SPECTRUM SHARING IN A MULTI-VENDOR ENVIRONMENT

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Abstract: With an increase in the number of submarine terminal upgrade vendors providing transmission technology, cable owners now require the ability to support overlaying additional vendor equipment on cables with existing incumbent vendor channels. In addition, the concept of selling spectrum on a cable instead of switched electrical capacity requires the cable owner to have a method of safely and securely providing access to the spectrum to a number of end customers.
A method is required ensure the spectrum, either filled with multiple vendors' equipment or sold to different end users, is partitioned and managed correctly. The management solution must be capable of avoiding conflicts and minimizing impacts of actions of one spectrum owner on another in a fixed-power environment. To minimize the impact of change a way of orchestrating changes and responding to fault events is required. This paper outlines a proposed architecture using open APIs and toolsets to perform this orchestration while providing flexibility and security to all end users of the spectrum.

1. INTRODUCTION

Prior to 2004, virtually all capacity upgrades of subsea systems were completed with technology provided by the original equipment manufacturer (OEM) that provided the initial combined turnkey cable and SLTE solution. Terrestrial equipment vendors introduced the concept of coherent transmission into terrestrial networks in 2008 with 100Gb/s data rates introduced to submarine cables as early as 2010, with trans-Pacific 100Gb/s ready for service (RFS) in early 2013[1]. Deployment of upgrade vendor equipment as an overlay to existing traffic requires that one or more sets of interconnected Submarine Line Terminating Equipment (SLTE) be coupled onto the fiber pair. Inserting a passive coupler can provide a solution to interconnect the SLTEs with field proven reliability; however such an approach has drawbacks in terms of performance, operation and security.

The use of a broadband coupler as shown in Figure 1 can results in operational difficulties in operating end terminal SLTEs. Manual coordination of provisioning and operation of each SLTE is required to ensure operational changes and failures of one SLTE do not impact performance on other SLTEs. Each SLTE does not have knowledge of the other terminals providing spectral inputs to the fiber pair, as such the end user is responsible to ensure that each SLTE does not attempt to use spectrum assigned to other SLTEs. In the receiving direction, the use of broadband splitters would provide identical copies of the spectrum to all parties, as seen by the receive spectrums represented in Figure 1. This can lead to privacy issues as a copy of the spectrum is presented to each SLTE, even if the signal is not meant for that terminal.

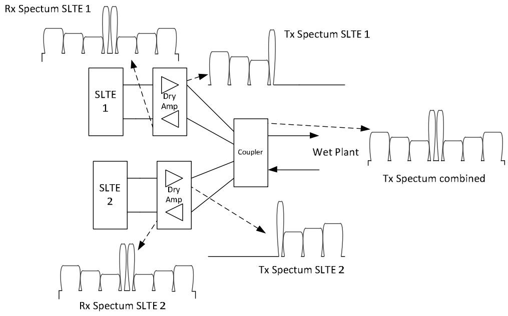

Figure 1 Broadband Coupling

The normal operation of the SLTEs can also result in performance impacts. For example, noise funnelling at the broadband coupler via the addition of ASE from each connected SLTE can result in a 3dB increase in the noise level, assuming each path has an equivalent Amplified Spectral Emissions (ASE) noise level prior to coupling. This will resulted in a lowered transmit Optical Signal to Noise Ratio (OSNR) of signals, as represented in the increased noise floor of the combined spectrum in Figure 2.

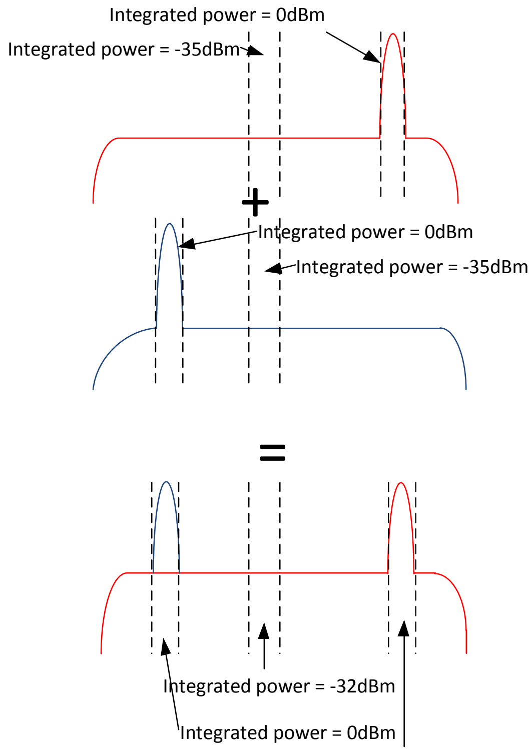

Figure 2 Noise Funneling

A method of partitioning spectrum between interconnected SLTEs that minimizes noise penalties while providing isolation and security between inputs in both the transmit and receive directions not only allows the owner of the subsea cable from combining multiple vendors on a single fiber pair but also opens the possibility to sale of secure spectrum on a fiber pair instead of switch electrical capacity.

