OpticalCloudInfra

Subsea Cable System 101

24 August 2017

Content

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- Brief History
- Traditional Subsea Cable System Architecture and Components
- Optical Fiber
- Submarine Cable
- Repeater
- Branching Unit
- Terminal Equipment
- Evolution

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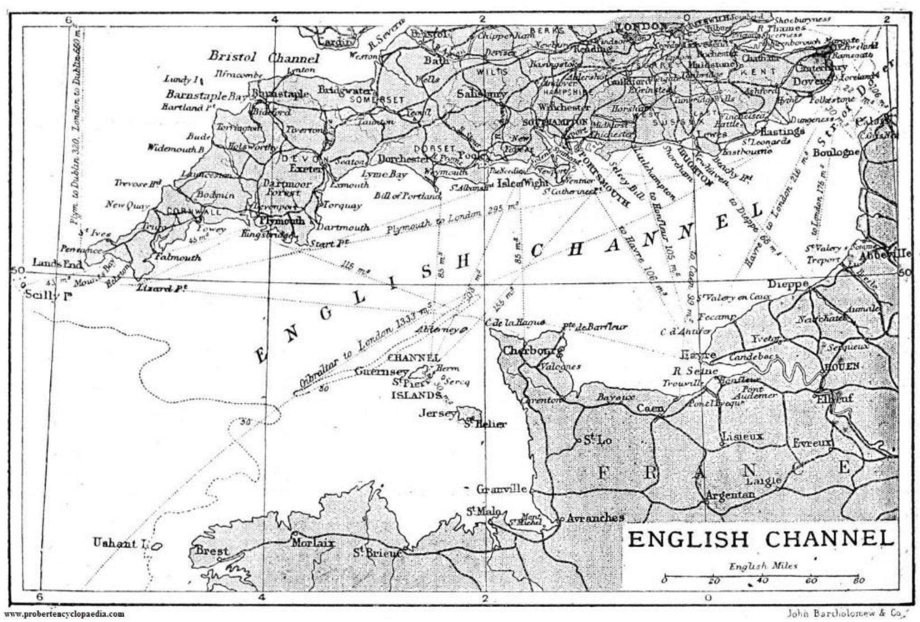
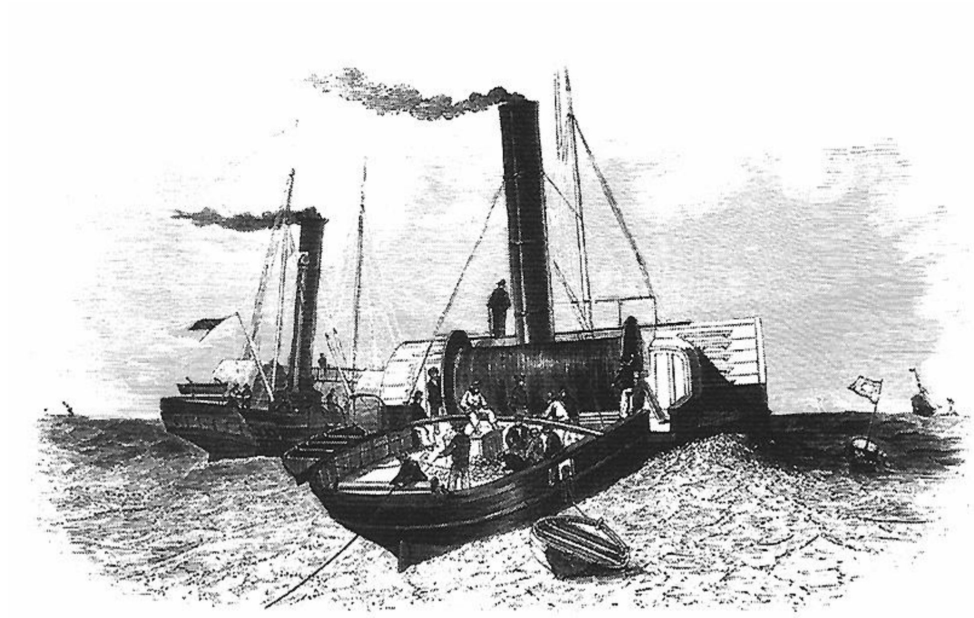
Brief History

At the Very Beginning

- **1850:** First international cable between England and France
  - 10 words per minute
  - Cable operated only for one day before being cut by fishermen





At the Very Beginning

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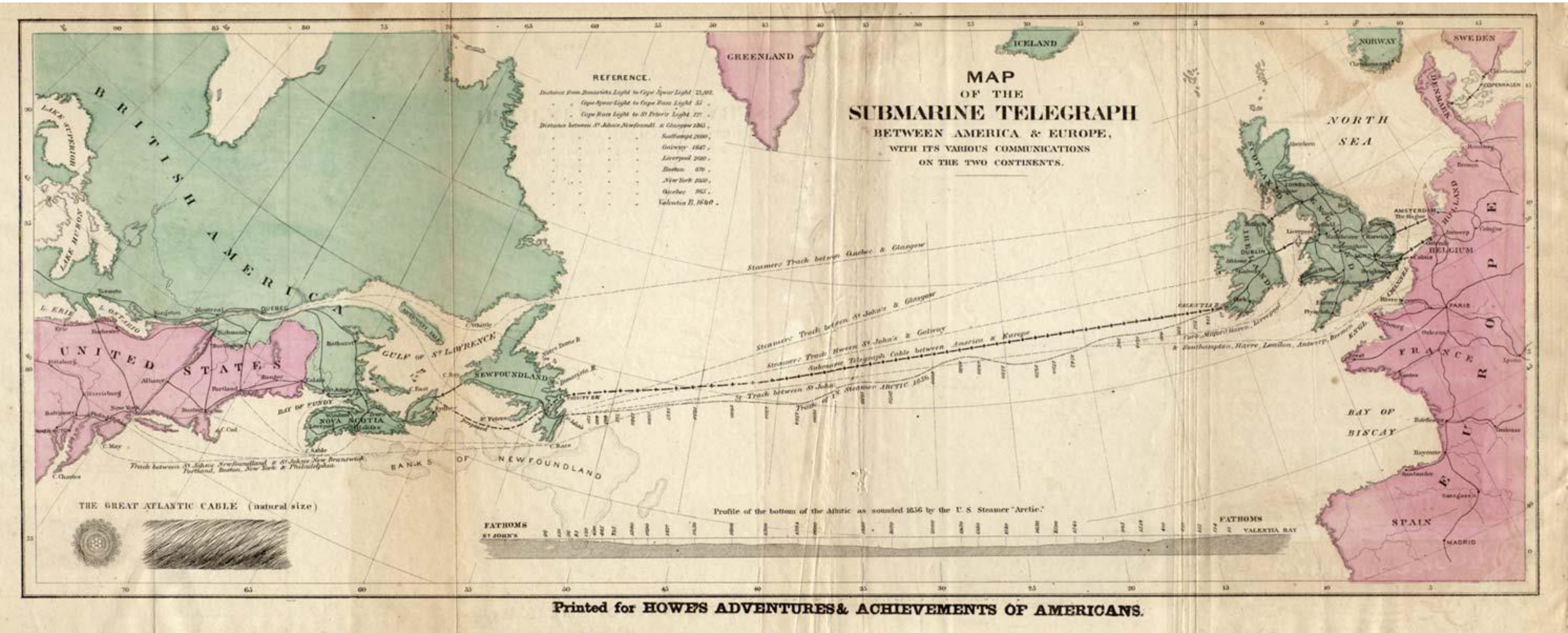
- **1866:** First real long-distance international cable (Ireland – Newfoundland)
  - A few previous attempts (but that did not last very long…)
  - 12 words per minute



First Global Cable Network (1870)

