SUPPORT OF HIGHER BAUD RATE AND LINE RATE OVER A LEGACY SUBMARINE CABLE SYSTEM: A CASE STUDY

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Abstract: Globenet's 23,000+ km submarine cable system extends from Tuckerton, NJ and Boca Raton, FL, in the US to Rio de Janeiro, Brazil, in a route diverse architecture, with other landing points in Bermuda, Colombia, and Venezuela. In the first half of 2018, the network underwent its largest upgrade since its initial deployment. Originally designed to support a capacity of 32x10G, all compensation managed segments (6 out of 7 segments of the cable system) have experienced at least a 20-fold increase in available carrying capacity. This drastic increase stems from the use of the latest transponder technologies and improvements in line system design. In particular, variable-baud transponders which can be adjusted based on network conditions allow 200G waves to be supported on some of the segments. Should the need arise, the performance of these latest generation transponders also allows the optical cascade of consecutive segments where regeneration is used today. This paper presents experimental data captured during the upgrade of this legacy cable network with high baud coherent test probes. Using this data, the propagation of higher baud and higher line rate carriers was simulated and extrapolated to demonstrate the compatibility of a legacy cable with next generation modem technology.

1. NETWORK DESCRIPTION AND OUTCOME

Globenet's network, depicted in Figure 1, consists in 7 segments arranged in a double ring architecture for high resiliency. The length of each segment and the landing sites are summarized in Table 1. Segment 5 was replaced in 2012 and a branch off segment 2 to Colombia was added in 2013. All segments (except S5 and the S2 branch) are dispersion managed and are equipped of four (4) fiber pairs (FP). The newer S5 and S2 branch are uncompensated and equipped with 2 fiber pairs.
Though architected as a double ring, the network can be looked at as two (2), low-latency, express routes between Brazil and the Unites States, with the interlink S1 closing the top ring.

Protected terrestrial routes extend the subsea network to PoPs in New York City (from Tuckerton), Miami (from Boca Raton), Bogota (from Barranquilla), Caracas (from Maiquetia), and Sao Paulo (from Rio de Janeiro).

The system was originally design for a capacity of 32 x 10G per FP across an optical bandwidth close to 2THz but carries today multiple terabits of capacity thanks to several upgrades along the years.
With each upgrade, advances in optical transmission (channel spacing, Chromatic Dispersion and Polarization Mode Dispersion compensation) and particularly in modem technology (modulation format, line rate, FEC, coherent detection (CD), digital signal processing (DSP)…) have pushed back the system design limit, allowed more capacity to be supported and thus extended

back the system design limit, allowed more capacity to be supported and thus extended the life of the system.

Figure 1: Globenet's System Topology

Segment	CLS	Length (km)
S1	Tuckerton, NJ Boca Raton, FL	1,820
S2	Boca Raton, FL Maiquetia, VEN	2,870
S2 branch	*BU* Barranquilla, COL	900
S3	Maiquetia, VEN Fortaleza, BRA	4,300
S4	St David's, BMU Fortaleza, BRA	5,300
S5	Tuckerton, NJ St David's, BMU	1,350
S6	Fortaleza, BRA Rio de Janeiro, BRA	3,400
S10	Fortaleza, BRA Rio de Janeiro, BRA	3,700

Table 1: Globenet's System

In the case of the Globenet's system, successive upgrades have seen the line rate / modulation format evolved from 10G On-Off Keying (OOK) Direct Detection (DD), to 20G Differential Phase Shift Keying (DPSK) DD, to 40G DPSK DD, to 100G PM-QPSK CD [1], to 150G PM-8QAM, and to 200G PM-16QAM in last year's upgrade. All the while spacing between wavelengths kept decreasing from 100GHz to 50GHz to 37.5GHz.

Last year's system upgrade not only drastically increased the cable system capacity by more than an order of magnitude as compared to the initial design capacity, but also helped improve its resiliency by the addition of OTN cross-connects at strategic points in the network to rapidly protect critical services (and thus enhance the quality of service).

As the traffic demand continues to increase, the cable system will need to support more capacity. The retirement and replacement of older modem generations with current modem technology will help but it is expected that new flexible, smart (software selectable) modems will further optimize the cable system capacity.

