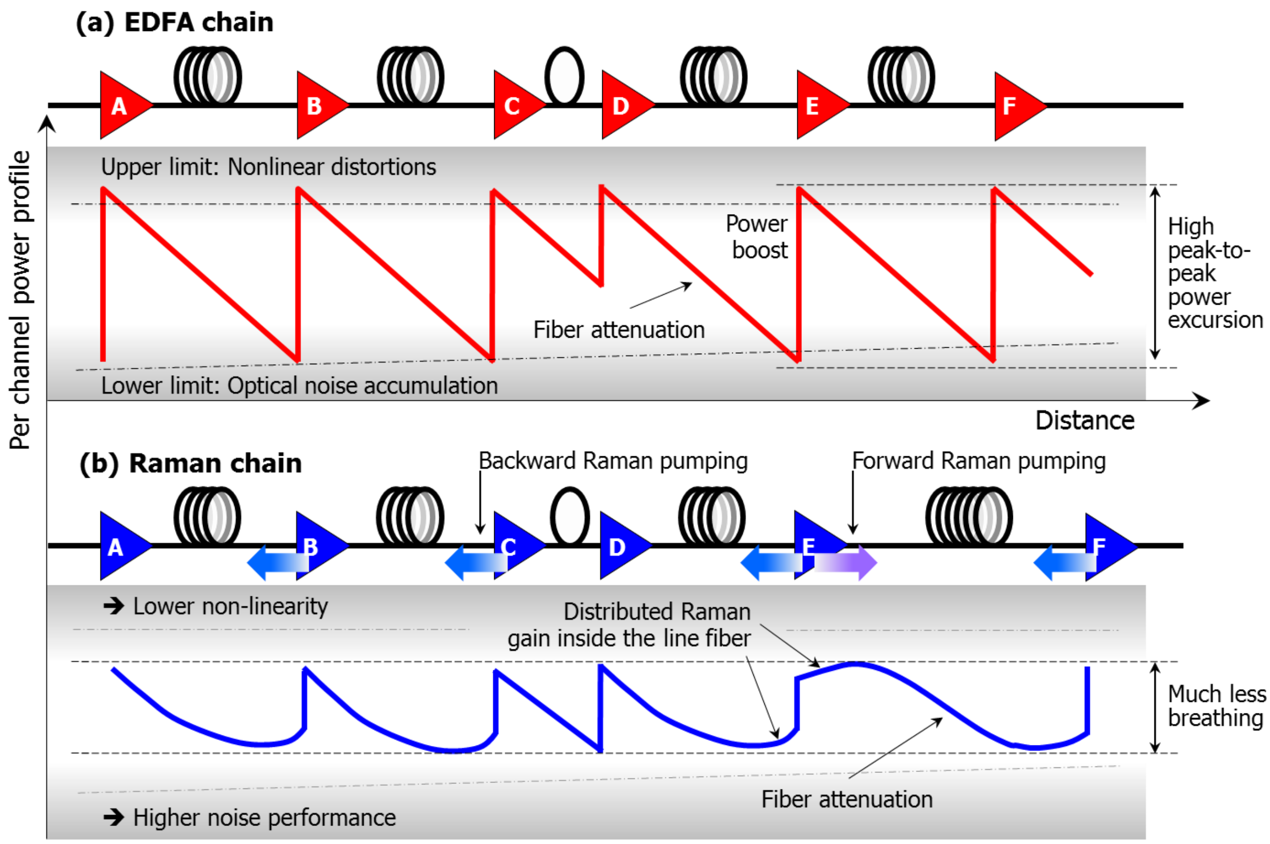

Figure 4: Typical per channel optical power profile as a function of the transmission distance in a chain of (a) traditional EDFAs and (b) optical Raman amplifiers.

With the advent of 200G and beyond channel rates, the performance benefits of Raman optical amplification are more relevant and necessary than ever to extend reach and eliminate the need for regeneration sites for long-haul optical networking. Optical Raman amplifiers offer better reach performance than EDFAs for three main reasons:

- Raman optical amplifiers create distributed optical amplification inside the line fiber, mitigating the fiber nonlinear effects experienced by the optical carriers;
- Raman amplifiers superior noise performance leads to higher OSNR figure, enabling transmission through more in-line amplification sites over longer distances;
- Relying on fundamentally different physical effects, Raman optical amplifiers enable a better and more dynamic control of the amplification gain shape and tilt when compared to EDFAs; this allows to better balance carrier power and optical noise across the spectrum all along the optical link.

