# Operator View: Drivers in the Submarine Networking Industry Today and moving Forward

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**Abstract** *This paper examines the current state of submarine networks and reviews their evolution in the light of traffic increase. The technical challenges of future submarine systems and required breakthroughs are also identified and discussed.*

## Introduction

The use of optical technologies to transport digital communications between continents has radically changed the perspectives of international connections. The old competition between submarine cables and satellites has largely turn into the advantage of wet solutions mainly due to the reliability of submerged equipments (25-years guaranteed), the transmission capacity, and the bandwidth cost.

The optical amplifier technologies were first introduced by mid 1990's on each of the two main submarine routes at that time (transatlantic TAT-12/13 and transpacific TPC5). Initial capacity was 5Gbit/s per fibre on a single wavelength. In less than 10 years, huge technological improvements like wavelength division multiplexing (WDM), chromatic dispersion management, forward error correction (FEC), repeaters performances (output power and noise figure) and advanced modulation techniques have enabled commercial systems to exceed the capacity of 100 channels at 10Gbit/s per fibre.

Meanwhile, the worldwide traffic has been increasing by about 40% each year since the end of Telecom hit in 2000 - 2002.

The objective of this paper is to review the reasons that explain the growth in bandwidth demand on intercontinental networks and its impacts on submarine systems.

## What are submarine networks?

Submarine transmission networks have been deployed to satisfy needs for communication between different continents. Since the first transatlantic telegraphic message between the Queen Victoria and the US President James Buchanan the 16th of August 1858, needs for communication have largely evolved from telegraph to voice. Today, submarine networks mainly carry internet and data traffic (Fig. 1)[1].

To meet this objective, submarine system must guaranty end to end transmission with very high performance and availability. The submerged plan must address the optical transmission challenges as well as the extreme environmental conditions.

Given their complexity and scale, submarine networks are usually very expensive. Most of them are thus operated by consortia of operators who share the system property, construction, maintenance and capacity assignments. This specific structure allows Telco's to alleviate investments and to mutualise forces.

## A short review of lit capacity

Since 2000, the number of submarine links has irregularly grown depending on geographical areas and following the usual "ups and downs" behaviour of the submarine market:

- Transatlantic route was massively equipped at the beginning of 2000's before the global downturn of the optical transmission market. The resulting overcapacity has driven several carriers' carriers to the bankruptcy. All systems have been upgraded today and no new deployment is expected in the next few years[2].
- Several high capacity cables have been upgraded or installed onto the Europe to Asia route since 2004 and the revival of submarine market.
- Intra Asia and transpacific areas have seen a considerable growth of lit capacity since the second part of years 2000. This can be partially attributed to 2008 Olympic Games in Beijing but also to the economical development of Asiatic countries.
- African area and to a less extend the South America are today probably the most active regions in terms of new cable deployments.

The global lit capacity per routes indicated in Fig. 2 at the end of 2009.

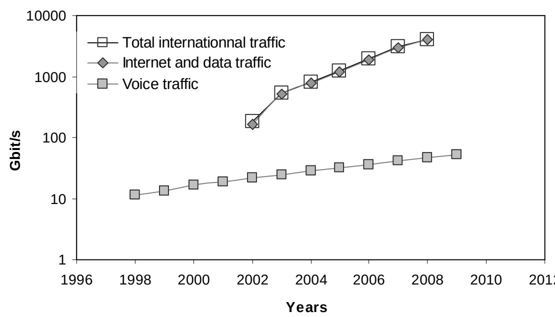


**Fig. 1:** International mean traffic growth by segments (Internet and data, voice)

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## Drivers of submarine bandwidth demands

### 1. Internet Worldwide Expansion

A well known driver for international traffic growth is the expansion of Internet with a continuous increase of the number of subscribers of high bitrate access[3]. African traffic grows very fast, especially due to mobile penetration rate, but still represents a small fraction of the international exchanges. This is partially due to the limited existing connections between African countries and the rest of the World as it can be seen in Fig. 2. The recent cable deployments and the projects under implementation or study will certainly contribute to the economical development of this continent which should generate more and more revenues in future. Also a combined evolution between terrestrial backbone and submarine systems will be essential to deliver the bandwidth to African end users, develop local economy and progressively replace expensive satellites connections.