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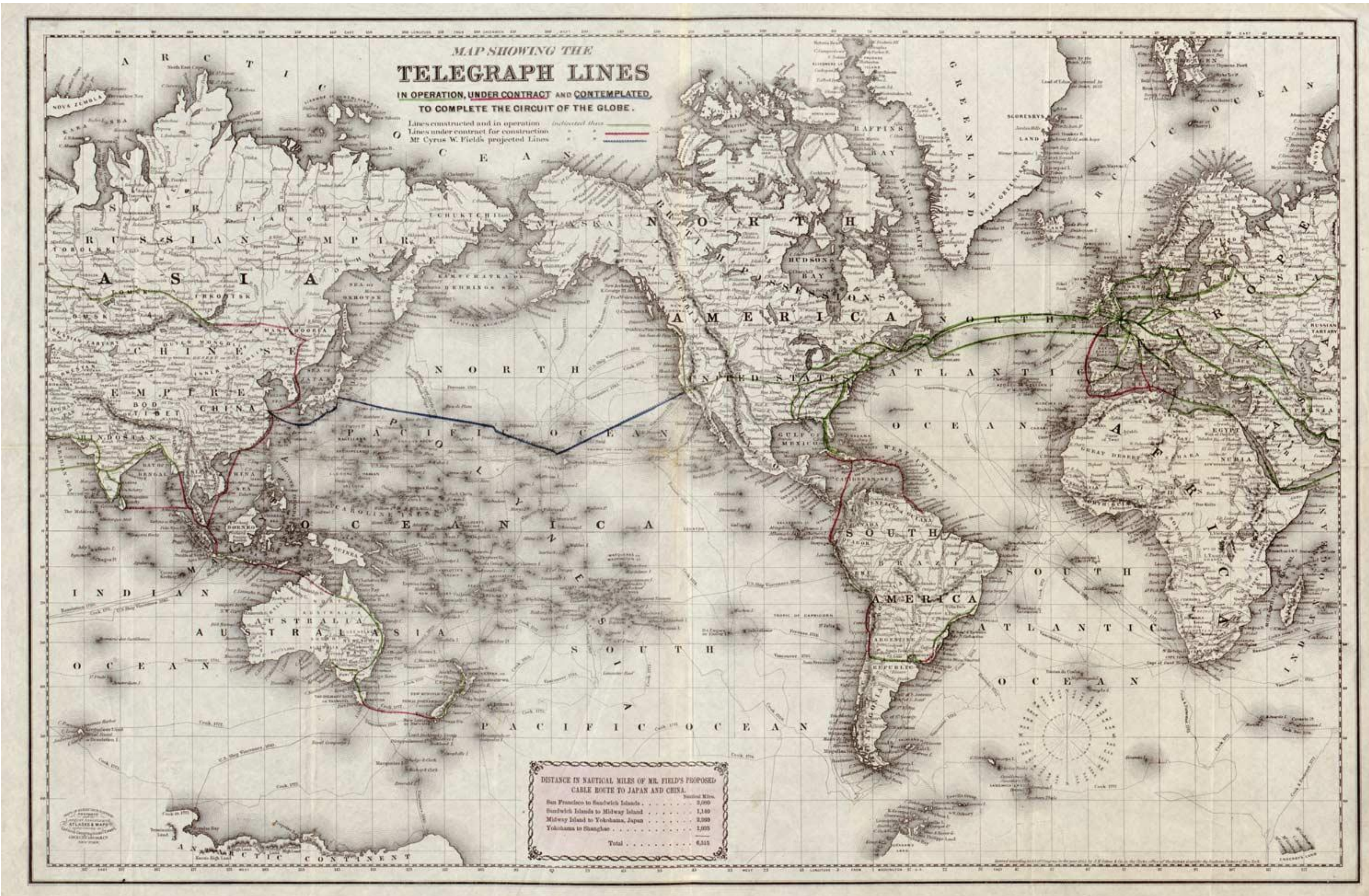
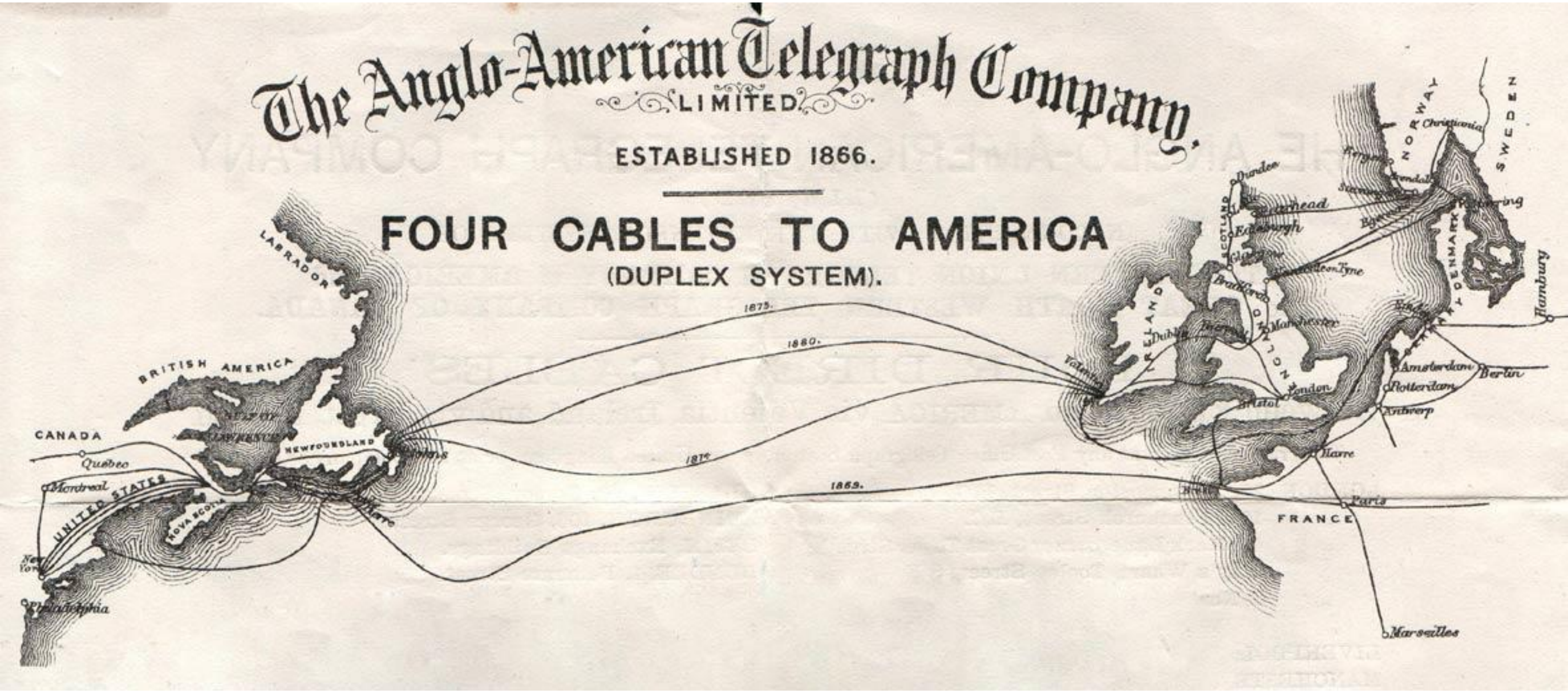


Need for Diverse Cable Route (1880)



More Global Cable Network (1924)

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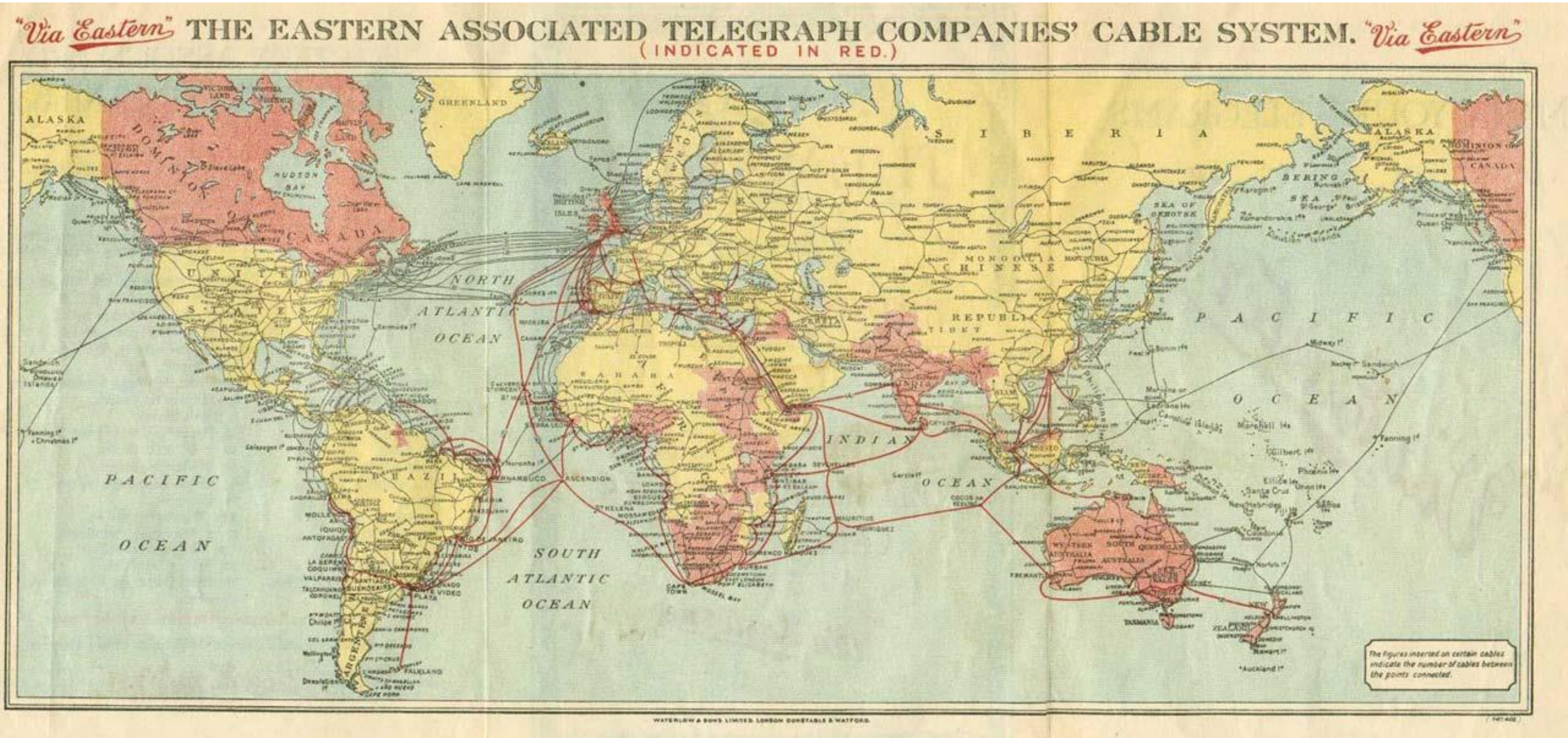