Field trials conducted by Xtera on the Verizon network in 2013 demonstrated that Xtera's commercially-available Raman line equipment enables 400G transmission over more than 2,000 km on an aged high-loss fiber plant in a real network environment.

More Spectrum

Raman optical amplification is generally thought of in terms of extending all-optical reach; this is the common use of Raman by all the vendors but Xtera. As implemented by Xtera, Raman amplifiers are conducive to optical spectra significantly broader than what is achieved by EDFA amplifiers (typically 36 nm spectrum). Raman amplifiers with a 100 nm spectrum have been deployed in the field by Xtera since 2004 (and have been operated since then with zero failure). A wider optical spectrum has many benefits and implications at the system level, including:

- A broader optical bandwidth turns into a higher channel count and fiber capacity for given channel spacing and spectral efficiency;
- A higher line capacity than what is possible with EDFAs can be achieved while using larger channel spacing or lower spectral efficiency, relaxing OSNR requirements;
- A wider optical spectrum offers more flexibility in wavelength allocation in all-optical wavelength-routed networks or with respect to the characteristics of the fiber plant (like, e.g., the wavelengths at which the chromatic dispersion or the optical attenuation is minimal).

Items 1 and 2 above lead to high line capacity and large capacity overhead that can delay the need to light new fibers for several years. A 61 nm spectrum, as offered by today's Xtera's Nu-Wave Optima™ optical networking platform, enables a line capacity of 15 Tbit/s using standard 100G technology and carrier spacing (50 GHz), and up to 40 Tbit/s with current 16QAM modulation format. When the market needs it, a 100 nm spectrum can be offered again by Xtera, leading to line capacities of 24 and up to 64 Tbit/s, respectively.

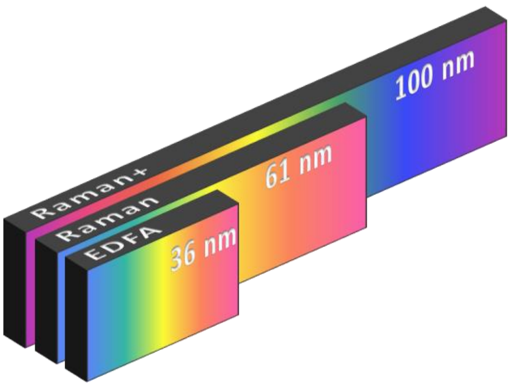

Figure 5: Optical spectra offered by EDF, Raman and Raman+ amplifiers.

Furthermore, Raman amplification can open up new transmission windows in the ultra-wide spectrum already available in optical fiber (only a fraction of this spectrum is accessed today in backbone networks). Expansion of the optical spectrum to tap into more of the optical fiber reservoir – as enabled by Raman amplification – is challenging the recent views on Space Division Multiplexing (SDM) and is an evolutionary, safe and efficient solution to meet both short- and midterm capacity needs with no need to deploy a new type of fiber and develop a new component ecosystem.

Xtera's Wise Raman™ Solution

The approach followed by most of the other vendors in their product development was first to optimize their design around EDF amplifiers with no plan for interoperating with Raman amplifiers. When pushed by the technical challenges of 100G and 100G+ carrier rates, these vendors then added a Raman box, often coming from a third party supplier. Such an approach results in a suboptimal hybrid Raman/EDFA implementation with poor levels of functional integration, two different racks or shelves to house the whole amplification subsystem, higher optical pump power requirement, non-optimum Raman amplifier controller, and/or two distinct management systems. Furthermore, competitive Raman implementations offer only limited reach extension capabilities, but do not address the spectral dimension for wider bandwidth.

From its inception, Xtera's objective was to develop a Raman-centric solution that brings together operational excellence and simplicity, as well as outstanding reach and capacity in optical transmission performances, in field conditions. Unlike competitive offerings where integrating optical Raman amplifiers with EDFAs is an afterthought, Xtera designed its optical networking platform from the ground up to combine different optical amplification flavors, ranging from simple EDFA to all-distributed Raman amplification.

