A SOLUTION FOR FLEXIBLE AND HIGHLY CONNECTED SUBMARINE NETWORKS

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Abstract: The profusion of different bit rates in a node - corresponding to the connectivity to different fibers or within the same fiber but with different destinations thanks to wavelength routing capability from the wet plant - should be routed cost-effectively and yet respecting OTN standard for proper network management. Solving this complex matching problem (e.g. 16-QAM 400G recoloring into 8-QAM 300G and/or QPSK 200G) while keeping webscale capacity switching and highly connected topologies at the node level will be described. Additionally, we will study the impact of trading margin against capacity which can be easily made available with new software defined transceivers.

1. INTRODUCTION

Surging demand for international bandwidth is putting immense pressure on the world's submarine cable networks [1]. This demand is driven by many factors, not least the traffic placed on those networks by web-scale content providers. The ultimate users of this content expect its flow to be immediate, seamless and always available regardless of their location. Content providers are battling to meet the demand for video streaming and distribution, as well as online commerce, gaming and sharing of all manner of information over a wide area.

The evolution of submarine systems reflects the insatiable demand for increased information exchange, swifter transmission and more flexible digital traffic flow. New wet plant is emerging, designed with larger spectrum and more fiber pairs to serve data centers with ultra-high capacity. At the same time, existing wet plant designed with legacy technology needs to support increased design capacity, improved connectivity and flexibility.

New submarine terminals relying on software defined transceivers (SDT) with modulation format adaptation and gridless capability offer the right features to cope with these challenging requirements all along the life of the systems.

2. MULTI-RATE SUBMARINE TERMINALS

A new generation of terminals allow bit rates of wavelengths to be tuned according to each specific application using a single line interface thanks to a simple software re-configuration between BPSK, QPSK, 8-QAM and 16-QAM with the additional benefit of providing a universal spare. In terrestrial or regional submarine networks, 16-QAM will allow a strong cost per bit decline as it will lead to fewer fiber pairs to reach inland PoPs and data centers with a lot of benefits for those renting or leasing this network section. In new transoceanic networks, 8-QAM modulation will act the same and supplant the QPSK modulation from its traditional place, making this constellation the major submarine enhancement of recent designs and the booster for submarine capacity on those networks.

Alongside, channel spacing adjustment beyond the ITU-T G.694 definition allows us to increase spectrum efficiency when combined with pulse shaping function. In order to optimize the use of spectrum with maximum fineness, the terminal requests a total flexibility of the wavelength and an architecture that avoids any guard band: this is called gridless functionality. In other words, this is the capability to select any frequency on the total spectrum at any value without restriction driven by any subsequent optical filtering elements or transceiver components.
The channel spacing, if any, is only limited by the spectral occupation of the signal itself and neighboring signals.
Gridless functionality is not limited to 37.5 or 50GHz grids, it can be 33, 34.3 or 40GHz… or any value that is needed by spectrum engineering strategy (use of the best spectral efficiency on a system by optimizing bit rate and channel spacing). Besides it uses the full spectrum without any guard band usually introduced by standard use of a WSS.

The push for higher speed and larger capacity has led to high bit rates for the WDM channels but Submarine Line Terminal Equipment (SLTE) still have to deal with client rates of existing equipment. This difference in pace of client and line bit rates is best addressed with separating client and line functions, with the advantage of rationalizing the cost of expensive WDM spares, but at the expense of implementing the interconnection that can provide in return some extra flexibility.

In terms of network architecture, traditionally the submarine network traffic was terminated in the cable landing station (CLS) and connected to the terrestrial network to reach in-land operator's point of presence (POP). There is now an extension of the submarine network beyond the CLS whose design should not penalize the design of the submarine cable and not increase the number of wet repeaters. The architecture of the nodes present in the CLS has then evolved to bridge both networks with the purpose of optimizing spectral efficiency per segment and following constrains to each sub-network: safety requirements and route diversity on the terrestrial part to protect the traffic, and implementation not likely to damage wet repeaters on the submarine part.

3. HIGHLY CONNECTED NETWORKS

Submarine networks can be deployed with several branches connected to a main trunk using different branching units (BU) including ROADM BU [2]. Depending on the optical networks traffic requirements, submarine Reconfigurable OADM BU provides flexible optical nodes with re-configurable add/drop capability over the system life and allows the reconfiguration of the transport capacity over the different digital line sections (DLS).

The increase of the transmission data rate reinforces the interest of OADM functions to increase the connectivity capability of submarine transmission systems. The different bit rates can be used to adapt to new reach.

