THE EVOLUTION OF A LONG HAUL SUBMARINE SYSTEM

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Abstract: The leading technology at the time of the last transatlantic cable deployments allowed for up to 80 x 10 Gbit/s channels per fibre pair. Through a transition to Differential Phase Shift Keying (DPSK) technology combined with a reduction in channel spacing from 50GHz down to 33 GHz or 25 GHz, the number of 10Gb/s wavelengths that could be carried per fibre pair has increased. That has been followed by the development of coherent Dense Wavelength Division Multiplexing (DWDM) technology allowing the delivery of greater line speeds. 40Gb/s and100Gb/s services can now be supported on systems designed to carry only 10Gb/s waves.

This paper looks at the road to 100Gb/s technology for the in situ long haul submarine systems showing the capacity improvements achieved since original system design together with how long haul systems can be upgraded efficiently in the future to achieve their maximum potential.

1 INTRODUCTION

It is 10 years since the last transatlantic system went into service. Despite strong capacity growth over the past decade the existing cable systems are still less than 20% utilised. This staggering figure is due to the technological jump from 10Gb/s to 100Gb/s DWDM delivering growth of potential capacity which outpaces demand.

Improvements in DWDM technology alone can greatly increase a system's design capacity, however a limiting factor will be the submerged plant, in particular fibre type and repeaters.Fibre type and repeater bandwidth of the existing long haul systems are not optimised for today's leading DWDM design. However, older systems can still benefit greatly from the adoption of current technology, both dramatically increasing ultimate capacity per fibre pair and allowing the delivery of new services enabling systems to keep pace with market demands.

2 COMMERCIAL DRIVERS FOR EXTENDING THE DESIGN CAPACITY

In an environment such as the Atlantic, where capacity has for some time been priced based upon terminal equipment costs only, the ability to increase the capacity available purely through terminal equipment upgrades has the potential to delay the need for further submarine build.Taking into account the high cost of laying the new submarine cable, driven predominantly by the high cost of submerged plant and marine installation, the ability to further increase the design capacity through the higher channel rate technology is important.

According to Telegeographydata the share of lit capacity in the Atlantic in 2009 was 25%. This percentage has decreased to 15% in 2012 [1], reducing the requirement for a new build system based on capacity demand even further. Telegeographyalso predicts that the demand growth will slow down, but still remain strong at 30%.

In the paper at SubOptic 2010 we asked thequestion: what are the drivers for 40Gb/s and 100Gb/s technology on the long haul submarine systems [2]? The conclusion reached 3 years ago still remains valid: it is the cost per 10Gb/s or 10Gb/s equivalent that will drive the adoption of 100Gb/s rather than the technical conformation with customer's terrestrial network standards. Furthermore, given that only 15% of capacity in the Atlantic is lit and there is plenty of bandwidthremaining,it is not surprising that the cost per 10Gb/s equivalent remains the main driver.

When first adopting 100Gb/s technology,questions will be asked about the reliability of the network as higher bit rates are transmitted over a single wavelength.

3 DEVELOPMENTS IN DWDM TECHNOLOGY – 100G SOLUTION

Improvement on WDM technology offers the capability to transport 100Gb/s over single channel or through super channel for longest reach in efficient spectral spacing. Spectral efficiency, which represents bit rate transport in a given spectral slot, is a relevant indicator to measure system capacity. Spectral efficiency has been increasing significantly with 40Gb/s /100Gb/s solutions as depicted in Table **1.**

Carrier bit rate (Gb/s)	Carrier Spacing (GHz)	Spectral Efficiency (b/s/Hz)
10	50	0,20
10	33	0,30
40	50	0,80
40	33	1,20
100	100	1,00
100	80	1,25
100	50	2,00
100	40	2,50

Table 1: Spectral Efficiency for different transmission solutions

The main technologies thatallow transmission of higher bit rates over the in situ long haul systems installed with Non-Zero Dispersion-Shifted Fibre (NZDSF) or +D/-D fibre,are depicted below.

Coherent Solution is the key building block to increase capacity. Thisdetection method is already applied widely in the microwave transmission receivers.

An effective coherent solution is provided by the combination of coherent detection, ultra high speed digital signal processing in the coherent receiver, and a **phase-modulated format** such as **BPSK** (Differential Phase Shift Keying) **or QPSK** (Quadrature Phase Shift keying) becoming state of the art on 100Gbps deployment.