C&W Network Designed for British Empire (1947)

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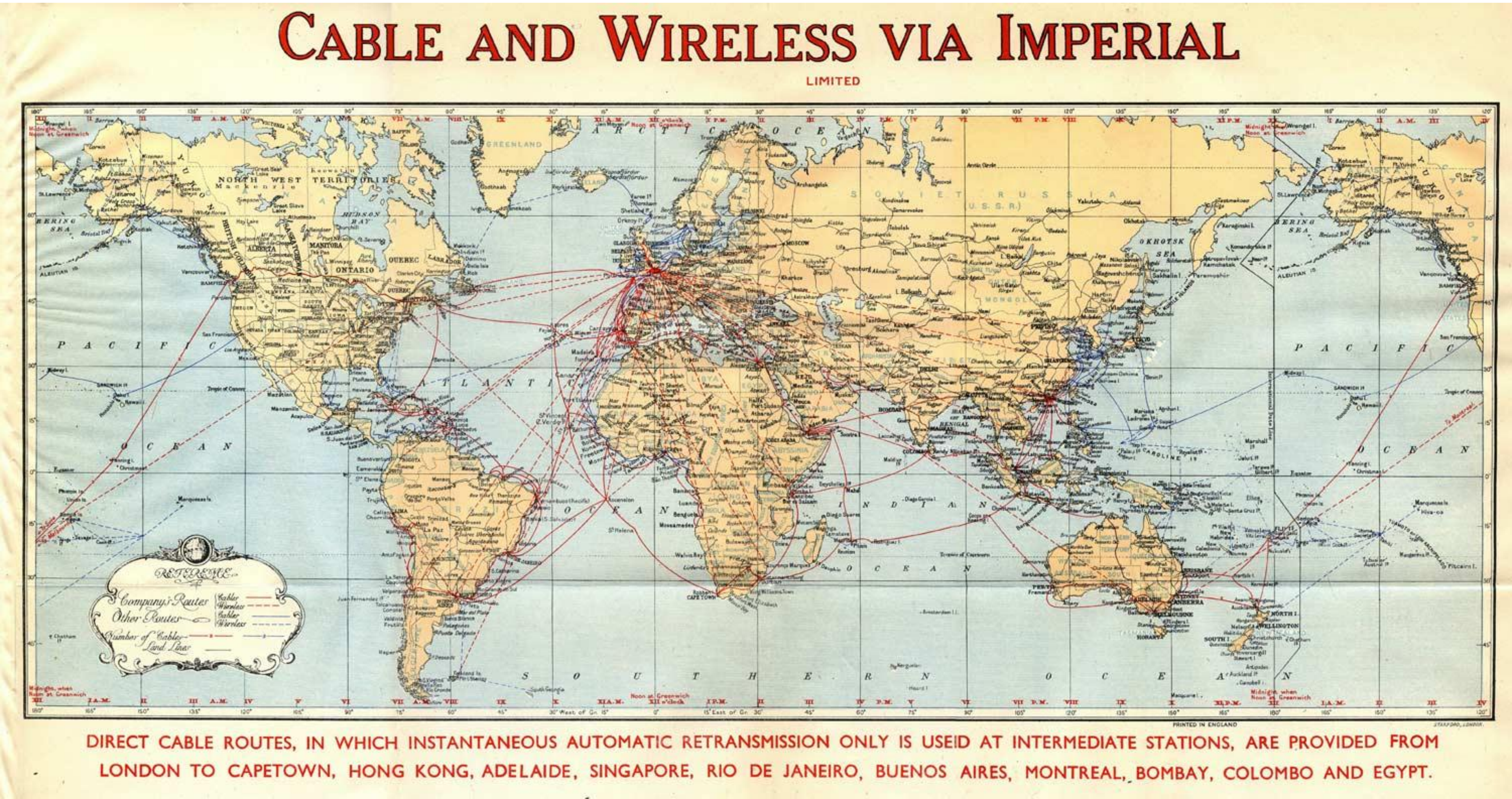

Global Cable Network (2016)

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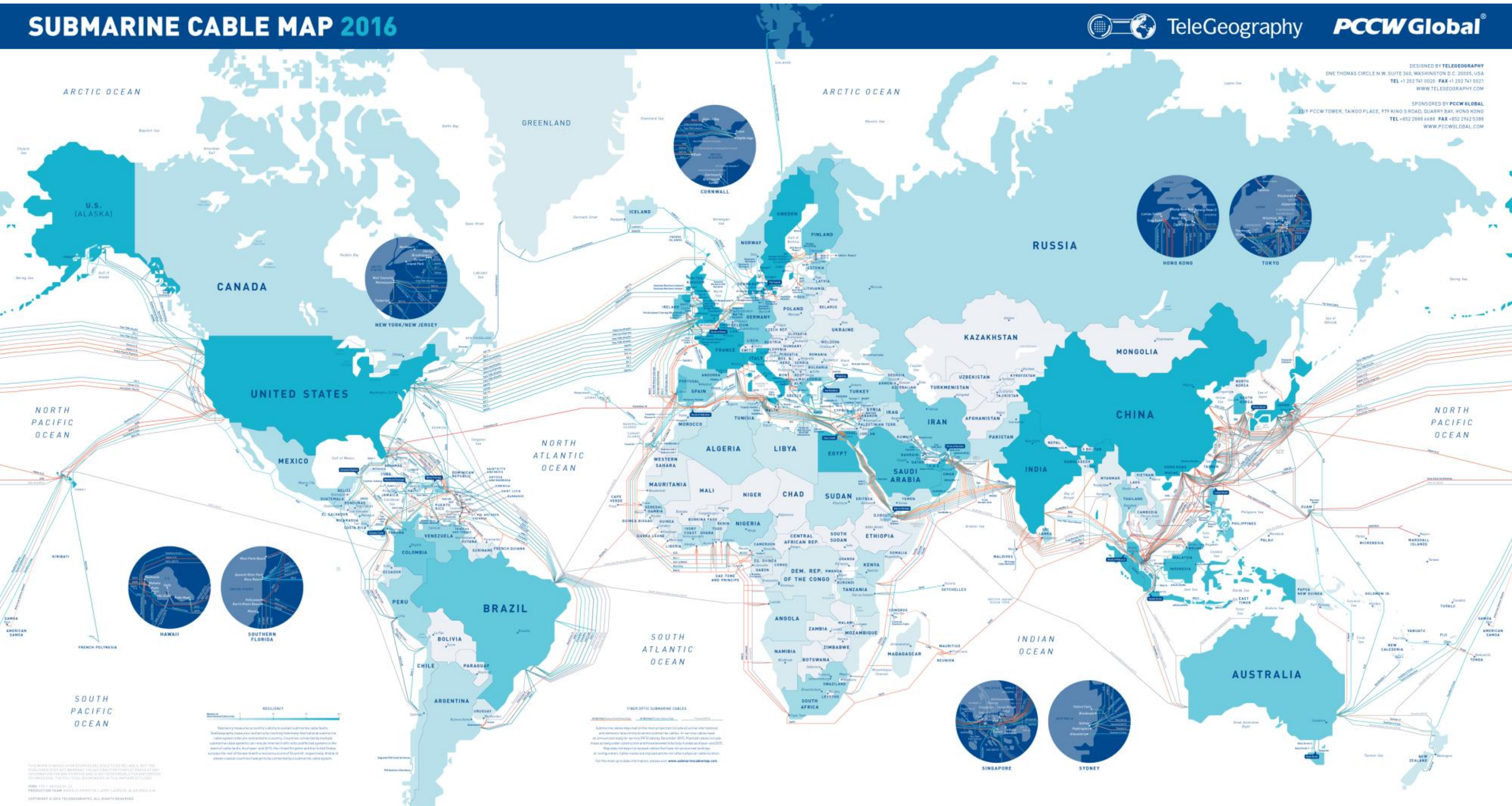