2. SOFTWARE ORCHESTRATION OF MULTIVENDOR SLTE

To address operational issue with managing multivendor SLTE environments it is possible to use a Software Defined Networking (SDN) orchestrator that communicates with the SLTEs via control interfaces such as Representational State Transfer Application Programing Interfaces (REST APIs).

In an environment where APIs are available an SDN orchestrator can be used to minimize the operational impacts of operating multiple SLTEs. The orchestrator would have the knowledge of the operation of each SLTE. All SLTE provisioning requests would be directed to the orchestrator which would perform rule checking to ensure the request will not impact the operation of other SLTEs on the fiber pair. Only when the rule checking passes would the orchestrator pass the provisioning request to the SLTE.

Further improvements to the operation of the SDN controller can be achieved by providing optical monitoring points at the common coupling point in the transmit direction to allow the orchestrator to validate spectral composition against the expected output provided by the data of each SLTE.

In a purely software controlled configuration concerns regarding noise coupling cannot be addressed as the passive coupling mux point still exists.

3. HARDWARE BASED SPECTRAL PARTITIONING OF MULTIVENDOR SLTE

A hardware spectrum partitioning device provides the ability to achieve the requirements of minimized performance impact, operational simplicity and security coupling address optical coupling concerns. To achieve these goals the spectrum sharing terminal would consist of three functions:

Spectrum Controller – responsible for allocating line spectrum and performing power management of unallocated spectrum

Input Signal Policer – responsible for ensuring the SLTE input spectrum aligns with requirements of occupancy and power

Security Controller – responsible for ensuring the spectrum defined for each SLTE is confided to only the ports assigned to that SLTE

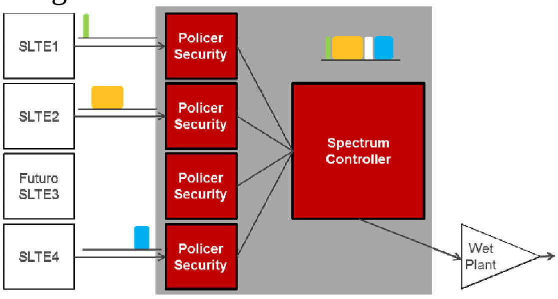

Figure 3 Spectrum Sharing Terminal

SPECTRUM CONTROLLER

The spectrum controller provides access to the line spectrum and ensures no spectrum collisions occur. Each SLTE would be connected to a dedicated port of the spectrum controller Wavelength Selective Switch (WSS). Requests to the orchestrator allow access to the spectrum and assign the requested spectrum to the appropriate input port. Requests for spectrum already allocated to other SLTEs would be rejected. Coupling of signals via the WSS ensure that even if spectrum is provided from an SLTE that is already in use by another SLTE input it will not be coupled to the transmitted signal and provide security from inadvertent wavelength re-use. The WSS also ensures that ASE from each input is not coupled, helping to maintain the transmit OSNR of signals, as shown in Figure 4.

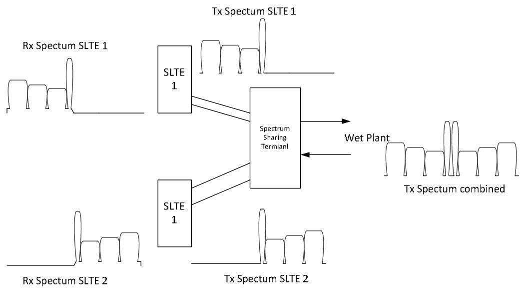

Figure 4 Coupling via a Spectrum Sharing Terminal

The spectrum controller requires the use of a device that can perform spectrum control on a flexible grid. Numerous component vendors provide variants of WSS devices that provide the ability to define pass bands on flexible increments. For example, devices that use Liquid Crystal on Silicon (LCoS) can provide control in 3.125GHz and smaller increments.