Wise Raman™ is Xtera's solution for introducing Raman optical amplification seamlessly into optical networks, with a specific focus on combining high-end optical reach and capacity performances with operational excellence and simplicity in real network environments. Wise Raman™ solution is not only about the photonic and hardware design of the Raman optical amplifier module; it is also about its integration and operation in both the equipment and the network.

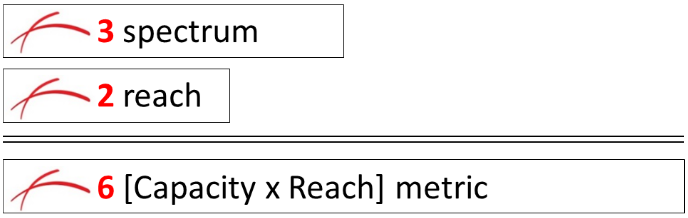

Figure 6: Spectrum and reach benefits from Wise Raman™ solution.

Today, Xtera is backed by an unrivalled 18 years of tremendous and unique R&D experience covering all the aspects of optical networks relying on Raman amplification: modeling, photonics, link engineering, network design, hardware, firmware, software, and network management. This long and thorough R&D background is combined with unparalleled operational experience in the field, built on more than 12 years of commercial deployments worldwide in diverse environments (densely populated areas, rain forest, deserts, etc.), in different applications (terrestrial and submarine transmission infrastructures) and for multiple types of customers (telecom network operators, service providers, power utilities, oil & gas, governments, etc.).

Operational Aspects of Wise Raman™ Solution

One key concern in the original design of Xtera's Wise Raman™ amplifiers was to offer a product as simple, if not simpler, to operate as EDFA-based equipment. Since its first deployments in 2004, Xtera's Raman amplifier sub-system has demonstrated flawless operation, high efficiency, excellent reliability (with zero amplifier failure since 2004) and unparalleled reach-capacity performances in the field due to the high integration of the different optical amplification technologies and development of a powerful controller.

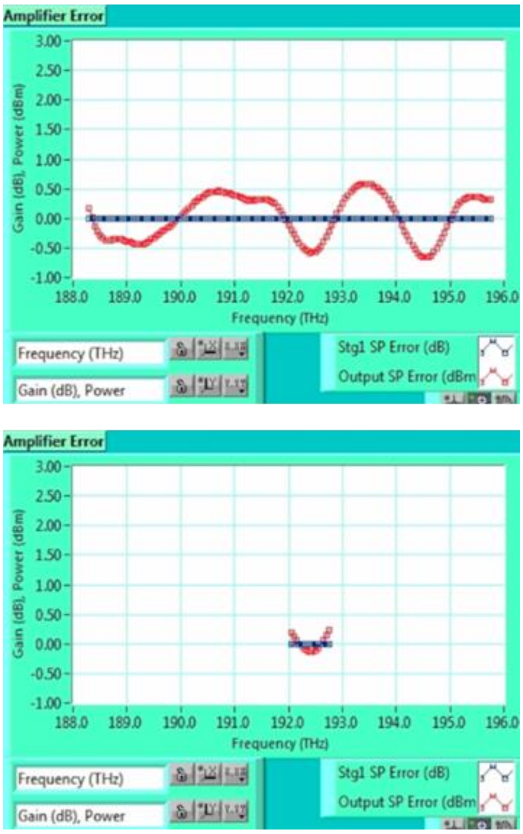

Figure 7: Wise Raman™ controller in action: gain error over 61 nm spectrum before and after 135 out of 150 channels are turned off (Vertical scale: 0.5 dB/div.).

Xtera's Wise Raman™ solution is designed to be transparent to operators in their networks and facilitate operation in the various daily tasks. With software embedded at different levels inside the product (from hardware to management system), automation and control loops are present in the equipment to facilitate its installation, turning up, testing, commissioning and operation. This includes optimization of span and link performances, Automatic Laser Shutdown (ALS) and power restart, addition of new channels, and more. In service in the field for over 12 years, the robust control algorithm works continuously to adjust optical amplifiers setting points and optimize performance for changing line conditions, including slowly increasing fiber attenuation or transients like sudden cable cuts. Deployments in more than 40 countries and in a variety of environments (including Brazil, Mexico and Togo) illustrate the maturity and transparent introduction of Xtera's Wise Raman™ solution into existing networks.