From a system design point of view, the design capacity of a connection depends on the distance covered by the optical transmission. It means that the longest distance can support a modulation format like QSPK and channel spacing around 40GHz, and on the contrary , the shortest ones can support a more spectrally efficient modulation format like 16-QAM at 33GHz. In between, all the combinations of formats can be used for intermediate steps. It means that each distance of connections could be optimized in terms of spectral efficiency and cost with some intermediate settings of modulation formats.

From a network point of view, the implementation of a network element at the CLS needs to cope with the connections to multiple fiber pairs from submarine and terrestrial lines and be able to support the high capacity need for submarine systems. The node which allows switching from one frequency (or bit rate) to another is called a recoloring node since each frequency is adapted to the best spectral optimization.

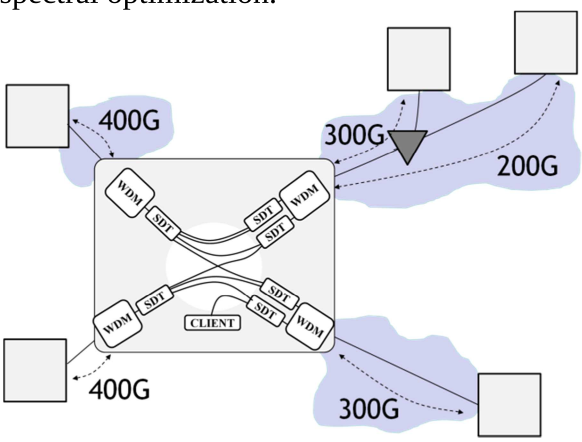


Figure 1

Figure 1 describes this type of networking with multiple POP that are connected to undersea fiber pairs with the capability to route the traffic from one fiber pair to another. The traffic can be dropped or added locally into the cable station. At the same time, the line rate is adapted to use the lowest cost technology and to maximize the spectrum efficiency at the same time. 400G is used to connect POP to CLS. 200G/300G/400G are used on the subsea line following the distance. Combined with ROADM BU in the network, the line rate can be adapted with the change of wavelength routing induced by its flexibility.

The terrestrial line can be implemented with some route protection to provide the high level of traffic availability for the entire network [3].

From an implementation point of view, the software defined transceivers are building blocks since they support all frequencies and modulation format capabilities. The issue to solve is then the interconnection of each transceiver. Figure 2 shows an example of the required 100G inter-connections.

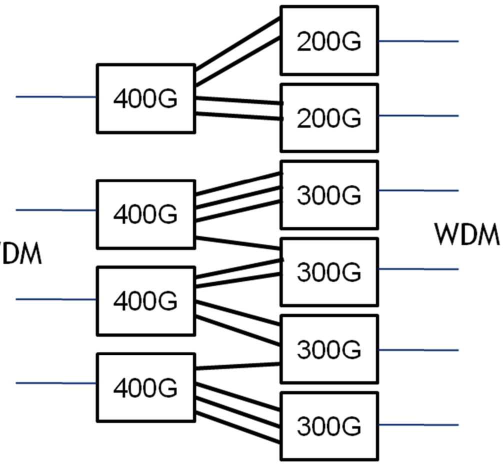


Figure 2

As all links are not predictable, traditional implementations will rely on a matrix but with loss of switching capability as all software defined transceivers are not at maximum speed and limited in terms of connectivity to the switching matrix capacity. An alternative is to use physical connections with 100G capacity to convey client traffic to the concerned transceivers.

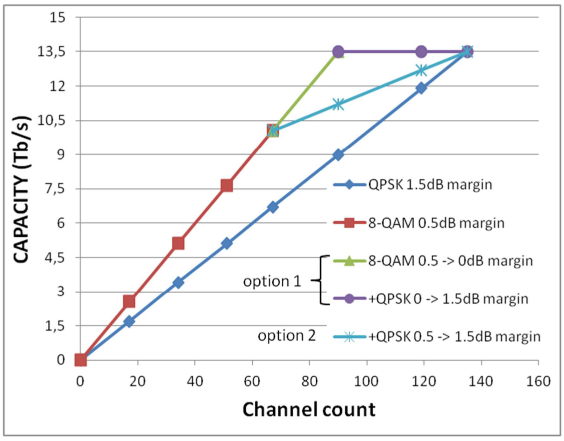
4. OPTIMIZING INVESMENTS WITHOUT AFFECTING CAPACITY

When possible, the operator will decide to push the line rate to the limit [4]. Submarine systems, contrary to terrestrial systems, deliver performance for the full capacity at the beginning of life of the system. This permits the use of higher line rates with lower cost per bit at the initial life stage. We advocate here a service with spectral management during the life of the system to optimize purchasers' investments.