Cable Technology and Capacity

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1. **Telegraphic cable**
   1866 to 1950
   Capacity limited to a few tens of words per minutes (120 in 1920)
2. **Coaxial cable**
   1950 to 1988
   Up to 4000 analog voice channels
   In direct competition with satellite technology (equivalent capacity but subsea coaxial cables offered higher quality and lower latency)
3. **Optical cable with optical/electr./optical repeaters (regenerators)**
   1988 to 1995
   Up to 2.5 Gbit/s per fiber pair
   No system upgrade was allowed as the capacity was dictated and frozen by the underwater regenerators.
4. **Optical cable with fully-optical repeaters (optical amplifiers)**
   Since 1995
   in 2016: 130 x 100G = 13 Tbit/s per fiber pair (de facto standard)

Traditional Subsea Cable System Architecture and Components

Traditional Subsea Cable System Architecture

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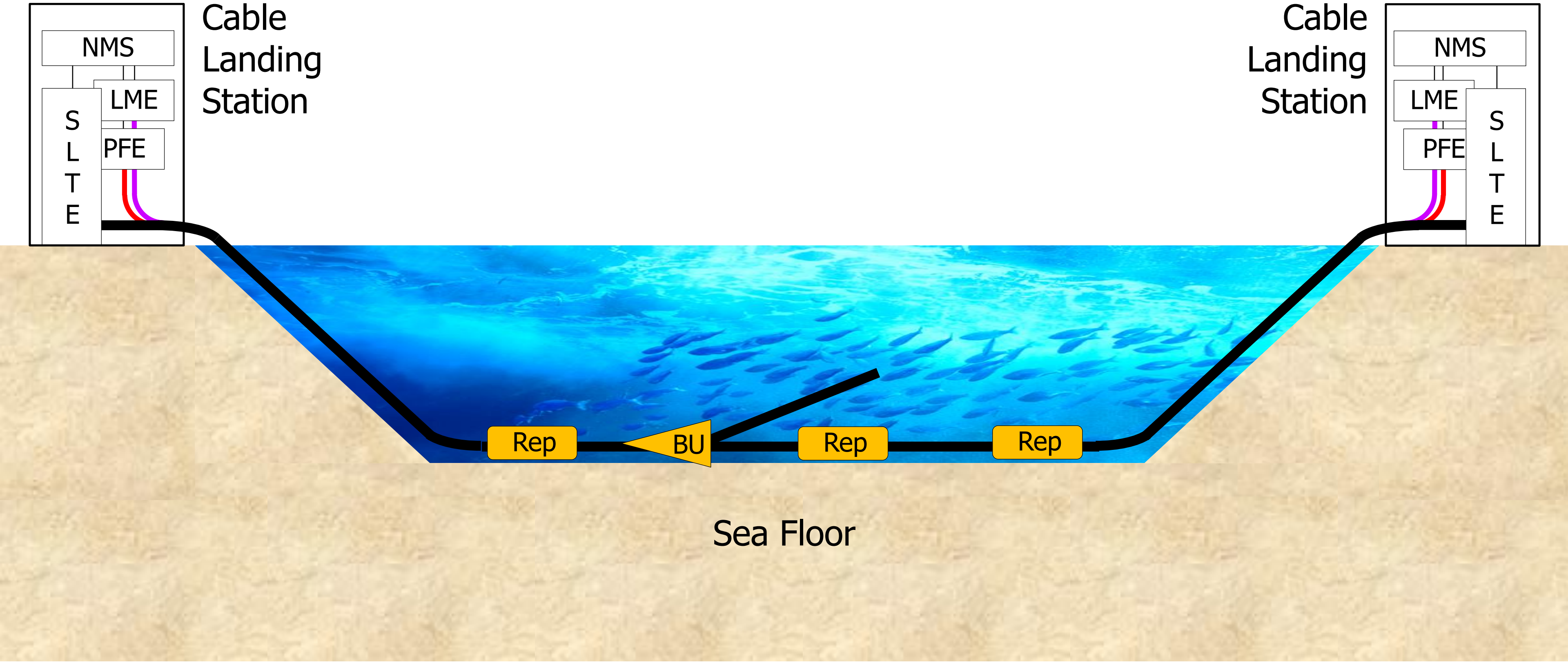
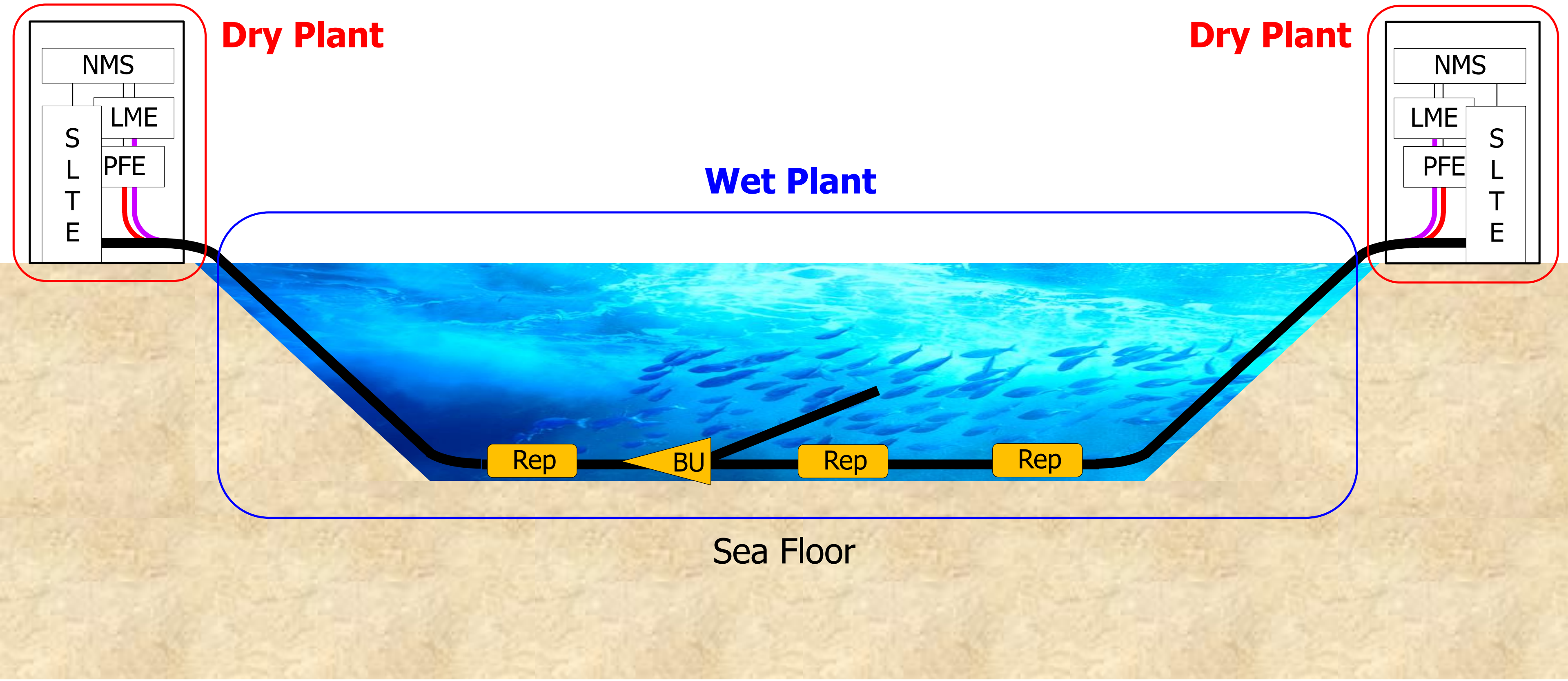
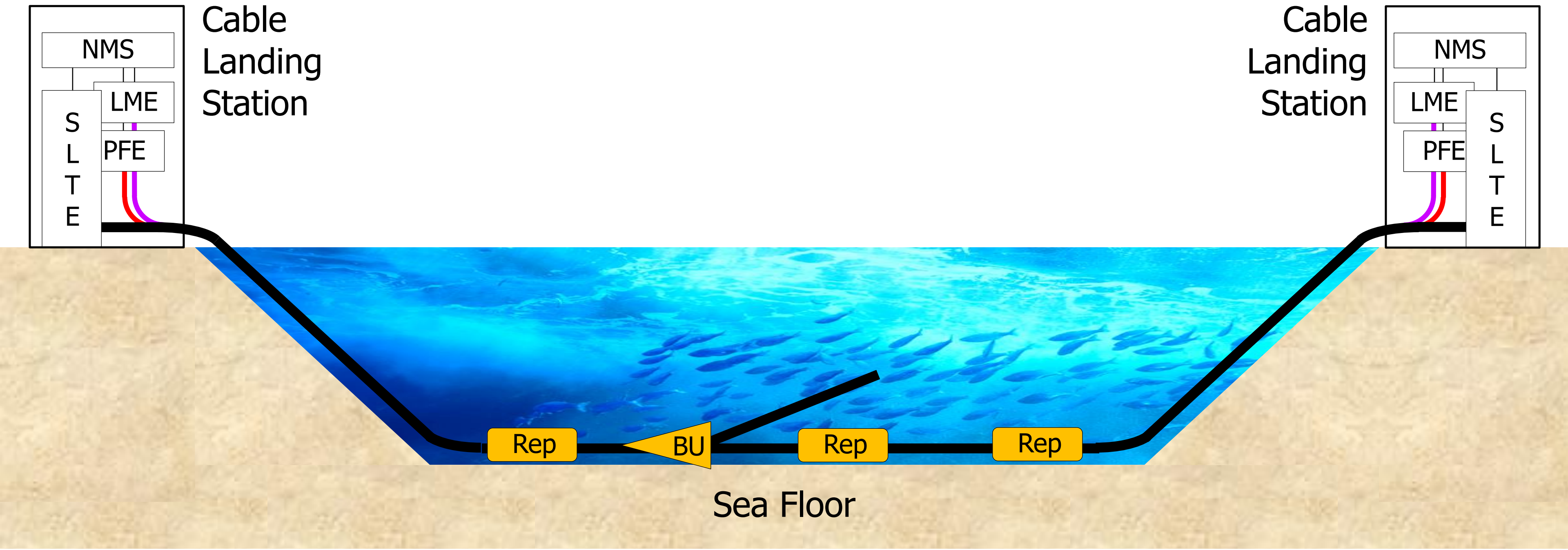


