INTEGRATED SUBMARINE AND TERRESTRIAL NETWORK ARCHITECTURES FOR EMERGING SUBSEA CABLES

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Abstract: This paper discusses front-haul network architectures integrating *emerging* subsea cables and terrestrial fiber networks. Integrating cable landing stations (CLS) and submarine line terminating equipment (SLTE) in a neutral urban point of presence (POP) optimizes costs while providing access to customers of subsea cable capacity. This paper presents various front-haul network architectures and benefits for extending the SLTE termination for subsea cables from remote landing points to inland POPs in urban areas. This is accomplished through use of terrestrial dark fibers, reconfigurable optical modules, and latest optical transport technologies to extend the reach from the traditional coastal CLS.

1. INTRODUCTION

Three tectonic shifts are shaping up in subsea networks to usher internet population into the cloud-centric economy. The first one is the share of new submarine optical cable ownership is shifting from traditional carriers to cloud/content providers and private cable owners. This is due to the center of gravity for international bandwidth is shifting from internet to private network traffic, for example, the trans-Atlantic market [1]. The second shift is embracement and deployment of "open" subsea cables with separation of termination equipment vendors from wet plant vendors. This shift leverages advances in line termination technologies with faster technology refreshments providing cost savings for cable operators, consortium members and their customers. This leads to extension of the economic life of subsea cables while increasing capacity and decreasing unit cost. The last shift is using strategic multi-tenant data centers for subsea cable termination with the benefit of faster deployment of CLS infrastructure. This shift provides open access and carrier neutrality for direct interconnection of dense ecosystems of subsea cable operators, network service providers, enterprises, financial companies, cloud, and content providers.

Historically there has been high interest to architect integrated subsea and terrestrial networks between city POPs on continents [2, 3]. Carrier neutral urban data centres (DC) with expansive network and interconnection density are fast becoming the choice of city POPs for new subsea cable termination. The term "back-haul" in this paper is used for the traditional concept of deployment of the terrestrial portion of the network between SLTE termination in a CLS and terrestrial line terminating equipment (TLTE) located at a city POP. The term "front-haul", as presented in this paper, is used to define the part of a submarine cable system on dry land from the beach manhole (BMH) to the termination point of SLTEs in city POPs or data centres. The distance of this front haul, from BMH to SLTEs, could extend up to one thousand kilometres or more depending on distance and technology reach factors.

2. DATA CENTERS AS CITY POPS

The majority of existing submarine cable infrastructure is carrier owned with the exception of a few privately owned systems. Both own cable landing stations housing PFE and SLTE which is also controlled and maintained by the same owners. This infrastructure has served the industry well over the years during the traditional carrier ownership model. Today, new cable owners are seeking new models for lower capital and operating cost, faster provisioning, open access, and the benefits of interconnection at carrier neutral landing locations.

A combination of recent optical transport technology advancements and new submarine cable deployment strategies is leading to integrated subsea and terrestrial network architectures with POP to POP connectivity. Interconnection is also driving the demand for international DC expansion. DCs originated as a central repository for a particular body of knowledge for a specific business. As customer demand for access to these "islands" of information began to grow, new devices, infrastructure, and architectures began to emerge providing access to this information.

The modern DC market has grown and will continue to grow providing enterprise, content delivery networks, content and cloud service providers, and network service providers with a carrier neutral location to interconnect with each other. Access to international capacity at these interconnection hubs has been limited; using dedicated circuits through various and sometimes numerous, physical connections to specific capacity of a specific customer to a specific cable system terminating at a specific cable landing station.

3. TRADITIONAL BACK-HAUL NETWORK ARCHITECTURE

Traditional back-haul network architectures have been considered a stand-alone or independent segment, connecting SLTE equipment located at the CLS to/from city POPs with terrestrial transport links using terrestrial line terminating equipment (TLTE) as shown in Figure 1. Hence most submarine cable system design has only been optimized for the length of the cable between the CLS locations. This legacy architecture has the following inherent limitations:

Provisioning: Requires longer procurement and provisioning cycles due to multiple termination points and limited providers in some cases.

Lower Resiliency: This architecture requires connectivity to multiple POPs on terrestrial networks with amplifier huts in route that introduce multiple points of failure.

Poor Latency: Longer routes along with back-to-back terrestrial transponders introduce more latency with transponder FEC and other equipment in POPs in route.

Higher Costs: Leases or IRUs for capacity along multiple backhaul routes, operation of terminals and inline amplifier locations, and dealing with multiple backhaul providers leads to higher CAPEX and OPEX.

