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The Submarine Network Game

And the Implications of Shannon's Limit

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AGENDA

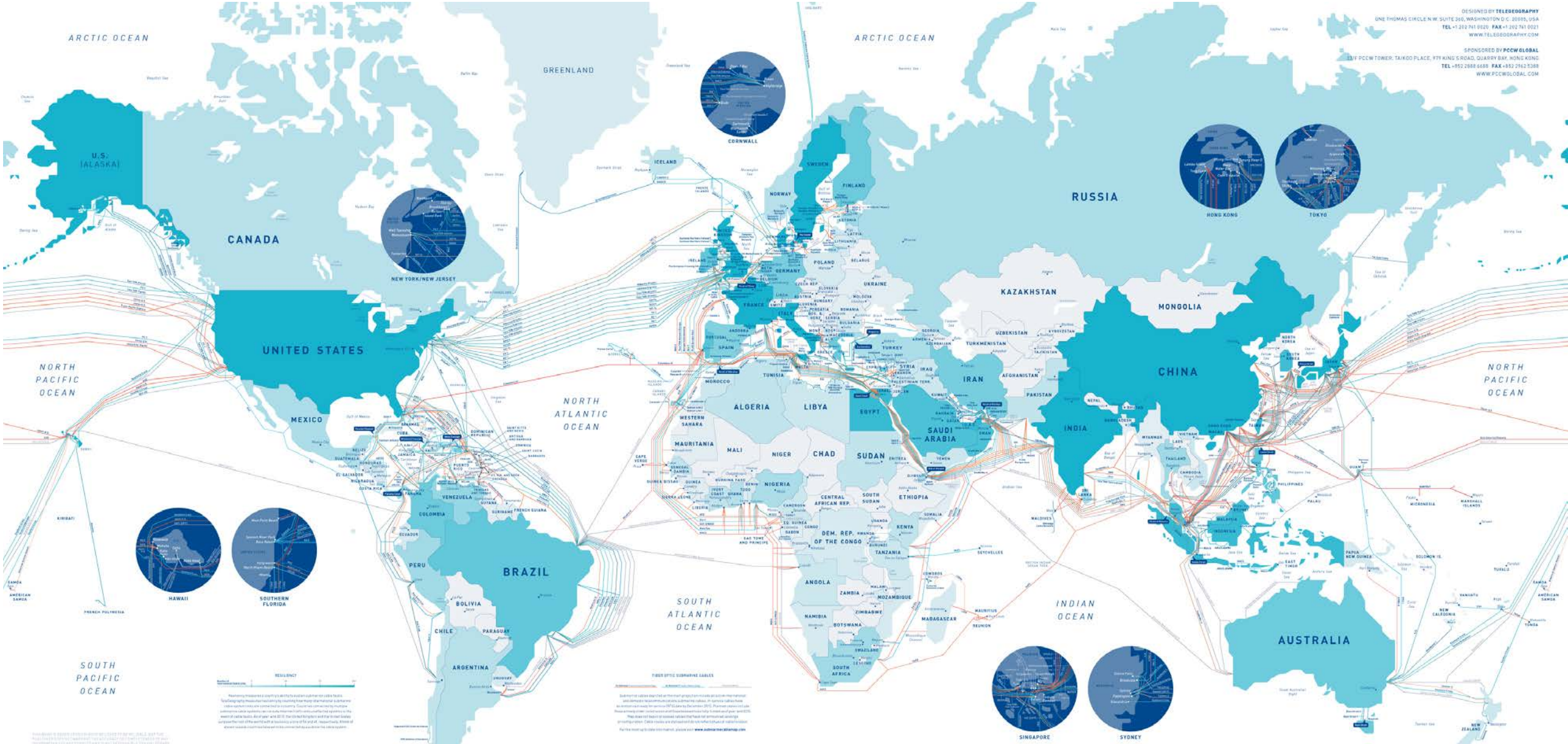
1. History & Anatomy of a Submarine Cable system
2. Factoring in Shannon’s Limit
3. Further developments

Pop Quiz: In what year was the first Submarine cable installed?