Traditional
Subsea Cable System Architecture



Traditional
Subsea Cable System Architecture



SLTE Submarine Line Terminal Equipment

PFE Power Feed Equipment

LME Line Monitoring Equipment

NMS Network Management System

Rep Repeater

BU Branching Unit

Traditional
Subsea Cable System Components

Subsea Cable	Provides power path to feed submerged active equipment Protects optical fibers from external aggressions
Repeaters	Houses optical amplifier (one amp pair per fiber pair) Amplifies a comb/multiplex of optical wavelengths
Branching Unit	Provides traffic and power routing between the trunk and branch cables
SLTE	Accepts client signals that need to be transported Launches a comb/multiplex of optical wavelengths into the subsea cable
PFE	Remotely feeds distant active equipment along the cable
LME	Monitors and controls the wet plant (: cable and submerged active equipment)
NMS	Manages the whole system (dry and wet plants)

Regional Subsea Cable System Typical Cost Structure

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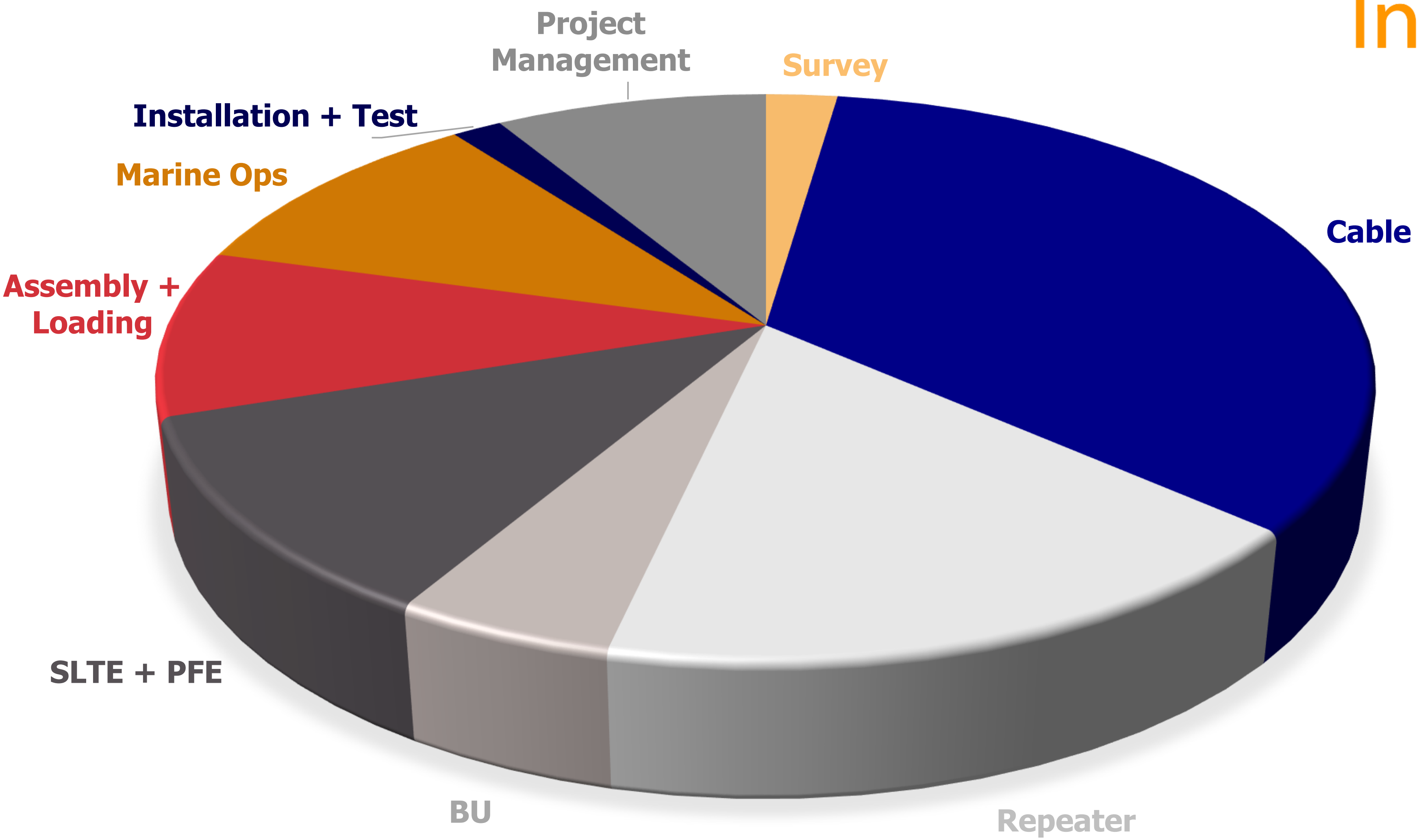

Note: The Marine Operations topic is not addressed in this tutorial.

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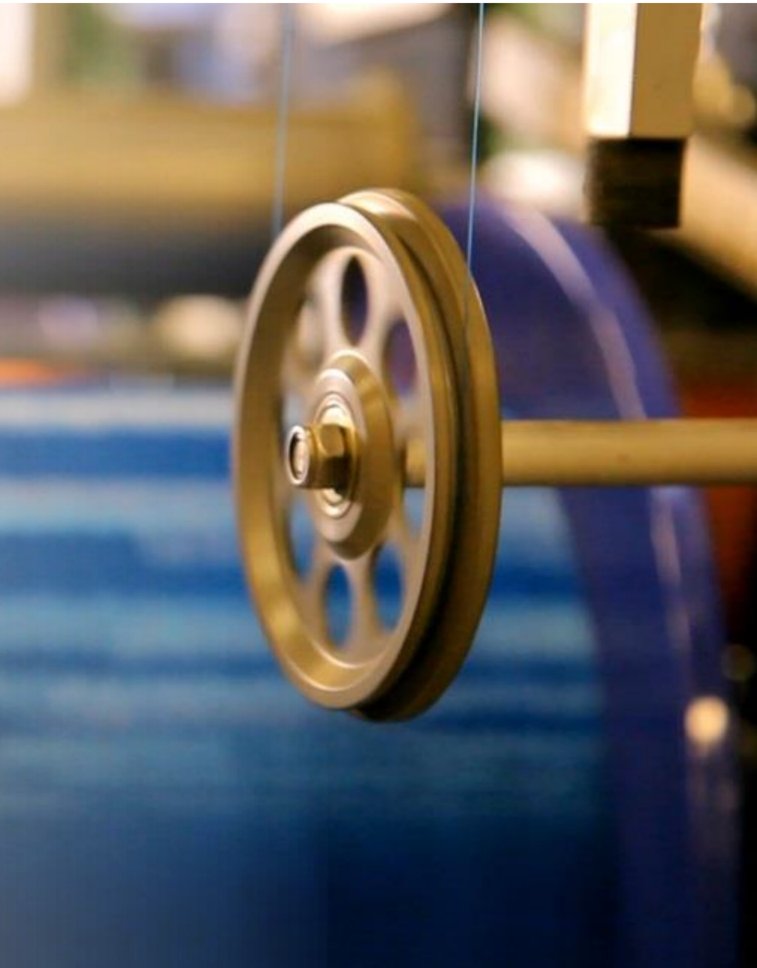
Optical Fiber