Lessons from 2013 Fields Trials (Still Valid Today!)

In 2013 Xtera conducted 100G (PM-QPSK) and 200G (PM-16QAM) field trials over the Verizon network fiber which was deployed around Dallas, TX, USA more than 13 years ago. All-distributed Raman amplifiers achieved optical gain inside the line fiber with 61 nm optical spectrum. For the purpose of these field trials, a 79.2 km cable loop, made of 432 fibers, was used. 19 of the 432 fibers were connected to Xtera's Nu-Wave Optima™ optical networking platform, with span loss ranging from 20 to 23 dB (0.28 dB/km average fiber attenuation); these 19 fiber spans resulted in a 1,504 km link and a string of 114 optical connectors along the optical path. The existing standard connectors (SC/PC) at Optical Distribution Frame (ODF) levels were left untouched. The G.652 fibers exhibited multiple splice points as a result of construction activities in the Dallas metropolitan area.

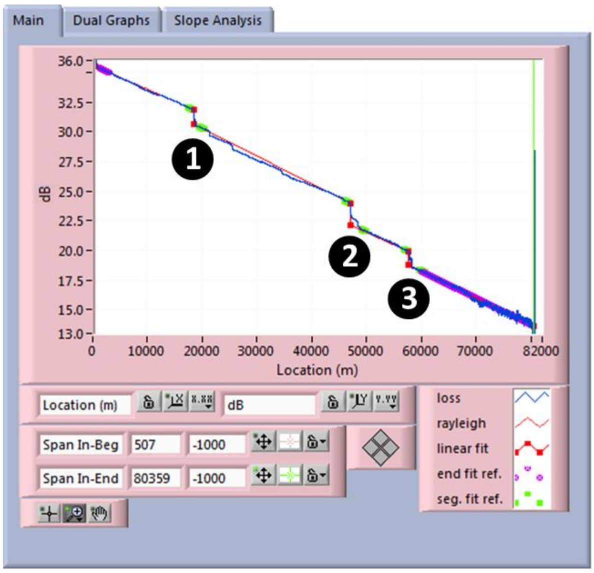

Figure 8: Optical Time Domain Reflectometer (OTDR) trace of span #11 showing three lumped losses, ranging from 1.1 to 1.9 dB, along the optical path.

Figure 8 represents the Optical Time Domain Reflectometer (OTDR) trace of span #11, showing three lumped loss of 1.3, 1.9 and 1.1 dB (all of them resulting from bad splices). These lumped losses are located at 17.9, 46.5 and 57.2 km along the spans; the first and third lumped losses are located where forward and backward Raman effects, respectively, are significant inside the line fiber. Given the high margin observed after 1,500 km transmission, this field trial demonstrates that 100G carriers can be transported over more than 4,500 km with no intermediate regeneration over aged fiber plant. With 200G carrier rate, the all-optical transmission distance is larger than 2,000 km.

Wise Raman™ maximizes the reach of any modulation format over any fiber type and vintage, while expanding usable fiber spectrum.

The main lesson from these field trials conducted in 2013 is that Raman amplification enables the transport of 200G carriers (with PM-16QAM modulation) and 400G channels (made of two 200G carriers) over more than 2,000 km in real field environment over an aged fiber plant exhibiting high fiber attenuation, multiple optical connectors and lumped losses along the spans.

Example Applications

Pan-European Data Center Network

In January 2016, Cinia, a Finland-based designer, builder and operator of intelligent connectivity and ICT solutions, announced the selection of Xtera for equipping a pan-European network to connect data centers across Europe.

This long-distance network involves advanced technologies like 200G optical channel rate and Raman optical amplification for ultra-high link capacity.

The same optical networking platform is used over terrestrial and subsea portions of this pan-European network, enabling a unified, seamless network from an operational perspective. Xtera helps Cinia develop an efficient optical backbone network and offer cutting edge connectivity services to provide big data, corporate customers and operators with a fast, reliable and high-quality network all over Europe.

Figure 9: Global view of Cinia's network (www.http://cinia.fi/en).

Xtera's Nu-Wave Optima™ optical networking platform offers Cinia a single solution for terrestrial and subsea applications throughout its pan-European network, turning into operational cost savings on spare units, training and management systems.