Answer: Across the English Channel in **1851**, and the Atlantic in 1866! (Telegraph)

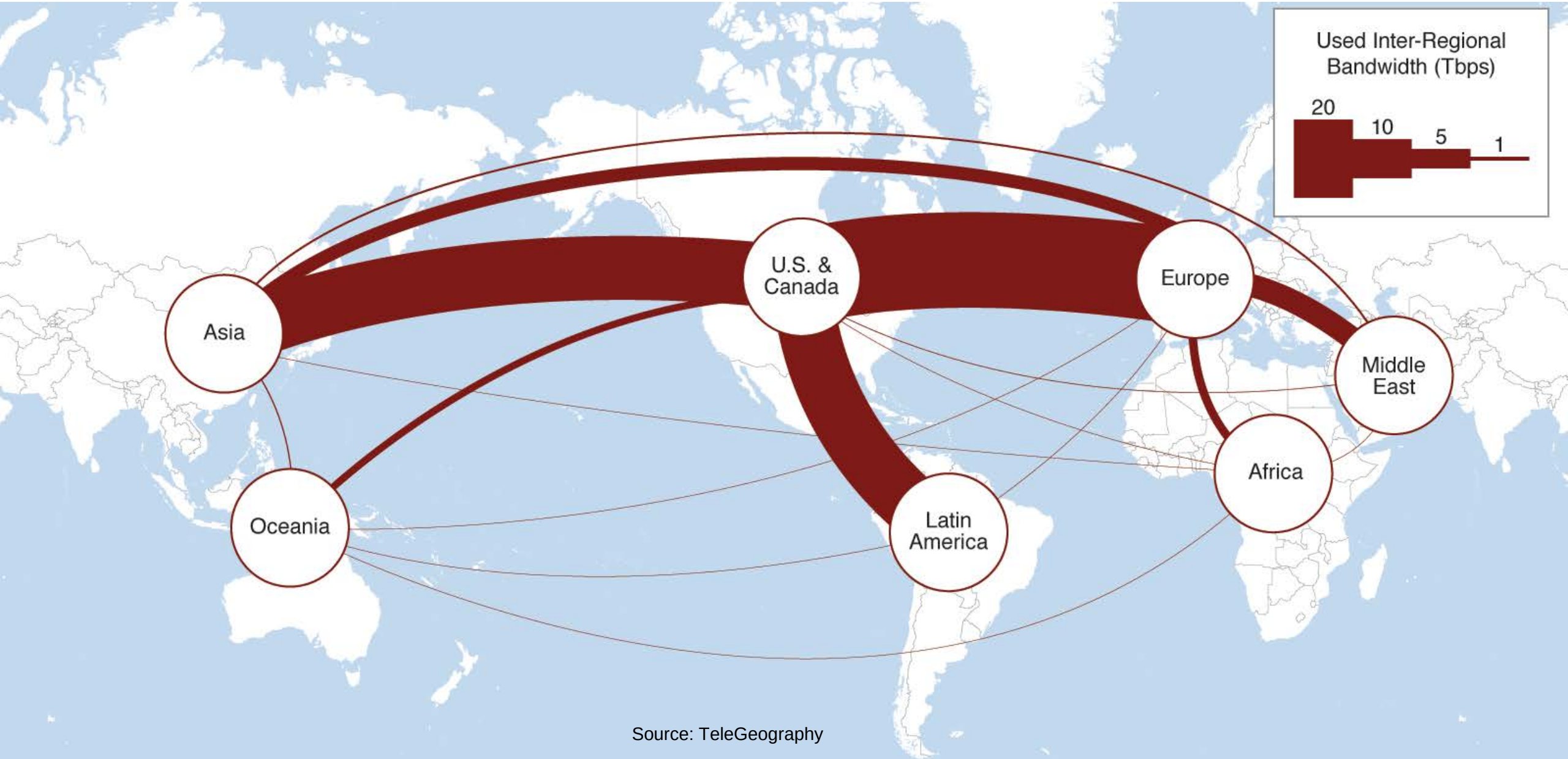
Source: Submarine Cable History, Wikipedia