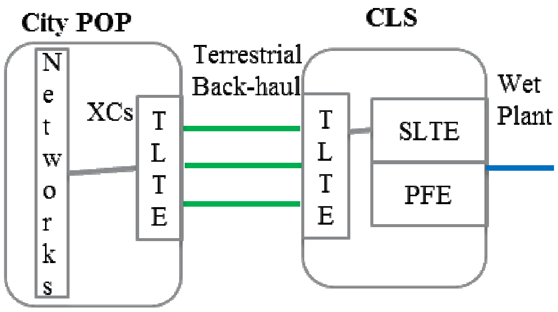

Figure 1. Traditional CLS and Back-haul Network Architecture

4. INTEGRATED SUBSEA AND FRONT-HAUL TERRESTRIAL NETWORK ARCHITECTURES

Integrated CLS in Coastal City POP:

The architecture shown in Figure 2 integrates all components of subsea cable termination into a coastal city POP. Because of high voltage power and ground cables between BMH and PFE (located in city POP), the distance of the dry plant for this front-haul architecture is generally limited to less than 10 Km. Location of the SLTEs in the coastal city POP allows all subsea capacityto cross connect to existing networks in the POP as well as to cloud and content providers that may choose to cache their content at the same coastal city POP location. City POPs such as DC offer 24X7 operations, security, redundant power, and some may offer the interconnection with other DCs in the same metropolitan area.

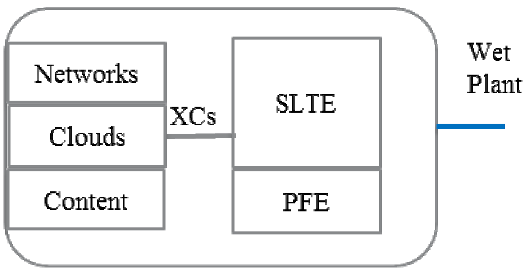

Figure 2: Integrated CLS in City POP

Integrated SLTE in City POP:

The architecture shown in Figure 3 locates the PFE in a protected facility near the BMH with wet plant fiber pairs spliced to terrestrial dark fiber pairs connecting to a city POP or data center where the SLTE is located. The terrestrial fiber pairs can be deployed over diverse physical fiber paths. This ensures protection of the traffic using network optical protection equipment such as optical couplers and optical switches [4].

It is possible that some of the subsea cable capacity can terminate at the PFE station if end customer location is near by. If the city POP, housing the SLTE, is in reasonable proximity to the BMH, no inline optical amplication is required. This distance is typically less than 100 Km from BMH. This type of architecture is suitable for large coastal metro areas such as Los Angeles, New York, Hong Kong, Tokyo, Singapore, and Mumbai to name just a few. An extension of this architecture is discussed next.

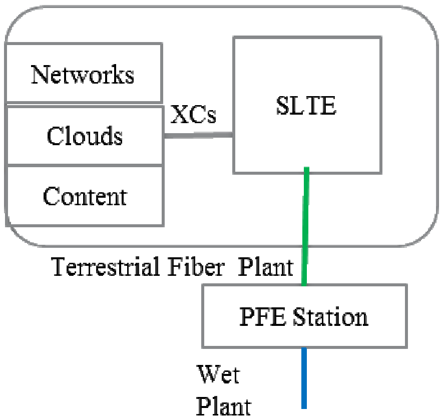

Figure 3: Integrated SLTE in City POP and PFE Station closer to BMH

Integrated SLTE in City POP with Terretrial Long-haul Dark Fiber Network:

An extension of the previous front-haul architecture uses much longer terrestrial fiber routes from a few hundred Km to over a thousand Km of terrestrial dark fiber route(s) to distant city POPs or cloud and content providers own data centers. Such an architecture requires new generation low loss dark fiber routes, use of remotely optical pumped amplifiers (ROPA), and a few inline amplifier huts along the path. The integrated optical network consisting of wet and dry plant between city POPs on both ends of the subsea cable system need to be carefully designed as a single network for optimization.

Integrated SLTE in multiple City DC and POPs with Spectral Management:
The architecture shown in Figure 4 splits spectrum on the wet plat plant fiber at the PFE coastal facility and may use multiple terrestrial fiber routes to the respective city POP destinations. For example, 96X100G channels on a fiber pair can be split in to 32X100G channel bands with each band destined to three different city POPs. This architecture is feasible to implement today with conventional or flexible grid reconfigurable optical add drop multiplexer (ROADM) technologies. This architecture is beneficial to reduce the number of wet plant fiber pairs and overall project costs.