Xtera's patent-protected Wise Raman™ optical amplification technology maximizes both fiber capacity and all-optical reach, while Xtera's flex-rate interface card, using the latest coherent optical technology to deliver 100G, 200G, 300G or 400G channels, helps Cinia seamlessly face unplanned capacity demands with minimal time to market and without additional investment.

Backhaul Networks in Wide-Scale Subsea Cable Networks

In February 2016, the Consortium behind the Asia-Africa-Europe 1 (AAE-1) submarine cable system project announced the signature of a supply contract with Xtera for equipping the three terrestrial segments in the AAE-1 Network. AAE-1 submarine cable system is one of the largest consortium cable projects under way, extending some 25,000 km and connecting Asia, the Middle East, East Africa and Europe. Xtera equipped the AAE-1 terrestrial segments in Egypt, Thailand, Malaysia and Singapore with its Wise Raman™ optical amplification and flex-rate channel card technologies, enabling 200G channels over ultra-long distances.

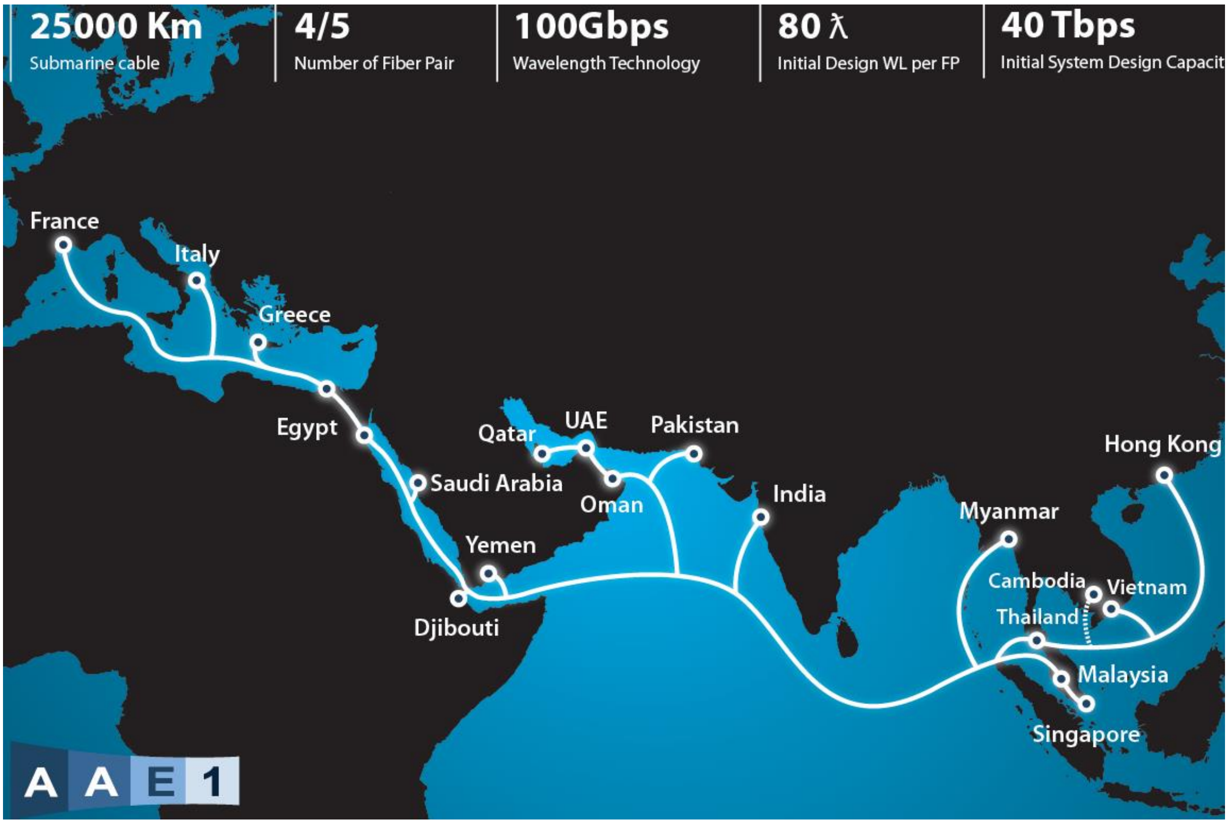

Figure 10: Global view of AAE-1's network, including three diverse terrestrial routes in Egypt, Thailand and Malaysia.