Global Submarine Cable Map



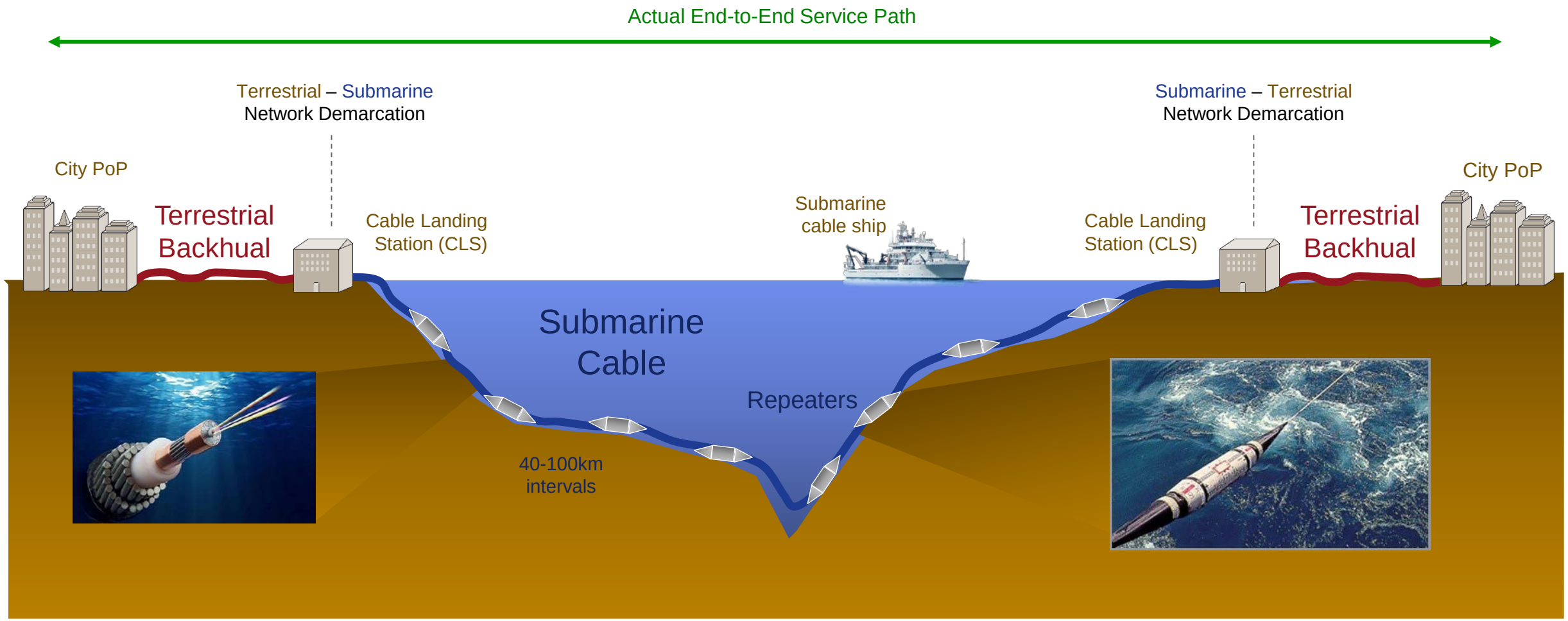
Source: TeleGeography

Global Submarine Capacity



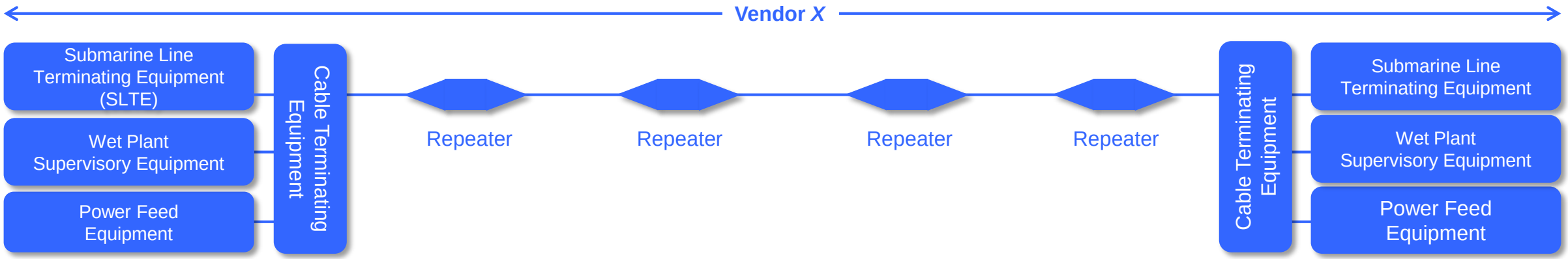
Source: TeleGeography

Typical Anatomy of a Submarine Cable System

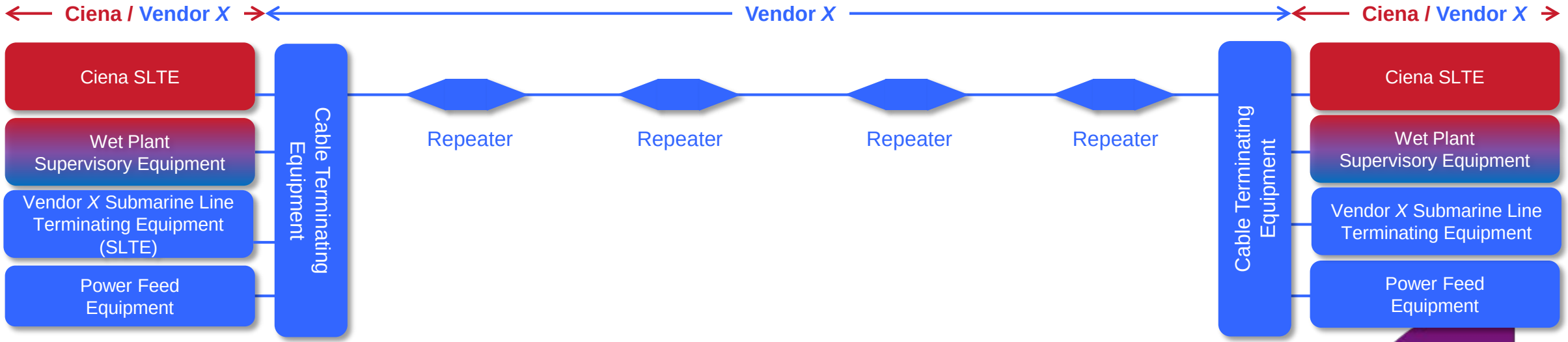


Submarine cable **Upgrades**

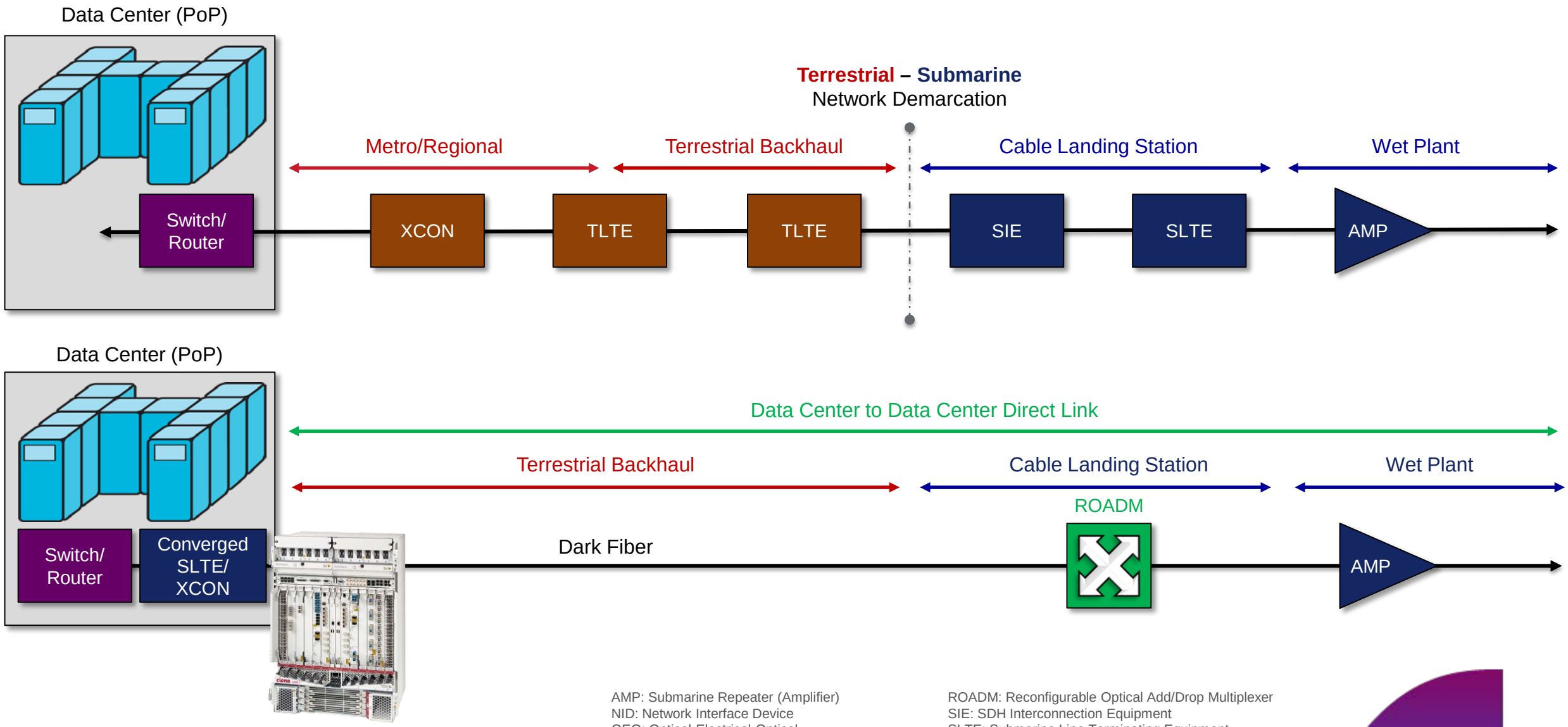
Traditional Turnkey Submarine Cable network



Upgraded Open Submarine Cable network