Advanced modulation schemes are compared to previous OOK generation in Figure **1**.

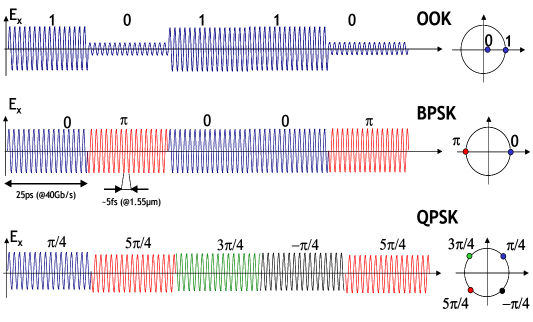

Figure 1: OOK, BPSK and QPSK modulation

The tolerance to noise is optimized with QPSK and BPSK format when an optimum detection method is used. BPSK thanks to a better tolerance to non linear effect offers more margins which can be used to reach longer distances than QPSK.

Use of both orthogonal polarizations of the optical signal for encoding multiple information. **Polarization division multiplexing** (PDM) doubles the transported capacity and increases the spectral efficiency.

Coherent receiver in optical transmission is depicted in Figure **2**.

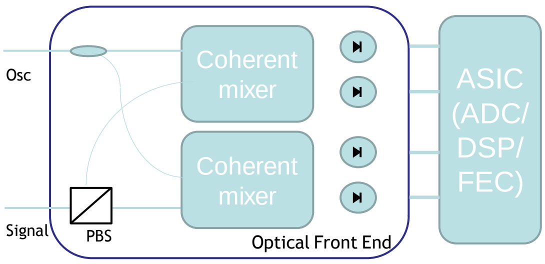

Figure 2: Coherent receiver

The signal is first split in two by a polarization beam splitter (PBS) which sent each one of the incoming polarization into two coherent mixers. The signal beats with a local oscillator (cw laser at frequency close to the signal one). Interference signals are then detected along four balanced photodiodes recovering in phase and in quadrature information for each polarization.

The four electrical signals are then digitalized by high speed analog to digital convertors (ADCs) and then processed by digital signal processing (DSP) block in an application specific integrated circuit (ASIC) using the latest CMOS technologies.

Coherent detection provides the full information transported by the optical field, giving access to all signal information such as polarization, amplitude and phase. This introduces tremendous opportunities for digital signal processing (DSP) to compensate for linear distortions such as CD and PMD, which are induced by transmission within the optical fibre.

The **Digital Signal Processing** (DSP) is done in several steps as shown in Figure **3**.

First, chromatic dispersion (CD) can be digitally compensated. A key part of the DSP is to demultiplex the two initial signals sent along two orthogonal polarizations, and to equalize simultaneously the two signals. This can be done by using Constant Modulus Algorithm (CMA) or other techniques. The filters used within this part, have to adapt themselves continuously to the incoming signal, to follow polarization fluctuation and PMD variations.

The last main part of the digital signal processor is the Carrier Frequency/Phase Estimation (CPE) process. This process is required to recover and cancel the frequency offset and track the signal phase.

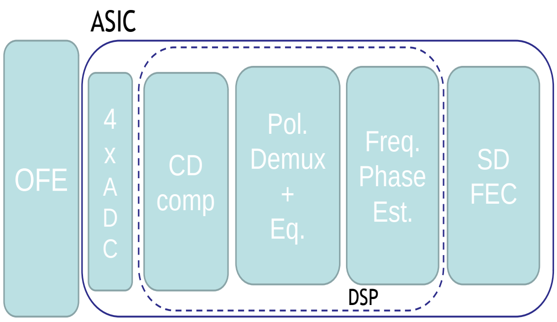

Figure 3: Digital Signal Processor

First generation coherent transponders were using hard decision forward error correction (FEC) and 7% overhead. In order to improve performance, **Soft Decision (SD) FEC** is implemented in the latest generation of coherent transponders, simultaneously with a higher FEC overhead, around 20 to 25%.

A soft decision decoder uses additional data bits to provide a finer, more granular indication of the incoming signal. In other words, the decoder not only determines whether the incoming signal is a "1" or "0" based (HD FEC result) on the threshold, but also provides a "confidence factor" (an indication of how far the signal is above or below the threshold crossing) in the decision.

