OPEN CABLES AND INTEGRATION WITH TERRESTRIAL NETWORKS

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Abstract: Today's undersea cable systems are increasingly complex and part of a much larger network topology that spans the continents. Operational efficiency can be significantly enhanced by integrating the undersea paths seamlessly into the overall network architecture. This implies that it is desirable to have one control plane for both the terrestrial and undersea parts of the network, one network management layer and similar transmission equipment. It is therefore not surprising that there is a tendency in the market to continue upgrading undersea cable systems with transmission equipment from the same supplier. This does not present a technical challenge as long as the undersea cable system is in operation and can be tested by prospective upgrade suppliers to ensure that capacity and system margin requirements can be met.

However, a significant technical challenge exists if the cable is not yet in operation. In that case the cable is not available for testing and capacity and system margin must be predicted from specifications guaranteed by the cable supplier. A generally accepted performance metric for the undersea cable is the available optical signal to noise ratio (OSNR), which is a necessary but not sufficient parameter to characterize transmission performance. OSNR does not capture nonlinear transmission impairments and system designs with the same OSNR but very different transmission performance do exist.

In this paper, we explore the two important cable implications of open cables: control plane requirements, and criteria for wet plant acceptance. We propose to use effective optical signal to noise ratio, which reflects a combination of linear and nonlinear transmission effects, to describe and guarantee cable performance for ultra-long haul and dispersion uncompensated transmission links.

1. OPEN CABLES

The advent and adoption of coherent optical detection and high-speed digital signal processing technologies has led to the commoditization of Submarine Line Termination Equipment (SLTE) line cards over the last few years, driven primarily by commercial merchant silicon and optical module makers. An effect of this is the increasingly shorter line card technology cycles relative to the typical two to three year cable system project planning and implementation cycle. In order to capitalize on the latest line card technology generation with respect to price, performance, and features, system purchasers are adopting the option of separating the technology and planning decisions concerning the undersea elements and the SLTE line cards, so that they can defer the latter to a time closer to activation of the cable system.

With the "Open Cable" model [1], the purchaser will purchase the cable system with only the undersea elements and the shore-based equipment necessary to power, monitor and control the undersea elements (i.e., PFE, etc.), and separately procure the line cards at a time closer to the actual cable activation time. This provides the purchases with the maximum number of options in terms of multiple sources and procurement timing. The Open Cable system approach is illustrated in Figure 1, and includes:

- Undersea elements (cable, repeaters, and other undersea network elements such as ROADM)
- Power-Feed Equipment ("PFE")
- Element and Network Management Systems (Maintenance Controller, "MC")
- Common Equipment, including: Command Response Equipment (CRE) and Line Monitoring Equipment (LME)

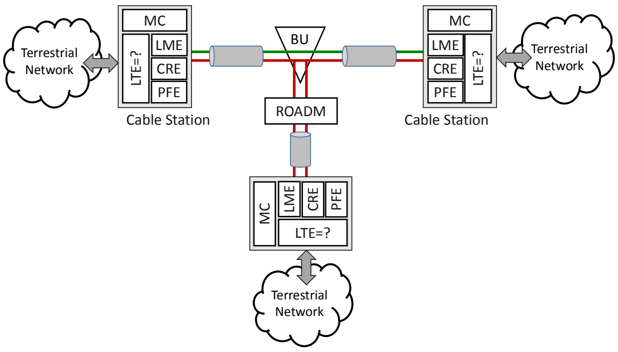

Figure 1: Open Cable System

Not included are any components related to the Line Termination Equipment (LTE) that is made up of the Wavelength Termination Equipment (wavelength multiplexing equipment, filters, couplers, amplifiers, etc.) and the transmission line cards themselves that carry the telecommunication signals.

There are a number of consequences to the separation of the line cards from the rest of the system. System performance acceptance challenges are discussed in Section 3.

Meshed terrestrial networks now reach directly to the fiber end at the cable stations. Undersea reconfigurable elements such as fiber switching units and ROADMs, previously not known to the terrestrial plane, eventually need to be included in the control plane of the larger network, helping optimize highly meshed redundant networks. Fault detection and protection mechanisms have to evolve to operate independently from any indicators traditionally delivered by the line cards. We explore this in Section 2.

2. INTEGRATION OF CONTROL AND STATUS

Higher levels of control plane integration can be progressively attained. Initially, terrestrial control plane decisions would depend only on signal alarms on the wet plant. This can be evolved to a more sophisticated approach, where the control plane decisions include the control of the reconfigurable elements of the wet plant and its common equipment:

- WSS-ILE loading equipment settings
- ROADM settings
- Spectral sharing (Ocean Spectrum Bandwidth Manager) status
- Line Monitoring System information on the wet plant
- Cable cut information detected independently from the line cards
- PFE voltage reporting
- Undersea cable network electrical powering states

Bandwidth on Demand may well be the first driver for an integrated submarine-terrestrial control plane, as well as dynamic provisioning of large amounts of capacity. Such services have already been demonstrated by terrestrial network operators. As the terrestrial equipment continues to provide increasingly complex network applications, so will the undersea segments that follow.