2. THE TECHNICAL CHALLENGES ASSOCIATED WITH THE UPGRADE OF COMPENSATED SUBMARINE CABLE SYSTEMS

Compensated submarine systems were engineered before modern coherent modems became available. These systems were optimized for the transmission of carriers supporting Intensity Modulation (IM) and information was extracted from these carriers using Direct Detection (DD). From an optical transmission perspective, engineering of these systems consisted in the development of the most cost-effective solution that would meet the following targets:

- Get the carrier with enough power to the other end

- Maintain the level of Amplified Spontaneous Emission (ASE) noise bellow a required level
- Get the pulses within their time slot before they reach the receiver

Before the introduction of electronic compensation, getting properly shaped pulses to the receivers meant that Chromatic Dispersion (CD) compensation had to be built within the propagation medium. This was achieved by mixing different types of propagation fibers in the right proportion. Higher launched powers are also typical on these legacy line systems. Because it carries information on power, intensity modulation is inherently more immune to phase distortions caused by Self-Phase Modulation (SPM) and cross Phase Modulation (XMP). This allows for the use of higher optimal launched powers to minimize the number of repeaters while maintaining Optical Signal to Noise Ratio (OSNR) above an acceptable level. Receivers using direct detection to extract information from an intensity modulated carrier are also less susceptible to polarization variations on the incoming carrier.

Compensated submarine systems do not offer ideal propagation conditions for polarization multiplexed coherent modulations. The main challenges come from fiber-based CD compensation and excess optical power management. Having CD compensation built in the propagation medium creates increased interaction between co-propagating carriers mainly caused by XPM. The fast carrier in one type of fiber becomes the slow carrier in the compensating fiber which leads into repetitive overtaking over the length of the system causing strong interaction patterns. Also, to prevent coherent modulated carriers to suffer from excessive phase distortion penalties, launched powers need to be set lower than what they would typically be for intensity modulated carriers. As the total repeater output power is constant, lower launched power for coherent channels results in excess power that needs to be consumed appropriately.

Although not optimized for coherent transmission, compensated cable can still provide adequate transmission characteristics for coherent modems if the proper solutions are put in place. These solutions involved both modems and terminal equipment as discussed in the following sections.

3. COHERENT TRANSPONDER TECHNOLOGY DEVELOPMENT

Digital Signal Processing (DSP) techniques applied to optical modulation became commercially available for the first time around 2005 [2][3]. The main focus at the time was to provide an alternate and more flexible solution to compensate for optical fiber chromatic dispersion affecting 10Gbit/s IM-DD transmission. Although this first breakthrough was intended essentially for terrestrial applications, it established the foundation for all the progress that was made in the last decade in the field of coherent modem technology.

The use of DSP to implement a dual polarization 40Gbit/s QPSK receiver in 2007 lead to the first “coherent invasion” of both terrestrial and submarine transmission networks [4]. This first generation of modern coherent modems brought DSP-based polarization tracking and maximum likelihood receiver providing OSNR sensitivity matching those of 10G receivers with four times the transmission rate.

Since the introduction of the first generation of modern coherent modems, significant improvements have been incorporated along various development axis. First, following the progress made on CMOS technology, ASICs supporting higher transmission rate have been introduced: 35GBd in 2012 [5], 56GBd in 2017 [6]. These higher baud modems provide better power distribution, increased performance, reduced power consumption and more cost-effective solutions. Significant progress has also been made in Forward Error Correction (FEC) with the introduction of SoftFEC in 2012 [5] as well as improved noise linearization (shown in Figure 2).

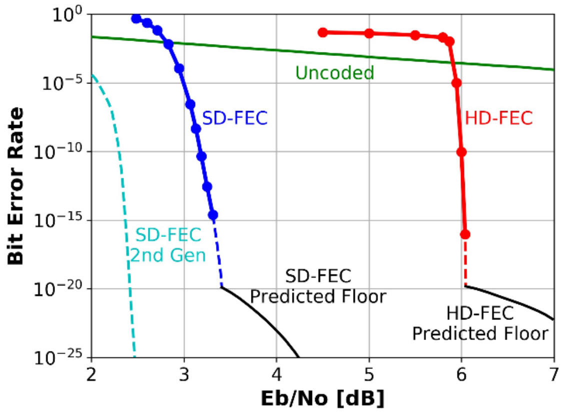

Figure 2: FEC Improvements

The Chromatic Dispersion pre-compensation function has been present since the introduction of the second-generation coherent modems. This function allows users to adjust the ratio of pre- vs post-compensation to minimize nonlinear penalties and increase optimal launched powers. It is one of the key functionalities that allows for the successful implementation of coherent modems over legacy systems. Multi-dimensional encoding has also been introduced to reduce cross polarization effect [7] and to improve performance.