Pre-2010 Fiber Requirements

Before 2010: Non-coherent transmission technology only

- Four enemies to fight against
  - Attenuation: the lower, the better
  - Nonlinear effects: the fewer, the better
  - Polarization Mode Dispersion (PMD): the lower, the better
  - Chromatic Dispersion (CD): need for high local CD, and low cumulated end-to-end CD ➔ Dispersion management map along the cable depending on the bit rate making cable manufacturing and repairs more complex



Post-2010 Fiber Requirements

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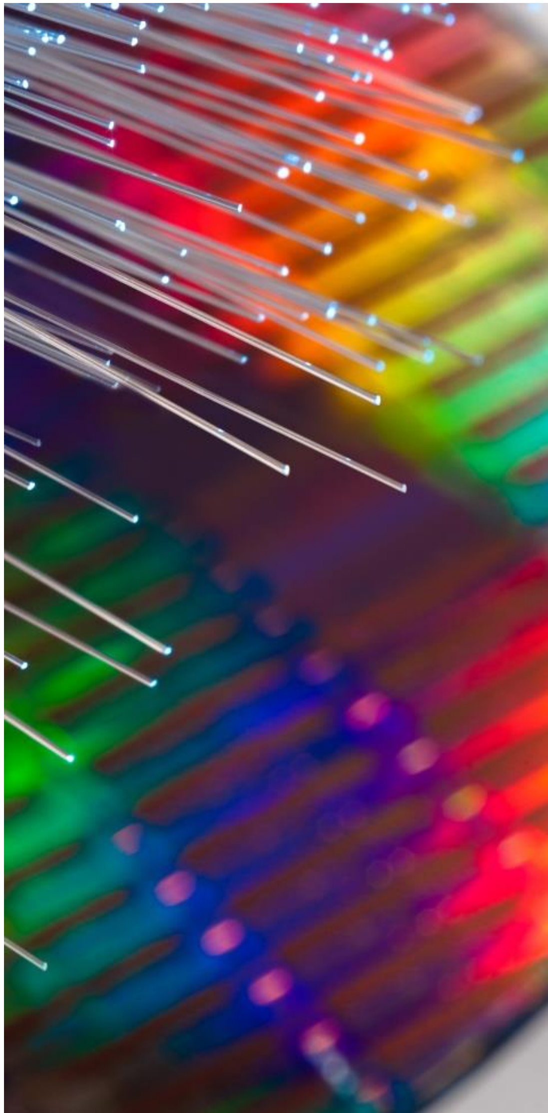
Since 2010: Coherent transmission technology

- Large effective area (for minimizing fiber nonlinearities)
- Low attenuation (for minimizing optical noise build-up caused by repeater string and/or increasing repeater spacing)
- Large chromatic dispersion is now a friend: coherent technology loves both high local and high cumulated dispersions.

  Note: PMD is no longer an issue (can be effectively compensated for by the coherent receiver).



These requirements have been valid since 2010 and are likely to be so for the next several years.

Submarine Cable

Submarine Cable Variants

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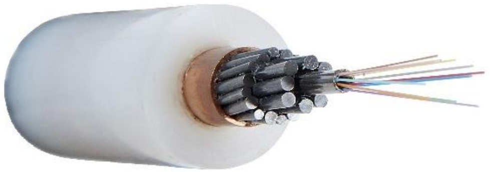

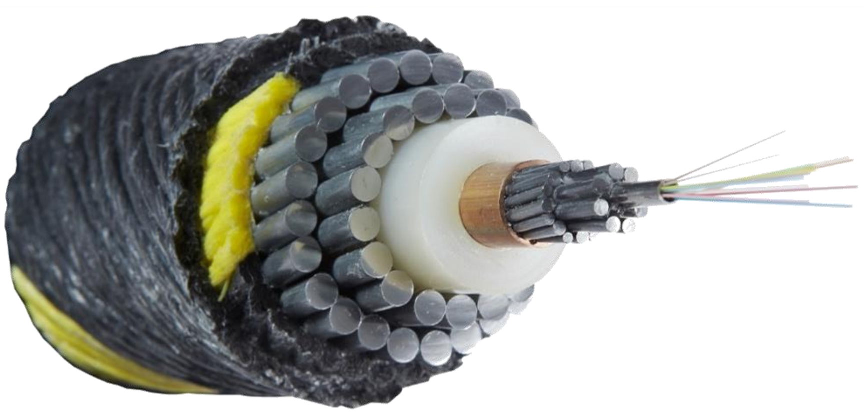

- Several variants (typically 5) are offered by cable manufacturers for various degrees of physical strength and protection.
- Shown here are
  - LightWeight (LW) cable
  - Single-Armored (SA) cable
  - Double-Armored (DA) cable
- Outer diameters range from 17 to about 60 mm.
- Design loads range from 55 kN (LW) to 300 kN (DA).

Courtesy of Nexans Norway

Double-Armored Cable Design

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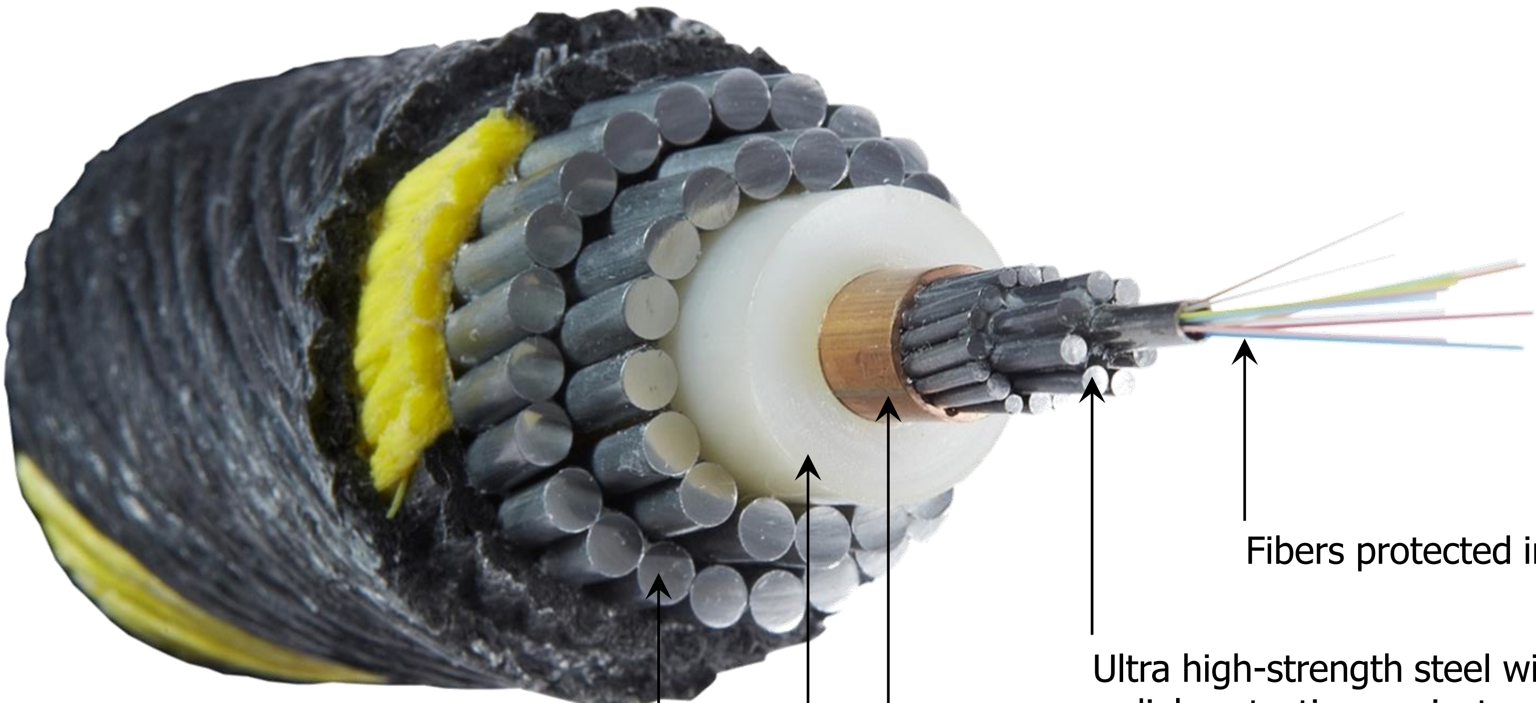