To meet this higher level of control, enhancements to the northbound interfaces need to be considered.

- Management of the agile and reconfigurable wet plant
- Reporting of line monitoring system information, which enables submarine network status awareness
- Support of ROADM, which brings an unprecedented level of configurability to the undersea systems.
- For ROADM and non OADM systems alike, the reporting of measures taken in the wet plant to protect trunk traffic by modifying the loading profile, and the ROADMS where applicable.

An open cable, as a result, is likely to require an open control interface specification from the cable provider. This can be achieved through Standards, or an open specification that multiple vendors and customers can adopt.

As is the case for turnkey systems, Open Cables must assure proper fault detection and recovery, but instead have to use a line card independent decision algorithm. SLTE data have been useful indicators of link status, and therefore system status, but may no longer be available in Open Cables since the control plane of the line cards may now be independent of the undersea control plane. However, a line card independent decision algorithm was already implemented in undersea ROADM networks: dynamic changes in common loading equipment, ROADM elements or fiber switching units work in concert to protect the data transport on unaffected segments. These measures exist today.

3. OPEN CABLE SPECIFICATION AND ACCEPTANCE CRITERIA

The practical adoption of Open Cable systems hinges on the ability to accurately characterize the performance of the wet plant on a standalone basis without any effects of the line card. The transmission Q-factor based commissioning approach used in turnkey cable systems is not suitable for Open Cables since the Q-factor is SLTE line card dependent. The traditional or “linear” Optical Signal-to-Noise Ratio (OSNR) - defined as the ratio of the channel power to the Amplified Spontaneous Emission (ASE) noise power from repeaters - is line card independent but is not sufficient to characterize the Wet plant since it, unlike the Q-factor, does not include nonlinear interference (NLI) effects [2].

A new Wet plant performance metric therefore is desirable that satisfies the following properties:

- Line card independence
- Includes both linear and nonlinear transmission effects
- Derivable from and verifiable using any line card
- Allows prediction of the performance of one line card based on that of another

Since modern coherent cable systems use uncompensated +D fibers and all-electronic dispersion compensation at the coherent line cards, the subsea cable (wet plant) design and line card design can indeed be separated. This is possible due to the key fact that the large, accumulated dispersion of the WDM optical signal along the undersea fiber over transoceanic distances makes nonlinear interference (NLI) effects behave like noise that is essentially additive to the Amplified Spontaneous Emission (ASE) noise from the repeater amplifiers. An "effective" OSNR, $OSNR_e$, can thus be defined that factors in the NLI effects as follows [3]:

$$OSNR_e = \frac{P_{ch}}{P_{ASE} + P_{NLI}^{eff}},$$

where P_{ch} is the channel power, P_{ASE} is the ASE noise power, and P_{NLI}^{eff} is the effective NLI noise power, both in the channel bandwidth. TE SubCom has developed analysis methodologies around the above formulation to estimate $OSNR_e$ in a line card independent manner, based on Q-factor vs. OSNR measurements made with a given line card.

The proposed methodology to predict the performance of a line card in an Open Cable system is illustrated in Figure 2 and involves the following steps [1]:

1) Using a reference line card, e.g., SubCom's state-of-the-art C100U+ line card, carry out Q-factor vs. OSNR measurements in back-to-back configuration (where $P_{NLI}^{eff} = 0$), by varying the OSNR and recording the Q-factor values.

2) Using the same line card and same terminal configuration as in step 1 above, carry out system Q-factor measurements on the actual cable and determine $OSNR_e$ using the above mentioned TE SubCom-developed methods.

3) With the knowledge of $OSNR_e$, performance prediction can then be made for any other line card with known back-to-back Q-factor vs. OSNR performance.

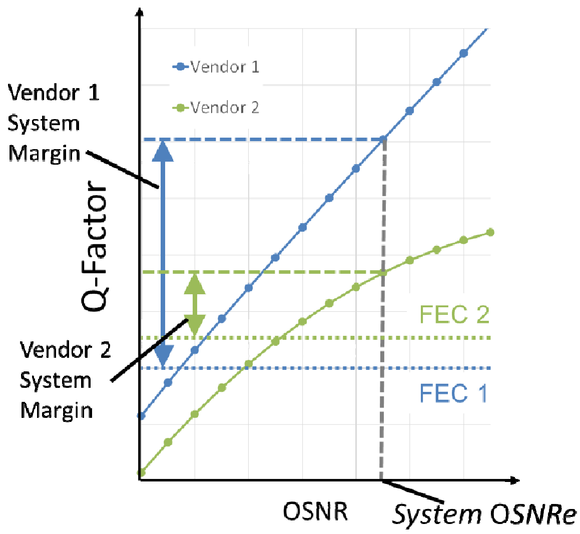

Figure 2: A reference Line card (Vendor 1) can be used to predict the performance of another line card (Vendor 2) on the same wet plant, and characterize the wet plant by evaluating its degradation.