Based on the model proposed by Vacondio [5], we have simulated the transmission on a fibre system optimised for an End Of Life (EOL) of 135 QPSK channels with a channel spacing of 33GHz leading then to a capacity of 13.5Tb/s with an operator margin of 1.0dB and margin of 0.5dB to take into account fibre or transponder ageing. No other margins were considered, in particular the manufacturing margin or design margin that yet can be present for instance in a dark fibre optimised for a previous technology target.

The simulation results described in Graph 1 show that we can install more capacity with up to 67 8-QAM channels with a channel spacing of 66GHz in this same system instead of QPSK channels with an impact on the margin of 1.0dB, allowing us to reach 10Tb/s, ~75% of the End Of Life capacity of the fibre with half the possible wavelengths (red curve).

Then two options are available to fill the last Terabits in order to reach total capacity. The first option is to continue installing 8-QAM transceivers in order to keep on benefiting from a lower cost per bit that this modulation format provides. Of course, this is at the expense of a reduced margin and a progressive frequency shift from a channel spacing of 66GHz to 50GHz that can be hitless if we keep the step speed and wavelength sweep in the tolerance range of frequency offset compensation of the coherent transceiver (green curve) [6]. This transformation of three 8-QAM @ 66GHz into four 8-QAM @ 50GHz relies heavily on the gridless capability of the terminal.



Graph 1

Eventually, to converge towards the EOL fulfil capacity to take into account margin loss during the life of the system, the modification of the bit rate from 8-QAM to QPSK should be done altogether with another progressive frequency sweep from 50GHz to 40GHz and finally 33GHz (purple curve).

Alternatively, and with less complexity, a second option can be implemented which does not allow the margin to decrease below 0.5dB. This consists of progressively changing the modulation format into QPSK on the channels with lower margin on the high frequency channels and to add new channels in between, on the 33GHz channel grid (cyan curve). Obviously, this solution offers the advantage of not having to shift already installed transceivers and eases the WDM operation. Nonetheless this operation cannot be hitless on 33% of client traffic that should be rerouted to another wavelength temporary in upper layer or during a maintenance window.

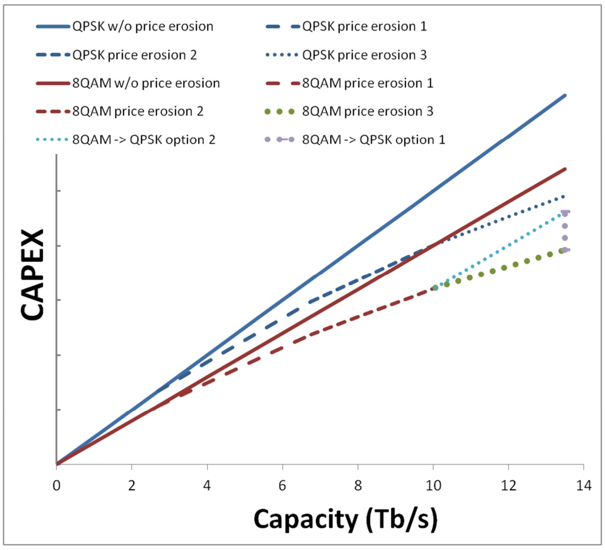
This specific management of the capacity upgrade can be called a time based service as the implementation depends on the performance of the system during its life. Taking into account submarine cables are upgraded in several phases with regular capacity increases, this time based service has tremendous gains in terms of purchaser investments over time as we show hereafter.

Following the scenarios of the previous simulation, we consider the Capital Expenditure (CAPEX) the purchaser will spend in time taking into account price erosion. Considering the software defined transceiver can address all bit rates at the same price with a 100G granularity, there is a cost reduction per Terabit when using higher modulation formats.

In Graph 2, we have plotted the evolution of CAPEX by increasing capacity in four phases characterised by a price erosion of 20% per phase. The lowest cost per bit of the 8-QAM format allows CAPEX savings in phases prior to the 10Tb/s limit when QPSK format needs to be introduced to fill the last Terabits. In this last phase, with one option or the other, even if we need to still add half of the transceivers to converge to the fulfil capacity, due to the cumulated price difference and erosion obtained earlier, the time based service is always the cheapest option and gives further advantages as the Return On Investments is shorter.

5. CONCLUSION

Connectivity, capacity and flexibility remain the main drivers for the evolution of submarine networks. Multi rate and software-configurable transceivers can adapt to any of these requirements thanks to their flexibility and their optimized spectral efficiency. And this also comes with interesting benefits in terms of investments when following a time based service strategy.



Graph 2

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