# PHOTONIC CABLE LANDING STATIONS

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**Abstract:** For decades, the submarine networking industry designed and implemented network technologies differently from their terrestrial counterparts, primarily due to the long distances involved with transoceanic routes. However, over the past few years, many new optical transmission technologies initially developed for long haul terrestrial networks have since found their way into submarine networks.

## 1 INTRODUCTION

The relentless increase in intercontinental bandwidth demand in all regions of the world has forced submarine cable operators to investigate innovative solutions to extend the lifespans of their existing undersea network assets to defer the decision to invest in new and costly submarine cable builds, especially where continents are already connected. The path from conception to *Ready for Service* (RFS) of a new submarine cable is extremely costly and financially risky making upgrading existing submarine cables a far more attractive alternative, which is why many new submarine cables intended to increase capacity along already serviced routes have been deferred, or cancelled altogether. Wherever possible, network operators are choosing the more feasible path of upgrading existing channels from legacy 10 Gb/s technologies to newer coherent-based transmission technologies operating at 40 Gb/s and 100 Gb/s rates. The simple swapping of Submarine Line Terminating Equipment (SLTE) transponder cards is a quick and risk-free method of breathing new life into aging submarine networks, at least until these cables approach *End of Life* (EOL) status. Coherent-based optical transmission technology was initially developed for long haul terrestrial networks but in 2008 was introduced into submarine networks and since then has since become the de facto standard for upgrading existing undersea wet plants to 40 Gb/s and 100 Gb/s. Another technology initially developed for terrestrial networks is the Reconfigurable Optical Add Drop Multiplexer (ROADM), which complements coherent-based transmission technology and together have seriously challenged legacy Cable Landing Station (CLS) designs.

## 2 COHERENT-BASED OPTICAL TRANSMISSION TECHNOLOGY

In just a few years, coherent-based optical transmission technology has quickly become the de facto standard for increasing capacities over both terrestrial and submarine networks. As such, submarine cable operators around the world are diligently upgrading from legacy 10 Gb/s technology to coherent-based 40 Gb/s and 100 Gb/s technology. Although the decision to upgrade from legacy 10 Gb/s to either 40 Gb/s or 100 Gb/s has recently been dictated by network economics and desired reach, coherent-based transmission technology continues to evolve at a frenetic pace resulting in 100 Gb/s soon to become the de facto line rate standard for all network segments, including transoceanic routes. This means using the same technology and line rate over a great variation of network segments yielding significant economies of scale that will benefit both optical vendors and network operators alike. A common optical transmission technology, regardless of the network segment, means simplified global network designs, overland and undersea, resulting in reduced inventories, learning curves, and most importantly, network operating costs.

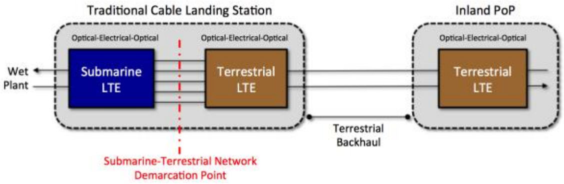
The significant performance improvements offered by coherent-based transmission technology has quickly led to its acceptance in both terrestrial and submarine networks the world over. In fact, there are cases where 40 Gb/s and even 100 Gb/s was proven operational over difficult fiber plants whose characteristics prevented operators from moving from 2.5 Gb/s to 10 Gb/s, which is a real-world testament to the incredible performance leaps of coherent-based optical transmission technology. The benefits of this innovative technology enable new network design possibilities that seriously challenge many traditional practices. One such area is within the CLS where significant improvements and optimization is now possible, which leads to the elimination of the traditional *demarcation* point where submarine-facing equipment hands off traffic to terrestrial-facing equipment. This demarcation point is where multiple optical-electrical-optical (OEO) stages are located and through its elimination, significant savings in cost, complexity, latency, power and space is achieved. The ROADM facilitates the elimination of this demarcation point.

One contributor to network latency is Forward Error Correction (FEC), which offers coding gain improvements in the electrical domain that improves achievable reach. When FEC was first introduced, the primary design goal was to achieve the highest coding gain possible to increase achievable reach and reduce operating costs through the elimination of expensive regenerators (REGENs), which due to their OEO stages and embedded functionality, also increased latency and network complexity. To achieve the greatest achievable reach, several high performance FEC algorithms were introduced that performed significant amounts of complex calculations resulting in added network latency. Low latency was not a primary design requirement at the time so these algorithms met their stated goal, which was to achieve longer reaches between REGEN stages. However, latency-sensitive applications such as video streaming, cloud-based services, and financial transaction services continue to proliferate resulting in more stringent latency requirements on global network designs. This means that traditional FEC is quickly becoming a hindrance to the adoption of certain services so new FEC schemes are required, such as soft-decision FEC implementations.