Courtesy of Nexans Norway

Fibers protected in central tube

Ultra high-strength steel wires, providing radial protection against pressure and high longitudinal mechanical strength

Copper tube, providing pressure resistance and power conduction

Double armor made of ultra high strength steel wires providing protection against external aggressions

Polyethylene sheath providing insulation between copper conductor and sea water (the "earth")

Repeater

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Housing (Optics and electronics)

Flexible Joint

Cable Termination

Buffer

Repeater

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- Needs to withstand water pressure, tension and corrosion
- Need to ensure mechanical, electrical and optical continuities in the cable


Courtesy of Xtera

Repeater

- Main functionality: to amplify all the wavelengths transported by each fiber pair
- Main parameters
  - Total output power
  - Noise figure
  - Optical bandwidth
- Governs the design capacity (and cannot be modified through the wet plant lifetime unless at the expense of heavy marine ops)
- Components
  - Passive optical devices
  - Active optical devices (pump lasers and photodiode)
  - Low-frequency electronics
  - High reliability design with ultra reliable components and optical pump sharing scheme

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Branching Unit

Branching Unit

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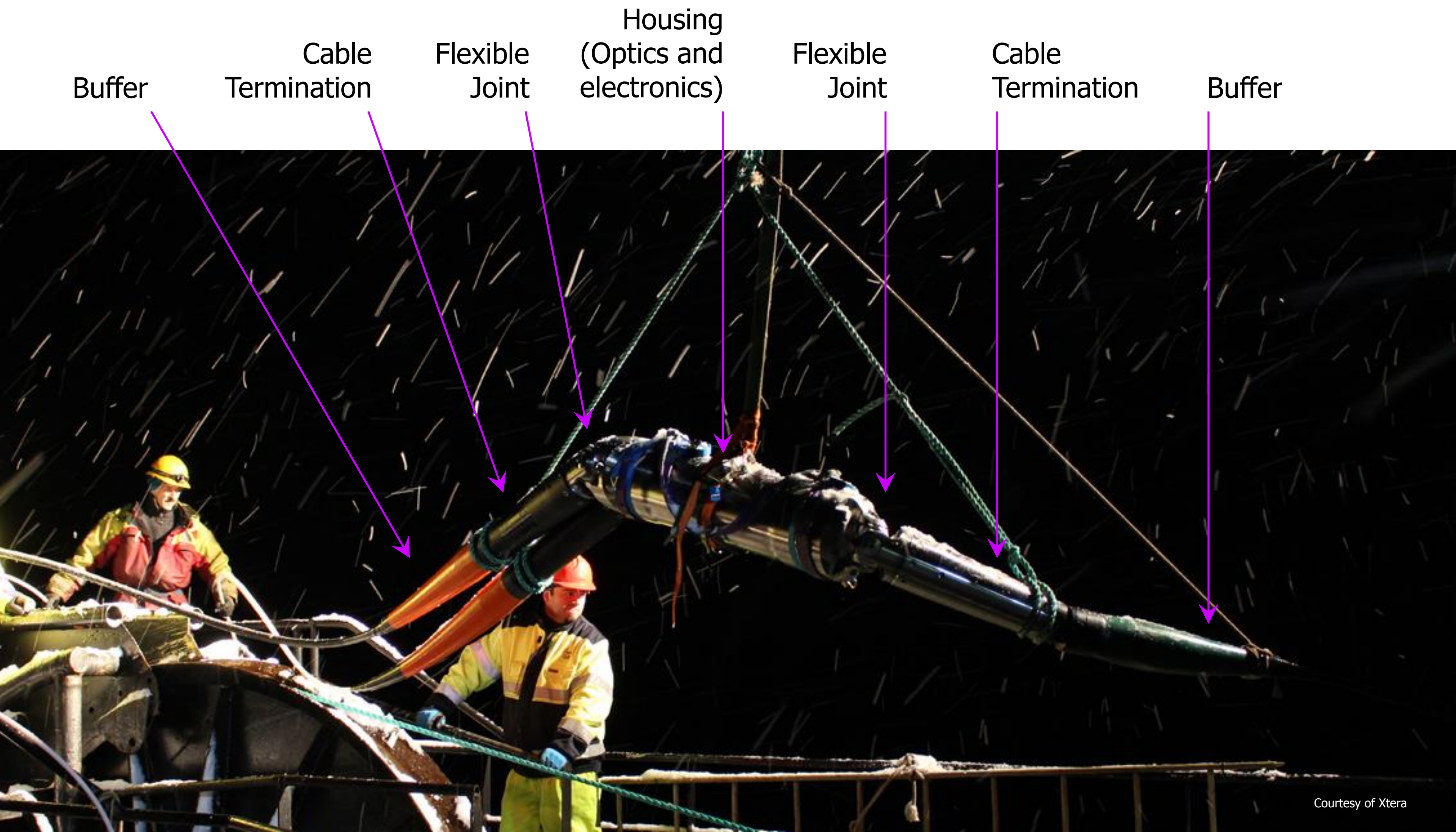

Branching Unit

- Needs to withstand water pressure, tension and corrosion
- Need to ensure mechanical, electrical and optical continuities in the cable

Courtesy of Xtera

Branching Unit

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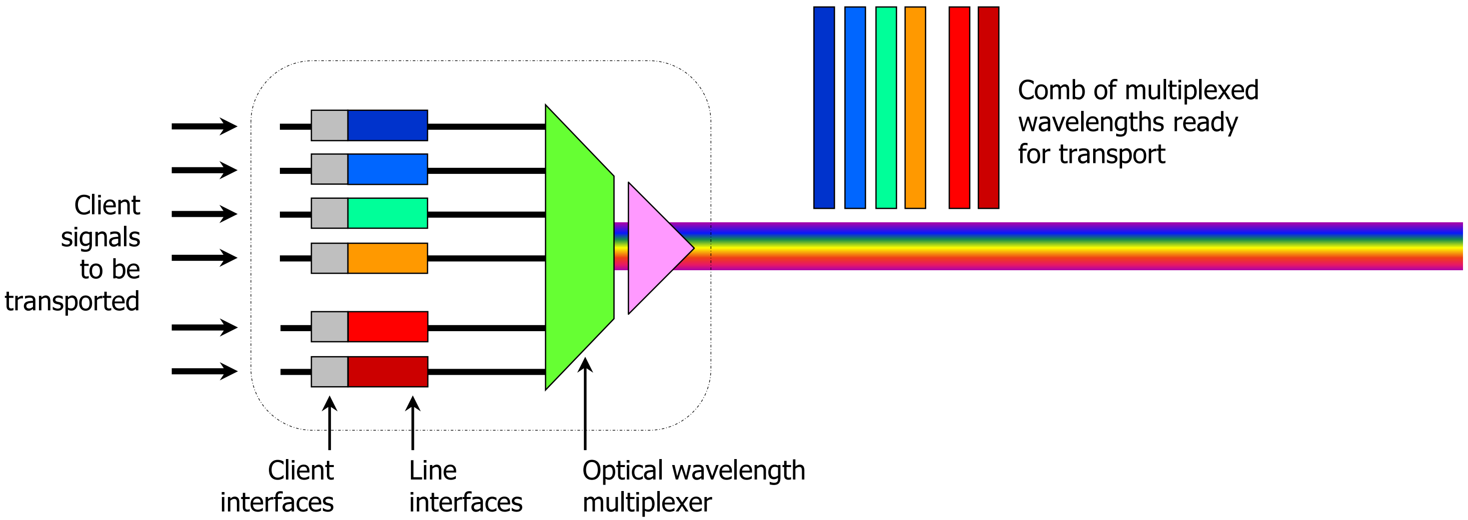
- Main functionality: to provide traffic and power routing between the trunk and branch cables, enabling reconfigurable network architecture for more flexible capacity configurations
- Power routing: switches optical fibers, optical spectral bands or optical wavelengths
- Governs the network reconfigurability
- Components:
  - Passive optical devices
  - Active optical devices (optical switches)
  - Low-frequency electronics
  - High reliability design with ultra reliable components

Terminal Equipment

Terminal Equipment



- Main functionality: to convert client signals into long-haul optical signals at specific wavelengths and combine them into the same optical fiber before connection to the subsea cable
- Typical client signal rates: 10G, 40G and 100G
- Typical line signal rate: 100G with coherent transmission technology (soon 150G and 200G)

Terminal Equipment

- Before 2007: Subsea cable systems made use of specific line terminal equipment (SLTE) at very high price.
- Since 2007: New players (cross-upgrade) with lower price.
- Since 2010: Coherent reboot. The terrestrial coherent technology was applied to subsea cable systems, driving to terrestrial/subsea convergence.
- Some features are specific for subsea applications (e.g. monitoring/control of the wet plant) and added to terrestrial line equipment.