Today, many initiatives are pending, which make the African area one of the most attractive places for submarine system deployments and a source for intercontinental traffic increase in the coming years.

### 2. New bandwidth consuming services

Fig. 1 represents the international annual mean traffic volume since 2002. The growth is about 40% at the top of the range of the forecasts made in 2006[5]. The trend for traffic growth seems to remain strong for the next few years even in the context of the current global crisis. Current bandwidth demand is mainly boosted by data transport and video sharing which are expected to even accelerate in the future, due to the continuous request for high-speed services. Fast development of bandwidth consuming services like high-definition TV, TV on demand, audio and video file sharing through dedicated web services (e.g. YouTube, Dailymotion) or with peer to peer (P2P) exchange, grid computing, and social networks (e.g. MySpace, Facebook) requires more and more transmission capacity. As an example, today, video sharing represents the biggest share of Internet traffic.

The continuous increase of bitrates in access networks, and the acceleration of FFTx deployments are expected to dramatically increase the amount of traffic in the next years. However, the expected growth of the access networks cannot be easily translated in terms of traffic increase in the international networks. The actual impact is hard to predict and will strongly depend on the traffic regulation (if any) operated by the Telco's and on the strategy of location of the data centres in the networks.

### 3. Real time applications and user-friendliness

New services and usages are also indirect drivers for

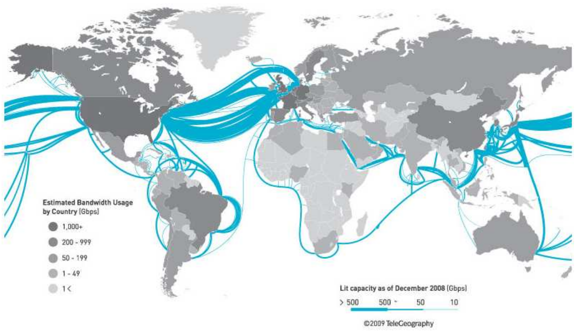


**Fig. 2:** Submarine lit capacity at the end of 2008. Source TeleGeography[4].

submarine deployment.

Services based on real time and interactive communications are steadily rising and have a great potential for development. The high quality of service (QoS) (availability, latency) required by e-health, network gaming and video-conferencing for example, has a non negligible impact on networks architecture and also on intercontinental systems that have to provide these services with the required bandwidth and the most performing transmission solutions.

Similarly, the internet appropriation by users allowed by the development of web 2.0 applications has changed the place of Internet in the people life and their expectations. Waiting for a web page loading seems now to be something abnormal. A high quality of connection with a guaranteed speed (even unlimited!!) is today the minimum expected by users. If the amount of international traffic generated by these new usages is not easily predictable, the associated connection speed evolution is clearly a factor that will increase the traffic.

### 4. Cost reduction thanks to technology improvement

The effective introduction of new technologies in the transmission systems market usually meets a need for additional capacity or a potential investment (CAPEX) or operational (OPEX) costs saving. In this sense, the new technologies are enablers for capacity increases in balance with demand increases. But they are also a driver for submarine network deployments when they allow system operators to reduce the cost of their systems and of the associated traffic for the benefit of the end user, so opening new markets for the international traffic. Fig. 4 presents the dramatic cost reduction of submarine systems since 1997 that can be explained for a large part by the technology improvement[6].