The ITU-T study group responsible for subsea communications standards is an excellent channel for the creation of a corresponding standard. In the meantime, the industry is cooperating to define wet plant performance based on OSNR and key wet plant performance parameters.

4. KEY PERFORMANCE PARAMETERS

Key performance parameters that define the basic transmission characteristics of the undersea plant include the following:

- Passband, which may differ from a terrestrial grid
- OSNR per channel, at beginning of life and end of life for the longest DLS
- Number of carriers
- Nominal span loss
- Number of repeaters

- Repeater total output power
- Repeater noise figure
- Fiber loss
- Fiber effective area
- Fiber dispersion
- Fiber dispersion slope
- Frequency of repairs planned for the system life, in both shallow and deep water, and corresponding losses

Given the parameters above, and in the absence of a physical wet plant that can be characterized, an equipment vendor versed in simulations can provide capacity and transmission margin estimates to the Open Cable system owner. While this approach is effective in communicating the basic features of the wet plant, it is difficult to capture the effects of wet plant manufacturing tolerances. Manufacturing tolerances are included in the effective OSNR characterization of the Open Cable and can be easily communicated using $OSNR_e$. $OSNR_e$ is therefore a more general concept than key system parameters alone. However, key wet plant performance parameters are an integral part of any Open Cable system performance assessment.

5. FIELD VERIFICATION OF THE OPEN CABLES $OSNR_e$ CONCEPT

The $OSNR_e$ concept has been verified in the field [4], using two generations of real-time DSP processing (Figures 3a and 3b). The first generation featured differential coding. The second generations used absolute phase detection, both with QPSK on dual polarizations. The use of absolute phase detection increased the total capacity of the wet plant from 10Tb/s per fiber pair to 12.1Tb/s. Channel spacing decreased from 40GHz to 33GHz when using the newer DSP techniques. While the Q-factor of each generation of DSP differed due to the improved signal processing algorithms, the measurement of back to back performance of each line card resulted in an equal $OSNR_e$ calculated value, within measurement errors.

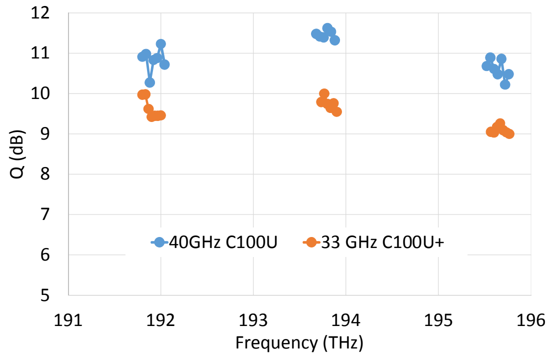

Figure 3a: Transmission performance of two generations of line cards on an Open Cable

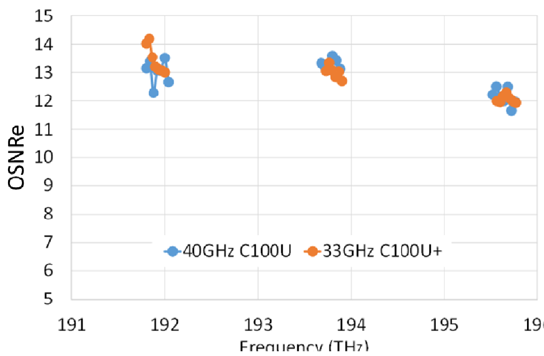

Figure 3b: Same $OSNR_e$ within measurement tolerances for the results of Figure 3a.

This result demonstrates how $OSNR_e$ can become a very effective metric for wet plant performance assessment and acceptance in an open cable system.

6. CHALLENGES

The approach above is not without challenges. Open Cable market acceptance exists on the part of the purchasers, but the contractual definition of a divided responsibility between an SLTE provider and an undersea system provider is one in which contention exists as both vendors prefer to minimize their own risk. The willingness of a purchaser to assume some level of system integration risk is clearly of some importance in allowing each party the fair share of the manufacturing margin even though the effective OSNR concept will help to minimize risk to the purchaser. Since achieving higher margin numbers in the wet plant is inherently costly, a savvy purchaser will do well to assure that margin is not consumed in unreasonable ways. Additionally, if a system is to be cost effective, risk cannot be offloaded from the SLTE vendor to the undersea vendor if this represents significant and costly additional requirements.

As a result of these challenges, traditional metrics for full capacity tests with a known line card, as well as continued turnkey solutions with a total system performance guarantee may not be completely eliminated from the industry.

7. CONCLUSION

The undersea cable industry has started offering the Open Cables option as a viable alternative to the established turnkey system model. This adoption will enable convergence between the SLTE and the established terrestrial mesh which may help to reduce OPEX for the network owner.

$OSNR_e$ can help to reduce the system integration risk for network owners and can be applied even during the implementation phase of the undersea network when field trial data is not yet available.

8. REFERENCES

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