Compensation in the cost-effective electrical domain facilitates the incorporation of complementary technologies that further enhances coherent optical networking capabilities, such as the implementation of *soft-decision FEC*. Traditional transmission offerings incorporated *hard-decision FEC* where receivers determined if a received bit is a *one* or *zero* based solely on a decision threshold. In contrast, soft-decision FEC incorporates probabilities into its decision algorithm allowing error correction decisions to be made with additional information that yields significant increases in optical reach and capacity via improved link budgets. Embedding *Analog-to-Digital Conversion* (ADC) and *Digital Signal Processing* (DSP) functionality into the coherent receiver facilitates soft metrics being readily available to implement soft-decision FEC. Optical transmission systems must provide service providers with *Bit Error Rates*

(BER) better than $10^{-15}$ meaning complicated mathematical algorithms are necessary, since performing multi-bit operations on signals operating at 100 Gb/s means 100 billion information bits are received each second creating vast data flows requiring incredulous associated processing capabilities. However, due to its "*soft*" nature, *software-provisionable* FEC, or *tunable* FEC, is made possible such that the FEC performance, and the amount of required calculations, can be *tuned* to achieve the required link budget performance using the minimum of required FEC, which in turn minimizes the latency incurred by the FEC engine resulting from its calculations performed.

Submarine cables are typically book-ended by terrestrial backhaul segments that connect the CLS at each end to inland *Points of Presence* (PoPs). These three network segments were traditionally designed and deployed as distinct network entities interconnected via standards-based SDH traffic handoff points. With the recent advent of coherent-based optical transmission technology, and its significantly improved achievable reach, in many cases there is sufficient available link budget to allow traffic to propagate in the photonic domain over all three network segments from inland PoP to inland PoP. This eliminates the need for multiple OEO stages (REGENs) along the two terrestrial backhaul segments at each end of the submarine cable. By eliminating REGENs, the PoP-to-PoP network link is significantly reduced in terms of cost, latency, power, space, and complexity through the elimination of network equipment both within the CLS and the terrestrial backhaul segments. Although strong soft-decision FEC is now integrated into the Submarine Line Terminating Equipment (SLTE), it is also tunable and can be optimized for specific link requirements, and since multiple REGENs are eliminated over the end-to-end network link, the overall latency will still be significantly reduced to the benefit of both network operators and their customers.




**<u>Figure 1</u>: Traditional Cable Landing Station Transport Network Elements**

Security is always on the minds of network operators so any method of further securing inflight data flows is highly valued. The inherent manner in which coherent-based transmission technology works makes it quite difficult to monitor by unwanted 3rd parties along the route. Complex soft-decision FEC, real-time performance optimization, and feedback loops between transmitter and receiver make tapping a coherent-based network a significant challenge indeed. By eliminating REGENs sites along the route, where signal are brought back into the more easily accessible electrical domain, further increases the security of coherent-based transport networks. Significant improvements in link budgets afforded by coherent-based optical transmission in many cases allow SLTE to be physically relocated to the inland PoP, which is typically a data center or carrier hotel, making it far easier to control physical access when compared to a CLS situated in a remote location. Improving inflight data security via the ability to optically traverse submarine and terrestrial backhaul segments is a significant benefit of coherent-based optical networks.

## 3 RECONFIGURABLE OPTICAL ADD/DROP MULTIPLEXER (ROADM)

Another optical networking technology initially targeted at terrestrial networks is the ROADM, which offers multiple tangible benefits to network operators. Two such benefits are channel bitrate-independence and the ability to remotely switch (route) incoming wavelengths to different optical network paths either via human or autonomous operations. Although network operators can use passive optics to route wavelengths, when compared to ROADMs, passive optics require manual operations implying onsite human presence for each operation, which can be difficult, costly, and time-consuming for the CLS situated in a remote location. Manual operations are also highly error-prone, and considering the amount of traffic landing in the CLS, can be disastrous when leading to network degradation or outages. ROADMs incorporate software intelligence that prevents erroneous operations and eliminates the need for people having to travel to the CLS at each end of the submarine cable by offering the ability to switch wavelengths from any convenient remote location. The ROADM is also a key building block of an autonomous optical network, governed by an intelligent control plane, which is the foundation for Software Defined Networks (SDN) where the network becomes a pool of programmable assets available to upper applications, such as cloud operating systems.