In parallel with the increase in baud rate, modulations using an increased number of constellation points have been implemented to support higher bit rate services. Currently, bit rates ranging from 50Gbit/s to 400Gbit/s with 50Gbit/s increments are supported. The implementation of probabilistic constellation shaping on more complex constellations will provide higher resolution on information transfer rate [8].

At this point in time, the development of coherent modems implementing symbol rates of 70GBd and higher provides a dramatic increase in the amount of information that can be transmitted on a single carrier. Given the signal spectral width at these higher symbol rates, digital FDM can be used to create subchannels for improved nonlinear tolerance [7].

4. TERMINAL PHOTONIC IMPROVMENTS

Over the years, photonic technologies from the terrestrial application have been carried over to Submarine Line Terminating Equipment (SLTE) to enable functions useful to maximize the benefit of modern coherent modems over legacy cables.

The introduction of Wavelength Selective Switches (WSS) in early 2010 as the central point of control of all the sources of light present at the terminal input provided accurate per channel control for ASE channel holders, power management idlers as well as for traffic carrying channels. This resulted in an improved control over a transmitted spectrum profile. It also allowed for a transmitted spectrum profile to be re-optimized following any change in the wet plant transfer function. Since 2015, flexible grid variants of the WSS have allowed users to take full advantage of the digital signal filtering capabilities of the coherent modems. Tighter spacing of 35GBd coherent channels represented a gain of about 25 % in the total system capacity over fixed grid systems. In many cases, this tighter channel spacing also helped with excess power management. Flexible grid WSS also allows for the introduction of new spectrum sharing services.

Unmodulated, low linewidth idlers are the key elements for excess power management. Optical signals that are benign neighbors for coherent channels that can be launched at high power allow efficient use of spectrum to maximize the number of traffic carrying channels.

Building over the spectrum profile controller provided by the WSS, photonic line controllers have been developed to automate capacity change operations. In turn, the development of a Photonic control plane has allowed the orchestration of the underlying photonic line controllers so that channel addition, channel deletion or automatic restoration can take place over multiple submarine and terrestrial segments in a seamless, automated manner.

5. SIMULATION RESULTS

Figure 3 provides the maximum capacity that can be achieved comparing three generations of coherent modems on two segments of the GlobeNet network: one operating at 35GBd, another at 56GBd, and an advanced technology prototype solution operating at 95GBd.

The performance achieved with currently deployed 35GBd modems was measured and used to align the simulation models.

A future 95GBd solution is expected to provide a total capacity increase between 20% and 32% from the existing 35GBd solution.

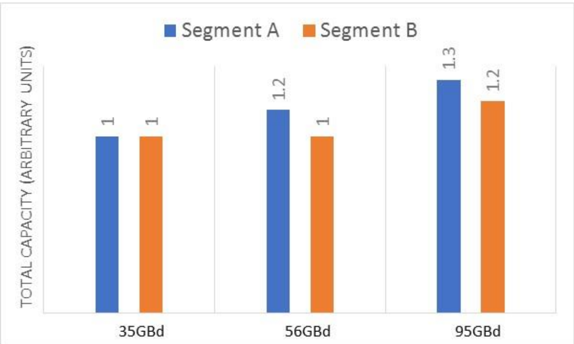

Figure 3: Capacity per FP on two segments as function of modem technology

The introduction of this 95GBd solution would increase the capacity, on Segment B for instance, almost 20 folds compared to the initial design system capacity, in the span of almost 20 years. That's a doubling of the design capacity every (less than) 5 years.

The use of the latest modem technology would also allow optical transmission over concatenated segments (without regeneration between the 2 segments), which was not possible with older generation modems. Removal of the regeneration point not only reduces the latency of the route but also improves the reliability of the system.

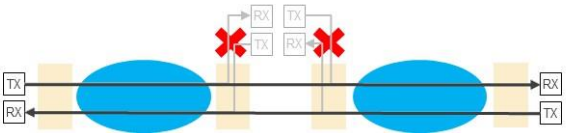

Figure 4: Concatenated segments

6. CONCLUSION

This paper showed the compatibility of legacy submarine cable systems with next generation modem technology and that Globenet's system can transport significantly more capacity than originally designed for with the proper use of coherent technology.

Also, the use of coherent technology, combined with recent advances in terminal architecture, can bring significant operational values and support for new types of services thus allowing to increase and diversify the service offering [9].

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