Application of Photonic Integrated Circuit based DWDM transmission equipment on legacy Repeatered Submarine Cable Systems

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Abstract: This paper details a feasibility and capacity trial showing the performance of Infinera Photonic Integrated Circuit based DWDM equipment on a Legacy 3100km submarine segment, and the subsequent upgrades on eleven repeatered submarine cable segments. It explains the differences between the traditional submarine cable systems approach to adding capacity and the approach using the Infinera Photonic Integrated Circuit equipment design. The paper shows and compares the Q performances achieved over various distances and the impact of changing the gains of the submerged amplifiers, giving some insight into the variation of performance due to non-linear and other line effects. Full band Fibre Bragg Grating dispersion units compensate the tilted dispersion profile of subsea links for all wavelengths. This compares with the legacy use of groups of standard dispersion compensation modules, each group compensating a band of wavelengths. The line connectivity, using a mix of existing, legacy, and new Infinera equipment is explained. This allows in-service supervisory control of the submerged amplifiers while the Infinera equipment is operating.

1. Introduction

With continued advances in technology there have been significant changes in the sub-sea upgrade market over the last few years, especially with the application of mass produced ‘terrestrial’ equipment on sub-sea systems. For certain applications, this has resulted in more choice and better value for system operators. The following paper outlines one example of such an application using the Infinera WDM product that was originally designed for the terrestrial market.

2. Capacity Trial

In order to verify that the equipment was suitable for use on submarine networks, a field trial was performed over a 3100km Global Crossing submarine segment. The trial equipment was placed in both Cable Stations and turned up as a point to point link. The main objectives of the field trial were to:

i) Validate the equipment ability to transmit >3000km over legacy submarine networks.
ii) Verify the ultimate capacity of this segment, using this equipment.
iii) Validate the full band dispersion compensation solution.
iv) Understand the opportunities for using this equipment on other Global Crossing networks.

The segment was chosen because of its age and length – the 3100km length was representative of the other ten segments that had been identified for upgrade in 2009. Additionally, the looped system (6200km) represented a transatlantic distance where future upgrades were being considered. It has been seen that most of the key considerations that need to be taken in to account when upgrading a cable system, such as the amplifier bandwidth, and fibre types, vary significantly.
depending upon the year the system was manufactured. Consequently, the age of the system (1999/2000) was also important. This is similar to the other segments considered for upgrade.

As can be seen in Figure 1, the trial equipment was connected to existing Post and Pre line Amplifiers, and loaded with 62 waves.

Figure 1: Transmit Configuration

![Figure 1: Transmit Configuration](image)

The transmit and receive spectra as well as the receive Q values are shown in Figure 2.

Figure 2: Transmit and Receive spectra and Q (3100km)

![Figure 2: Transmit and Receive spectra and Q (3100km)](image)

When the equipment was turned up the receive Q values were in excess of 12.5, with very little optimisation, immediately indicating that the system could support traffic with this loading. Note that when the system is loaded with 62 waves the Q values are only measured for every alternate wave (the 31 even channels), hence only 31 readings are shown on the graphs. The test was then repeated with the system looped to give a 6200km segment. Figure 3 shows the Q performance when the system is loaded with 62 waves and with 31 waves.

Figure 3: Q Values with segment looped (6200km)

![Figure 3: Q Values with segment looped (6200km)](image)

As time was limited and as the line characteristics were not known in advance, these measurements were taken without optimal dispersion values or line tilt applied. However, the equipment still managed to give stable Q values above 9.5dB with 62 waves loaded, over 6200km. It is believed, that with more time and an optimal dispersion FBG these values could be improved further. This indicates that the equipment could be applied and operated over transatlantic distances, assuming the submerged plant is of similar vintage, with similar line characteristics and limitations.

The power of the odd channels was then reduced to see the effect on the performance of the even channels, that were being measured. Since the total power of the line system is constant, this reduction in power of the odd channels had the effect of raising the powers of the even channels. Figure 4 shows how the Q performance changes as the power delta increases (i.e. increase in even channel power). Each line on the graph represents the Q performance of a separate wave, as the channel power increases.

Figure 4: Q Variation with Transmit Power (6200km)

![Figure 4: Q Variation with Transmit Power (6200km)](image)

It can be seen that for most channels the Q improves as the channel power increases.
The exception is the first few red end (higher wavelength) channels that start to dip when the power delta reaches 3dB. This gives a good indication that non-linear effects are limiting the performance of the few red channels, whereas the other channels appear to be noise limited.

3. Technology approach

The technology approach adopted here varied from the traditional methods in three main ways:

i) Photonic Integrated Circuits (PIC)

The Infinera equipment has ten lasers incorporated into a single integrated circuit, each operating at 10Gb/s. For this application two of the ten lasers are filtered out as they fall outside of the repeater pass band, leaving eight lasers per PIC. Figure 5 shows the output from a single PIC unit with a channel spacing of 200GHz.

Figure 5: Single PIC output spectrum

ii) Spread spectrum rather than band loading.