The ROADM benefits expressed above are equally applicable to terrestrial networks explaining why they are already commonly found in metro, regional, and long haul terrestrial networks. The most recent network area for ROADM adoption is the submarine network, and in particular, the CLS where terrestrial and submarine networks meet, which is referred to as the terrestrial-submarine demarcation point. Since currently available coherent-based optical transport solutions are equally applicable to both submarine and terrestrial networks, this demarcation point will quickly become a relic of the past since it can now be eliminated by optically passing the wavelength to and from the submarine cable using either passive optics or ROADMs, although the latter is the far better approach. Wavelengths coming from the submarine cable into the CLS can be destined for the inland PoP, via the terrestrial backhaul network, or destined for the next CLS along the greater submarine network. Using the combination of coherent-based SLTE and agile ROADMs, the destination can be dynamically changed based on evolving network demands. In many cases, ROADMs can and have been configured to offer optical route protection without the need for costly OEO conversions. As the achievable reach afforded by coherent-based transport solutions continues to increase, the addressable application space for PoP-to-PoP networking will also increase further inland. It is the combination of coherent-based transmission and ROADMs that have united submarine and terrestrial networks.

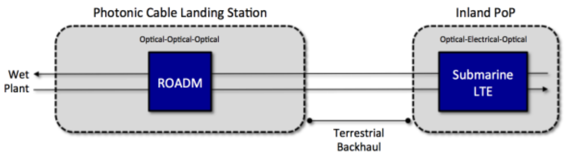



**Figure 2: Photonic Cable Landing Station Transport Network Elements**

Unlike REGENs, ROADMs are both bitrate-independent and protocol-independent meaning they can switch incoming wavelengths equally well be they 10 Gb/s, 40 Gb/s, 100 Gb/s, SONET, SDH, or Ethernet. This enables significant flexibly in that network operators can easily upgrade channels from legacy 10 Gb/s to coherent-based 40 Gb/s and 100 Gb/s rates without having to change all REGEN cards within the CLS and along terrestrial backhaul routes. This provides the important benefit of future-proofing a CLS as optical transport technologies continue to evolve. In a traditional CLS, a clear submarine-terrestrial demarcation point exists along with multiple OEO handoff stages, so upgrading from 10 Gb/s to higher channel rates means upgrading all OEO stages along the entire PoP-to-PoP route. ROADM bitrate and protocol independence, along with its many other enabled benefits, is why the photonic CLS has quickly gained acceptance in submarine networks around the world and will continue unabated.

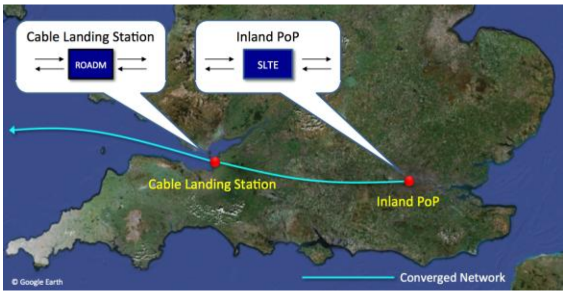



**Figure 3: Converged Global Network by Leveraging Photonic Cable Landing Stations**

## 4 CONCLUSION

As cloud services continue to gain in popularity, the increased distances between end-users and their data will result in stricter performance requirements imposed upon the global network infrastructure in terms of capacity, availability, latency, packet loss, and inflight data security. The *Quality of Experience* (QoE) for cloud services delivered over the global network, overland and undersea, is expected to be similar to the QoE when data centers are located far closer to the user if global cloud services are to proliferate, especially *Infrastructure as a Service* (IaaS). Simplifying the global network by optimizing the CLS itself is a step in the right direction in helping to achieve these often conflicting network design goals. Cloud services are here to stay so preparing for them is simply prudent.

Intensified competition in all regions of the world has resulted in significant price erosion, even in the face of voracious bandwidth growth. To remain competitive, and financially viable in the long term, global network operators are seeking new options that challenge traditional network design guidelines to improve service differentiation and protect shrinking profit margins, especially related to wholesale services. Operating cost optimization achieved via global end-to-end network simplification reduces capital and operating expenses helping to combat global price erosion resulting primarily from hyper-competition. The recent convergence of optical networking technologies allows service providers to benefit greatly from economies of scale using a common networking technology overland and undersea. The photonic CLS ensures a seamless handoff between terrestrial and submarine networks so this technology convergence can be fully leveraged across the entire global network.