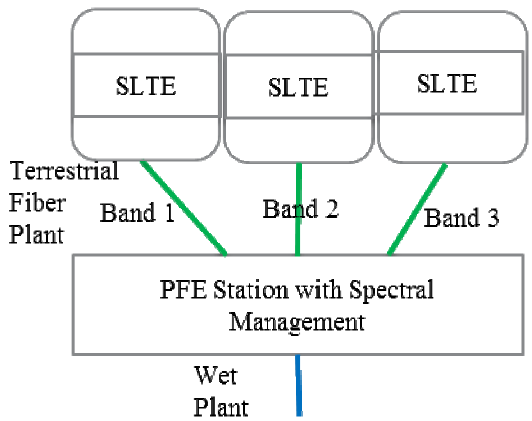

Figure 4: Integrated SLTEs in Multiple City POPs and PFE Station with Spectral Management

Integrated Terrestrial Fiber Network with Unrepeatered or Festoon Submarine Cables:
The architecture shown in Figure 5 uses unrepeatered wet plant in point to point or festoon type configurations. Wet plant for these type of systems typically uses high fiber counts such as 72 pairs or 96 pairs.. Wet plant fibers and terrestrial fibers are spliced at landing points (LP). Submerged Branching units (BU) provide drop of the wet plant fibers. Remote optical pumped ampliers (ROPA) and conventional amplifiers huts could be present on the terrestrial fiber. Customers typically lease dark fiber pairs and procure their own equipment. ROPAs can be used for wet plant in low fiber count unrepeatered links or festoon networks [5]. Existing or new unrepeatered submarine links between two islands or between an island and main continent can also serve as segments of front-haul for transoceanic cables.

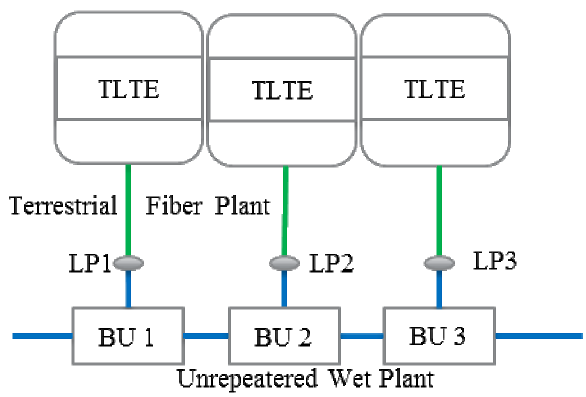

Figure 5: Passive Unrepeatered / Festoon Wet Plant with TLTEs in City POPs and DCs

5. SYSTEM DESIGN CONSIDERATIONS

System designers employing front-haul architectures need to evaluate various design considerations. They include:

Reach: System reach extension beyond the wet fiber plant is possible with the advent of advanced modulation schemes, coherent detection, ROADM, and ROPA optical technologies. However, desktop studies and designs should factor the terrestrial fiber plant type and loss characteristics. New ultra low loss SMF28 fiber type is preferred for terrestrial fiber. Cable owners may need to secure long-term IRUs on relatively new fiber plant before consideration for going public with landing locations.

Capacity: Shorter reach subsea cables can consider 8 QAM or 16 QAM for higher channel rate of 200 Gb/s to increase system capacity.

Dry plant protection: As described earlier, diverse terrestrial cable route consideration increases the system resiliency.

(Re)Configuration: The degree of configuration and reconfiguration is facilitated based on the selection of conventional or flexible grid ROADM technologies.

Choice of POP terminal location(s): Consideration of secure terminal location with reliable power supply is important for submarine cable owners. Just as important is an open and carrier neutral location with a market place of customers reachable with fiber cross-connects should factor into the POP selection criteria.

6. BENEFITS

The architectures described above address the limitations of traditional submarine cable back-haul architectures as follows:

Ease of Provisioning: Since there is only one line termination equipment (SLTE) instead of multiple backhaul systems between city POPs and the CLS, provisioning cycles are improved. Advances and application of new control plane technologies such as software defined networking (SDN) to submarine cable and termination equipment may further improve system provisioning and monitoring.

Resiliency: Resiliency is improved since there are fewer points of active equipment.

Latency Improvement: Removal of additional sources of latency such as terrestrial transponders with FEC improves latency. City POP selection with existing target customer base connecting to subsea capacity with simple fiber cross connects also improves latency. Latest generation of express path subsea cables with shortest terrestrial path extension also contribute to the latency improvements.

Improved Economies: Locking-in favorable long term IRUs for least number of fiber pairs from BMH to city POPs, eliminating separate terrestrial transport systems (back/back transponders), and sharing of city POP space with many occupants versus sharing a CLS with few occupants improves CAPEX and OPEX. Utilizing local DC O&M services on as needed basis over dedicated O&M personnel allows for OPEX savings.

7. CONCLUSION

A combination of recent optical transport technology advancements and new submarine cable deployment strategies enable the consideration of various front-haul network architectures to integrate with emerging subsea cables. Application of these network architectures along with careful selection of city POPs for housing SLTE are beneficial design choices that lead to business success for subsea cable owners.

8. REFERENCES

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