This approach means that the waves are added to the line in fixed groups of eight, spread across the full repeater pass band. Traditional vendors usually add waves in frequency bands, with waves grouped together in the same part of the spectrum in bands of around 3nm. The necessity to load the waves using a single unit, in this spread spectrum fashion, limits the line optimisation that can be carried out as it is difficult to adjust transmit powers on a per wave basis. Consequently the traditional pre-emphasis optimisation can not be carried out but instead the tilt across the band of wavelength is adjusted. With the distributed loading of the spectrum the wave powers are more evenly spread than with the traditional, narrow band, equipped system where loading in only a portion of the band can cause an imbalance in the power spread across the spectrum.

iii) Fibre Bragg Grating (FBG) Dispersion management

Sub-sea cable systems typically contain concatenated segments of positive and negative dispersion fibre which are not exactly slope matched. Therefore, at the end of a long link, there is a net dispersion slope over the band, with the centre of the band typically designed to have zero dispersion. The dispersion solution adopted by Infinera is to use a Fibre Bragg Grating unit to compensate dispersion across the full band. This requires prior knowledge of the line dispersion characteristics so the correct dispersion unit can be built. As an example, Figure 6 shows typical FBG dispersion vs. wavelength characteristics.

Figure 6: FBG Dispersion vs. Wavelength

The FBG used during the trial was not optimum for the line but the effects on performance of its distribution between the transmit and receive ends of the segment were simulated. Using a single FBG, the dispersion can either be pre-compensated or post-compensated by placing it at the transmit or receive ends respectively. Symmetric compensation is achieved by using two FBG’s, one at either end. The simulated performance for three different wavelengths is shown in Figure 7.

Figure 7: Simulated Q vs. Channel Power for different FBG locations
As can be seen from these graphs, the optimum performance is obtained by splitting the dispersion between each end of the segment. Note that the trial used pre-compensation, which shows the red channels having larger nonlinear penalty, which supports the data seen in figure 4. Consequently we would expect to see the Q values measured during the trial improve slightly with optimised dispersion. For the roll out over the sub-sea segments the dispersion characteristics were measured in advance and appropriate FBGs installed.


On successful completion of the trial the decision was taken to roll out this equipment on the eleven repeatered sub-sea segments identified for upgrade. Most of these segments were equipped with repeaters that had active supervisory and gain control. In order to determine the optimum repeater settings, the performance of the waves across the spectrum was monitored while the repeater gain was adjusted over its four gain levels. This allowed some determination of the effects of amplification and line loading on line performance and facilitated the decision on which repeater setting should be used in future upgrades. The following graphs show the performance of different combinations of line loading with 16, 24 and 32 wavelengths.

It can be seen from these results that, within the limitation of these load scenarios, with more waves on the submerged line the higher repeater gain became more suitable and conversely, with fewer waves on the line the lower repeater gain was more suitable. This allowed a better understanding of the wave loading verses repeater setting relationship for each segment. The two main points of interest being:

i) Understanding when (at what wavelength loading) to next adjust the repeater gain, in order to maintain the optimum Q across all waves.
ii) Understanding when/if we can reach a point where we simply adjust the repeaters to their maximum value, while still maintaining an acceptable, albeit perhaps not optimum, line performance.

What is noticeable is how much the performance degrades if the wrong repeater setting is chosen. In particular, how the performance degrades at the red end of the spectrum (higher wavelength end) with a higher amplifier power setting and how much worse the performance is across the whole spectrum with a low wave loading and high power setting. This is what would be expected as the nonlinear effects increase at the higher powers and limit the performance. These concepts are well known in general terms but the benefits here are that as an operator we have specific data for each individual cable segment. This allows us to make decisions on which repeater settings to use as we progress through the upgrade cycle, for each segment. This in turn minimises the outage times and impact on customer traffic as we upgrade.

5. Maintaining in-service Repeater Supervisory

In an upgrade path where the new supplier does not have active repeater supervisory functionality on their SLTE, it is advantageous to maintain the existing repeater supervisory functionality for as long as possible. In a normal overlay upgrade this may be done by keeping a single band of the legacy equipment coupled on the line for that purpose. However, due to the broadband nature of the Infinera solution this is not possible and the repeater supervisory is maintained by leaving two waves equipped on the legacy equipment for this purpose. The terminal configuration is as shown in Figure 11.

Figure 11: In service Repeater supervisory

These supervisory waves are interleaved with the new capacity and the optical spectrum, with sixteen transmission waves equipped and two legacy waves for repeater supervisory are shown in figure 12.

Figure 12: Spectrum with Supervisory waves

6. Conclusion

The capacity trial successfully demonstrated that the 10Gb/s PIC transmission equipment could be applied to suitable legacy submarine cable systems of up to 6200km and that operational capacity could be applied across the full transmission band, with a 25 GHz channel spacing. This enabled the decision to purchase the equipment for installation on eleven repeatered submarine segments.

It was shown that the FBG dispersion solution was effective and that a balanced distribution of Post and Pre compensation gave optimum line performance, facilitating the equipment design.
Following the trial in April 2009 the equipment was successfully manufactured, shipped, installed and commissioned on the original eleven submarine segments identified for an upgrade. During the commissioning of the equipment a good understanding of the limitations of the legacy submerged plant was achieved and the repeaters were set and optimised for the initial wave loading. By experimentation, suitable repeater settings were identified for future upgrade scenarios.

The last of the eleven segments was completed and operational in October 2009.