4 100G CLIENT INTERFACE

10Gb/s is the most widely deployed client interface in the Submarine Telecom Market. 10Gb/s client interfaces are supported through hardware pluggable interface standards such as XFP or SFP+.

100Gb/s Client interface standardization is already available on CFP LR4, and on going on CFP LR10.

In addition to the 100Gb/s transponder solution there is also a scalable solution from 10Gb/s to 100Gb/sclient interface without changing the line as described in Figure **4.**

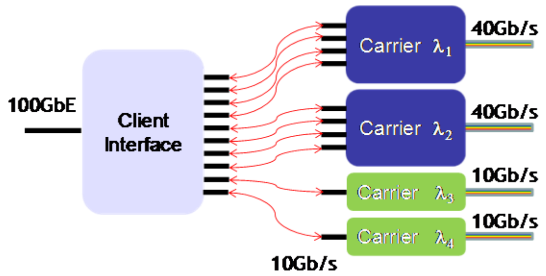

Figure 4: 100Gbe interconnection

Given that the current technology does not afford deployment of 100Gb/s single carrier in all cases due to limitation on very long system or on part of the bandwidth on NZDSF systems, this solution provides an alternative for 100GbE service.

Performance monitoring and fault management services which are mandatory can be provided through ODU Flex layer implementation.

In order to interface subcarrier with current technology the aim is to demultiplex the signal in 10Gb/s OTN frames (bit to bit transparent transport) which are installed in Submarine Line Terminal Equipment.

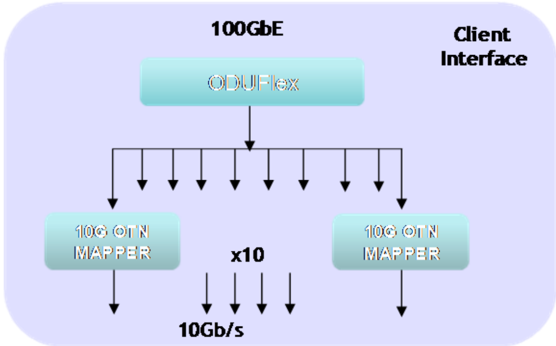

Figure 5: 100GbE client interface architecture

The technical challenge was to multiplex subcarriers in the original 100GbE and to compensate the latency introduced by thedifferent paths or equipment for all subcarriers induced by the variety of Forward Error Correction algorithms already installed.

5 EVOLUTION OF A LONG HAUL SUBMARINE SYSTEM

In order to discuss the evolution of a long haul submarine transatlantic system we can look back at the prevailing design in place 10 to 15 years ago when current systems were built. Repeater design, spacing and bandwidth varied, and system design capacity was between 16 and 80 x 10Gb/s per fibre pair.

With a reduction of channel spacing from 50GHz down to 30GHz or 25GHz and transition to DPSK technology the design capacity of the long haul systems increased. However DPSK technology was not ideally suited for all parts of the spectrum, the optimal solution still included a combination of DPSK and OOK (On Off Keying) technology to achieve maximum capacity on a fibre pair. The capacity is further improved by deployment of 40Gb/s and 100Gb/s technology, increasing the design capacity significantly (see Table 1).

The other factor to be taken into account when looking at the capacity increase on each fibre pair is the existing technology already installed. The marginal cost of adding capacity may well be affected by the cost of replacing existing technology in addition to the cost of adding new transmission equipment for additional sales. Therefore the ability to have the next generation of equipment able to operate alongside the older versions of transmission equipment is an important factor in upgrade planning. For example, it is important to be able to deploy new 40Gb/sand 100Gb/s technology alongside the existing 10Gb/s technology on the same fibre pair, that way making the upgrades simpler and more economical.

6 CONCLUSION

Technological improvements in the past decade have provided an unprecedented growth in potential design capacity, even for cable systems that have been deployed ten or more years ago.

7 REFERENCES

[1] Telegeography International Market Trends Presentation, PTC 2013

[2] Transatlantic Submarine System – The Planning of System Upgrades in a Competitive and Evolving Environment, Daniel Hughes, Maja Summers, SubOptic 2010

[3]G. Charlet, “Coherent detection associated with digital signal processing for fiber optics communication”, invited, Compte rendu physique, vol9, issue 9-10, November-December 2008, pp1012-1030