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Evolution

Evolution

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Optical Fibers

- Lower loss, larger effective area
- And still high positive chromatic dispersion

Repeater

- Wider optical spectrum (C+L band amplifier or Raman), lower noise performance, distributed amplification inside the line fiber (Raman)
- Electrical power is seen today as the fundamental limit to optical cable capacity.

Branching Unit

- Reconfigurability at the wavelength level
- The move from point-to-point to richer connectivity is likely to have a strong impact on the way to monitor/control the wet plant.

Terminal Equipment

- 100G QPSK is the de facto standard rate for long-haul cables.
- Next are 150G and 200G 8QAM.

Evolution
Subsea Cable System Architecture

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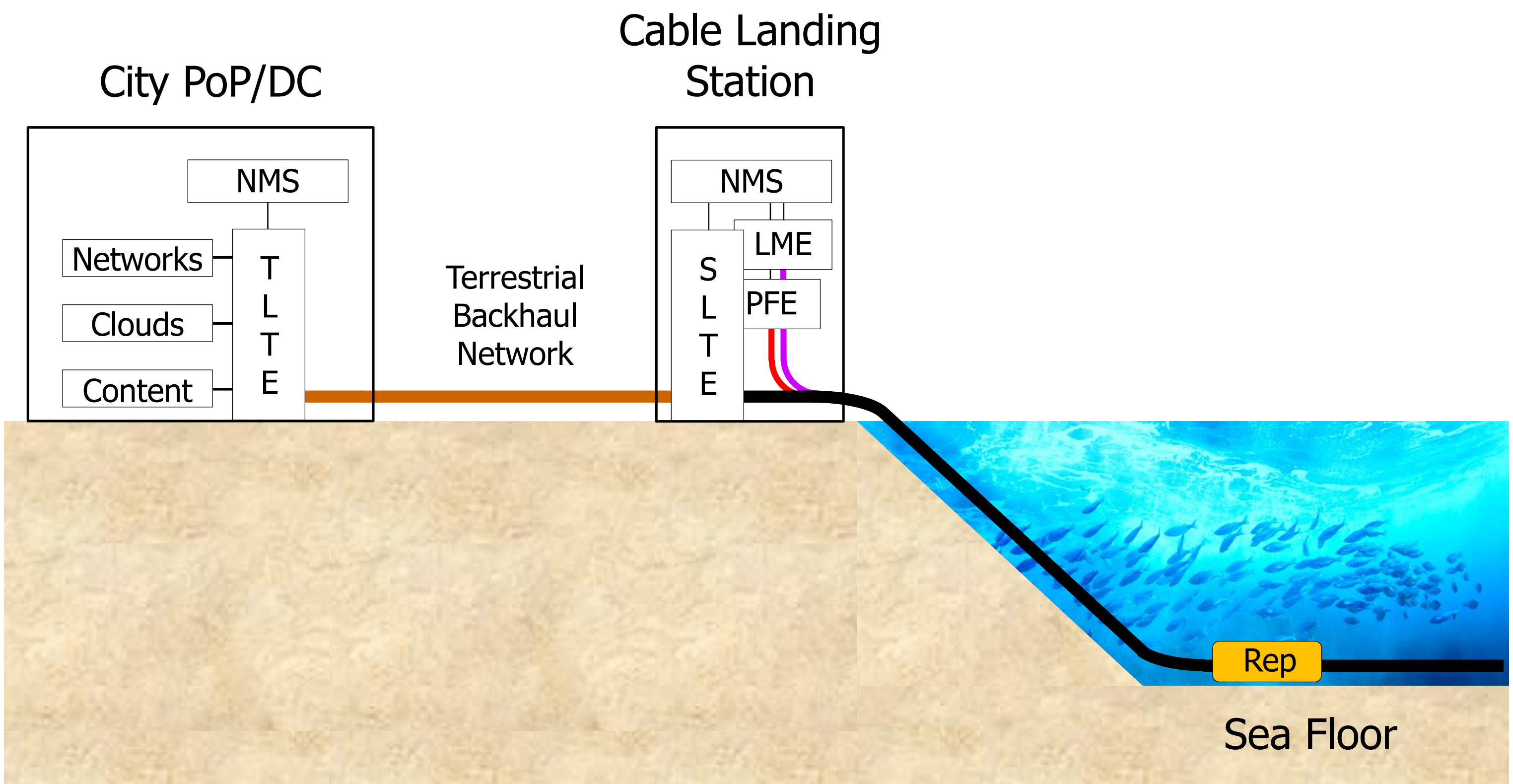

- Traditional approach with “closed” subsea cable system
- Interface: SLTE client interfaces
- What is between the SLTE client interfaces is a black box.

Evolution
Subsea Cable System Architecture

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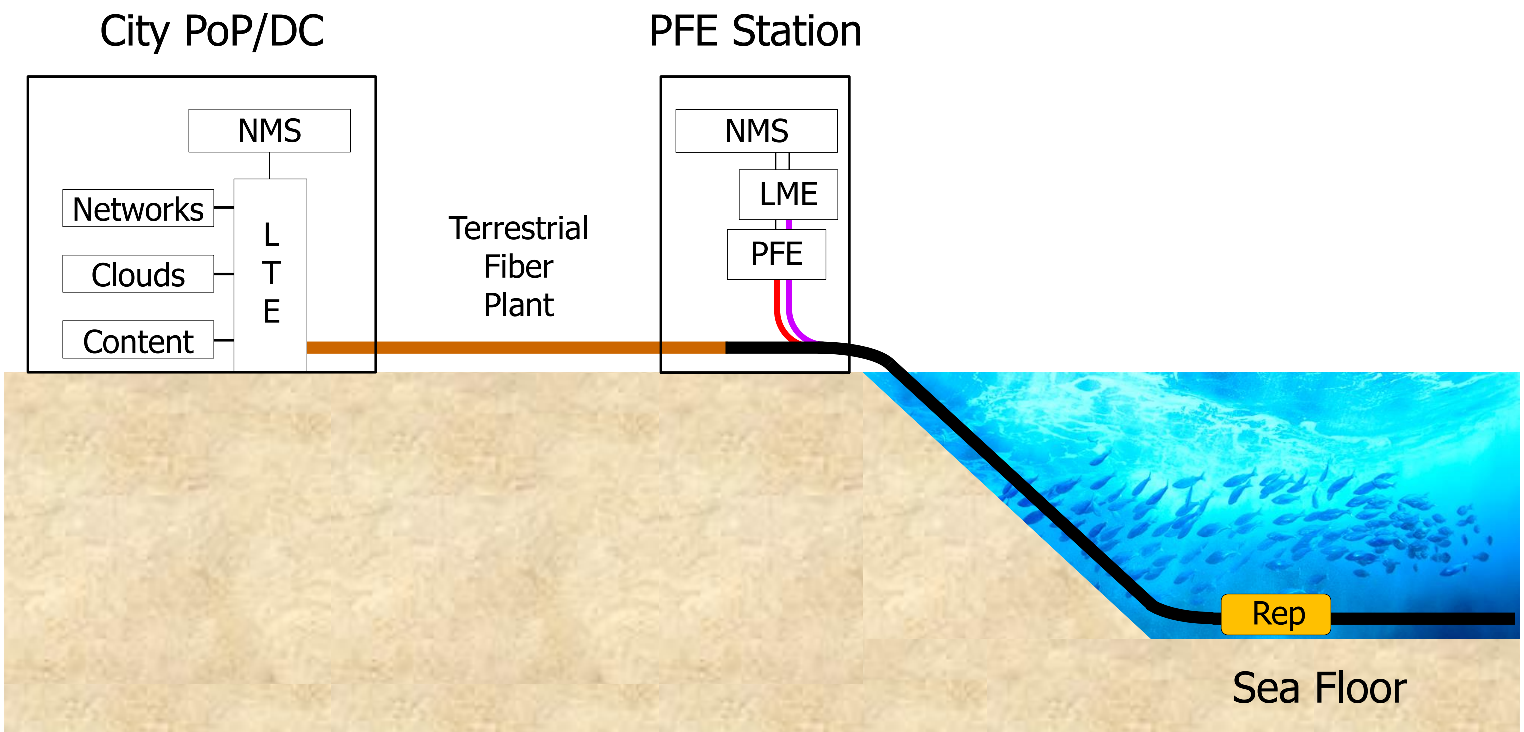

- Open cable system with terminal equipment moved into data centers
- CapEx and OpEx savings, easier provisioning
- Higher reliability due to fewer equipment

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Worldwide Web and Cloud