The Malaysia–Singapore terrestrial segments (about 1,000 km long) directly terminate in two separate data centers in Singapore.

For this project, Xtera offered a future-proof solution based on its advanced Nu-Wave Optima™ optical networking platform combining 200G coherent technology, Wise Raman™ optical amplification solution, and fast protection switching.

Each terrestrial segment is made of two physically diverse routes supporting minimum 18 Tbit/s cross-sectional capacity per fiber pair. Xtera's flex-rate channel card features integrated service protection, offering fast 50 ms protection switching and enabling 99.999% service availability.

Raman Can Do More and Better!

Raman amplification benefits (excellent OSNR performance, unrivaled optical spectrum, lower fiber nonlinearities and dynamic behavior to respond to changes in the fiber plant or traffic pattern) have been demonstrated in terrestrial networks since 2004. More recently, Xtera launched in 2013 the first Raman-based subsea repeaters for submarine cable networks with exactly the same benefits as their terrestrial counterparts. Now data center to data center networks over terrestrial and submarine legs can be designed and deployed with a common set of technologies with neither spectral bottleneck, nor demarcation at the beach manhole level.

With traditional EDFA amplification technology, extreme distance requirements demand a more robust, and hence lower-rate, modulation format in order to minimize the degradation brought by fiber propagation. Ultra-long-haul applications have driven the development of, e.g., the 50G PM-BPSK modulation format. Raman-based optical networking platform enables, however, the transport of 100G carriers over most of ultra-long distance applications, maximizing the fiber capacity and the network asset value.

Moving from ultra-long-haul to ultra-high-capacity applications, high-capacity networks require 200G or higher carrier rate. With traditional EDFA amplification technology, 200G carriers can be transported over long distance but at the expense of intermediate regeneration sites that increase the cost per transported bit per km as previously discussed. Raman amplification technology enables cost-effective long-haul 200G transport in real network environment, even on aged fiber plants. The same reach benefit applies to higher carrier rates.

Summary

Long-haul data center to data center networks require high capacity per fiber and shall make use of 200G or higher carrier rate. Compared with 100G carrier transport, 200G transmission experiences stronger limitation in reach, which can impose intermediate regeneration sites while this type of networks are generally pure point-to-point links with no need to access the traffic at intermediate site. Regeneration sites negatively impact CapEx on Day One, OpEx during network lifetime, and both incremental cost and time to market when new capacity is needed.

As demonstrated by Xtera with seamless integration into existing networks in the past decade, issues commonly blamed on Raman technology (like performance sensitivity on non-ideal fiber plants or issues with ALS mechanisms in case of fiber cuts) are the results of poor implementation by other vendors, not of the technology itself. Xtera achieved the challenge of making Raman amplification a new high-performance network technology over existing fiber assets without imposing new constraints or practices to operations teams.

Xtera's optical networking solutions for long-haul Data Center Interconnect (DCI) applications enable ultra-high capacity per fiber pair, long regen-free reach, and operational simplicity offered by common management system, sparing and training throughout the network, even in the presence of water stretch along the optical data path. Xtera's disruptive Raman-based 200G/400G technology help service providers and operators of Content Delivery Networks (CDNs) face the inflection point where the optical communications industry needs both the fiber capacity and reach that Xtera can provide. Also offered by Xtera is a high level of flexibility at the equipment level so that service providers can seamlessly face unplanned capacity demands with minimal time to market and additional investment.

Maximizing Network Capacity, Reach and Value

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About Xtera Communications, Inc.

Xtera Communications, Inc. (NASDAQ: XCOM) is a leading provider of high-capacity, cost-effective optical transport solutions, supporting the high growth in global demand for bandwidth. Xtera sells solutions to telecommunications service providers, content service providers, enterprises and government entities worldwide. Xtera's proprietary Wise Raman™ optical amplification technology leads to capacity and reach performance advantages over competitive products. Xtera's solutions enable cost-effective capacity to meet customers' bandwidth requirements of today and to support their increasing bandwidth demand fueled by the development of data centers and related cloud-based services.

For more information, visit www.xtera.com, contact info@xtera.com or connect via LinkedIn, Twitter, Facebook and YouTube.

Edition Date: August 2016
Version: 1.0