### 5. Traffic protection through submarine cables diversity

As mentioned above, integrity of transmitted data is a key issue especially for new services. Submarine systems are highly reliable and can usually offer less

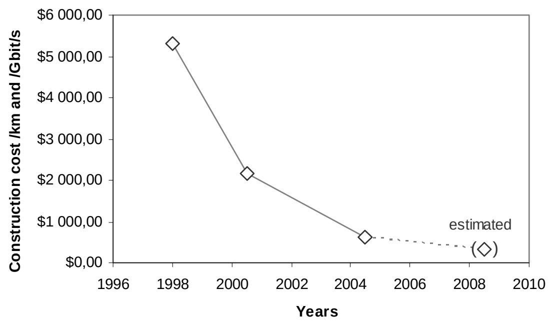


**Fig. 4:** Construction cost, defined as initial cable construction cost divided by total length and initial capacity for submarine systems exceeding 3000km and 10Gbit/s capacity[6]

than 5 min/year outage thanks to various protection schemes. Whether the protection is achieved through channel redundancy inside the cable or through purchased bandwidth in other cables, the result is that the high availability required for submarine cables makes mandatory the deployment of back-up bandwidth (dedicated for protection or not) with adequate dimensioning. Cable diversity remains fundamental to meet the availability criterion for submarine networks and a strong driver for capacity deployment. This holds true even when upgrading systems, as restoration plans have to be updated after each increase of capacity. This may be problematic when the upgrade capability is not the same on each cable. In that case, other solutions including new cable deployment have to be considered.

**Technical challenges**

**1. 40Gbit/s available technologies**

Since many years now, 40Gbit/s systems have been understood as the next step for submarine systems by the Industry. Although 40Gbit/s has never been deployed on submarine networks, it is still widely discussed in forums and is frequently part of the Invitation To Tenders (or Request For Proposal). The delay of 40Gbit/s introduction into submarine networks can be explained by the downturn of the telecom market at the beginning of years 2000. The 40Gbit/s systems development costs could not balance their hypothetic revenues. This has also been emphasized by the cost of components compatible with 40Gbit/s transmission. Moreover, most of the supplier's experiments were usually lab oriented and did not always take into account the field constraints (e.g. Polarization Mode Dispersion (PMD) especially) and consequently were not adapted for real deployment. Meanwhile, the development of enhanced hard/soft FEC decoding and Differential Phase Shift Keying (DPSK) format at 10Gbit/s made possible long transmissions with 25GHz channel spacing and satisfactory margins, delaying the need for 40Gbit/s channels.

Even today 40Gbit/s remains the next submarine standard and the main technical challenge it will face will be PMD. If the PMD issue was solved at 10Gbit/s choosing adapted fibres for trans-oceanic propagation distance, this can not be applied anymore because even drastic fibres characteristic are not today able to match with 40Gbit/s constraints over such distances. Thus PMD issue at 40Gbit/s must be mitigated on the dry side. Two types of solutions are likely to be commercially proposed at 40Gbit/s: (i) DPSK modulation format with additional PMD compensator at receiver end and (ii) DQPSK format (20Gbaud symbol rate is compatible with typical PMD of most of the submarine fibres). Based on them, many lab experiments have demonstrated that 40Gbit/s channels can be deployed over long distances. Some examples of the most recent experiments are reported in Tab. 1.

It is worth noting that most of the 40Gbit/s experiments uses Dispersion Managed Fibres (DMF)[7-10]. They are composed of concatenated sections of positive and negative chromatic dispersion fibres in every span to maintain close to zero the chromatic dispersion slope. This fibre management is already used at 10Gbit/s for some systems[11] but is usually deployed only for very long haul systems. However, even if no 40Gbit/s system was deployed to date, more and more operators are seeking for compatibility when building their 10Gbit/s system and are ready to use DMF despite its additional cost.

Unfortunately, the ratio between extra cost / extra capacity seems not to be in favour of the 40Gbit/s system design approach yet[12]. With current technology, 40Gbit/s will most probably be introduced for specific customers requests in upgrades of existing cables.

However, upgrades of 10Gbit/s legacy system with 40Gbit/s channels can cause clear issues. Indeed a 40Gbit/s channel using phase modulation surrounded by 10Gbit/s intensity modulated neighbours is strongly penalized by cross non linear effects[14]. A guard band is mandatory to minimize interactions, and part of the potential extra capacity is lost.