The spectrum controller provides access to the requested pass band, referred to as a Media Channel (MC) in the ITU flexible grid specification, but does not impose any restrictions on the spacing of channels within the pass band. Each SLTE can have multiple pass bands assigned if non-contiguous spectrum is requested.

Any spectrum not defined as traffic pass bands for SLTEs would be filled with power management to maintain a constant loading of the subsea repeaters and provide a predictable gain evolution.

INPUT SIGNAL POLICER

Once a pass band is defined the end SLTE is responsible for control and power management of the signals within the assigned spectrum as long as the signal stays within specifications defined by a policing profile.

To ensure the effects of operation of each SLTE on signals from other SLTEs the input spectrum must conform to a defined profile based on the spectrum assigned. The subsea system has a total output power (TOP) defined by the wet plant repeaters that must be shared among the inputs. The policer profile for the spectrum includes a definition of a portion of the TOP available for each SLTE. The policer is responsible for maintaining the portion of the TOP assigned to each SLTE via changes to the provisioning of the WSS. In the event that the input power to the spectrum sharing terminal is too low for the policer to achieve the TOP the input spectrum would be replaced with power management. In the case of a fault in the SLTE that would result in the loss of an input the ability of the policer to replace the offending signal with power management results in the ability for the system to be resilient to SLTE faults that would cause performance impacts on the remaining inputs in a simple passive coupling scenario.

In addition to TOP the policer profile includes a definition for the expected power spectral density of the input signal. The use of a power spectral density definition instead of a total power definition for the pass band is required to ensure on SLTE does not place all power assigned to a narrow bandwidth and change the operation of the wet plant EDFAs which can result in a gain evolution change to the line system that will affect all connected SLTEs. If the input does not conform to the profile the policer would replace the signal with power management.

SECURITY CONTROLLER

Connecting multiple SLTEs to the same subsea line systems via a passive coupler/splitter arrangement will result in the receiver for all SLTEs receiving a copy of the entire transmitted spectrum. Using a WSS in both the add and drop paths in a route and select type architecture provides security by matching the provisioned spectrum bi-directionally and only supplying the spectrum defined in transmit direction to the matching port in the receive direction. This results in the SLTE receiving only signals from within its assigned pass band, as shown in Figure 4.

4. COMBINING SOFTWARE AND HARDWARE CONTROL

Augmenting the hardware solution with a SDN orchestration layer provides a solution that the can allow the cable owner to not only have the ability to use multiple different SLTE vendors on a cable but also allows the cable to be operated as a number of virtual private cables. The creation of the virtual private cables enables the cable owner to sell not just switched electrical capacity but optical bandwidth.

In a virtual cable configuration the cable owner can provide end customers access to APIs on the SDN orchestration layer that would allow for the ability to request for changes in the assigned spectrum. Once validated against available spectrum the SDN orchestration layer would provide access to the spectrum to the end user, along with details of the spectrum policer profile, while notifying a billing engine of the change in spectral usage.

5. CONSIDERATIONS FOR SPECTRUM SHARING

Before performing spectrum sharing the end user must consider the application and value of performing spectrum sharing. In upgrade scenarios where sharing spectrum provides increases in bandwidth available to the end user by opening the spectrum to capacity not supported by existing terminals the value is understood. The value to be considered is the value in sharing the spectrum via the active equipment outlined in the proposed architecture vs. sharing the spectrum via passive means.

If the cable owner is willing to perform the manual activities required to share the spectrum between multiple SLTEs the additional costs, inclusion of single points of failure and complexity of the SDN controller may not be deemed as acceptable.

In cases where the cable owner is interested in using a spectrum sharing terminal to control access to allow the sale of spectrum, instead of electrical switched capacity the question for the cable owner to answer is how will the spectrum be priced to ensure the value of the spectrum is correctly monetized. As new technologies become available that can provide the customer more transport capacity over time in the same amount of spectrum the resulting value of that spectrum can increase.

6. CONCLUSION

The architecture for spectrum sharing using active components that is proposed minimizes penalties to the terminals that are sharing the spectrum while providing resiliency to failures in the attached SLTEs and end user security in the spectrum allocated. The use of an SDN controller to orchestrate spectrum sharing activities simplifies the operation of the functionality provided by the spectrum sharing terminal while providing options for software integration with end terminals via the use of REST APIs.

7. REFERENCES

[1] J. Chesnoy, Undersea Fiber Communication Systems (2015) pg. 13