As explained above, current solutions proposed for 40Gbit/s are not perceived as suitable solutions for common 40Gbit/s deployment. Necessary technological breakthrough will more probably come from coherent detection.

| Nλ | Modulation | Δλ (GHz) | Length (km) | Ref. |
|---|---|---|---|---|
| 40 | ApolRZ-DPSK | 100 | 9180 | 7 |
| 18 | RZ-DPSK | 133 | 6250 | 13 |
| 50 | PM-RZ-BPSK + PT | 66 | 5200 | 8 |
| 42 | RZ-DPSK | 100 | 4820 | 12 |
| 24 | RZ-DPSK | 133 | 4450 | 9 |
| 151 | RZ-DQPSK (C+L) | 50 | 4080 | 10 |

**Tab. 1:** 40Gbit/s recent submarine lab experiments overview (PM: polarization multiplexing, PT: polarization tracking using polarization controller, C+L: using C+L band)

## 2. Coherent detection

Since 2005, the application of coherent detection to signals based on phase modulation has gained a large renewal of interest. Improvements in electronic Analog to Digital Converters (ADC) have allowed the transfer of complexity from the optical Phase Locked Loop (PLL) to digital communication domain largely investigated by the radio community for a long time. This convergence between optical and digital communication opens the door to great developments for the next few years. Coherent detection has the ability to easily compensate for chromatic dispersion and PMD with almost no penalty on performances. These mitigations are performed thanks to digital signal processing (DSP) embedded in transponders. Moreover, coherent detection makes easier the implementation of polarization demultiplexing that allows to increase the system spectral efficiency[15]. This technology offers today the best alternative for 40Gbit/s deployment in submarine systems.

## 3. OADM branching Unit

OADM functionalities were first introduced on SMW-3 system. OADM nodes were inserted in the submerged branching units (BU) to allow the “add and drop” function of 1 or 2 channel(s) from the express path to the intermediate branch station using fixed Bragg filters. Unfortunately, this cost-effective solution to connect stations proved to be not well adapted to continuous upgrades scenarios observed today[16]. The upgrade of the branch capacity, beyond what original design allowed, was very challenging.

Alternative networks using express paths between the trunk stations and omnibus paths connecting branch stations were proposed and deployed. This solution is the most flexible in terms of upgrade capability because no filtering function are used within the full fibre BU. Unfortunately, it requires a dedicated fibre pair even if only a small number of WDM channels is provisioned on the omnibus path. Although the residual capacity can be used to carry express traffic, this solution requires that each branch station is equipped with back to back transponders. Depending on the number of branch stations, such upgrade(s) could become very expensive.

OADM with per segment upgrade capability could be the solution. Band OADM BUs as proposed today offer a good compromise between upgrade flexibility and cost. The natural evolution towards reconfigurable OADM in BU (as it is already proposed for terrestrial systems) remains however very challenging at two levels; (i) reconfigurable technology reliability (to be compliant with wet plan features) and (ii) consortium agreement to share the system capacity and cost.

## 4. Control plane

The control plane allows auto discovery of network topology, automatic and simplified end to end services provisioning, and dynamic restoration schemes. GMPLS (Generalized Multi-Protocol Label Switching) is the most standardized protocol suite for control plane issues. It is standardized to make possible the interoperability between different suppliers and to simplify multi layer interactions.

Traffic recovery is today usually based on pre-planned reservation of capacity, sometimes used for pre-emptible traffic. In the context of submarine networks, the use of control plane on several cables would permit dynamic resources allocation for restoration in case of single or multiple cable cut(s). Even if this solution is technically attractive, provided full interoperability between suppliers is achieved, the problem of implementation will stem from the fact that cables are usually owned by a large number of operators having all different contributions in each cable. For this reason, it seems today difficult to generalize GMPLS on submarine systems and a solution might be an implementation per operator depending on its strategy.

## Conclusions

The current state of submarine networks was presented. Drivers of their past and future evolutions were reviewed in the light of the worldwide bandwidth growth. Internet expansion with its collection of new usages bandwidth consuming, the capacity cost reduction allowed by technology improvement as well as traffic protection with routes diversity are today the mainspring of submarine network industry. 40Gbit/s deployments thanks to coherent detection, flexible OADM branching unit and control plane have also been identified as technical challenges for the next years.

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