Simplifying Submarine Cable system



AMP: Submarine Repeater (Amplifier)
NID: Network Interface Device
OEO: Optical-Electrical-Optical
OOO: Optical-Optical-Optical
PoP: Point of Presence

ROADM: Reconfigurable Optical Add/Drop Multiplexer
SIE: SDH Interconnection Equipment
SLTE: Submarine Line Terminating Equipment
TLTE: Terrestrial Line Terminating Equipment
XCON: Cross-Connect

Why the ‘Shannon Limit’ Is a Key Factor in New Cable Planning

Design choices today define future upgrade capacity

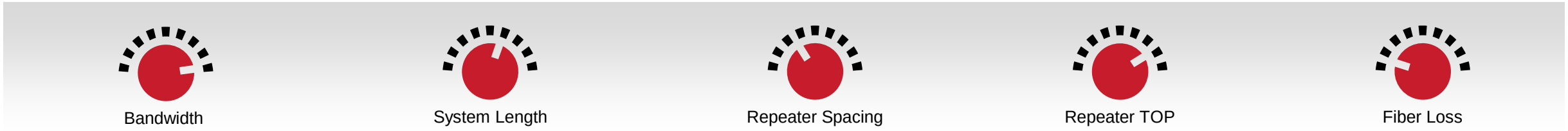
Shannon's Limit defines the maximum theoretical limit of the rate at which information can be transmitted over a communications channel of a specified bandwidth in the presence of noise

Simple equation: $C = B \log_2 (1+S/N)$

- C = capacity
- B = bandwidth
- S/N = signal/noise ratio

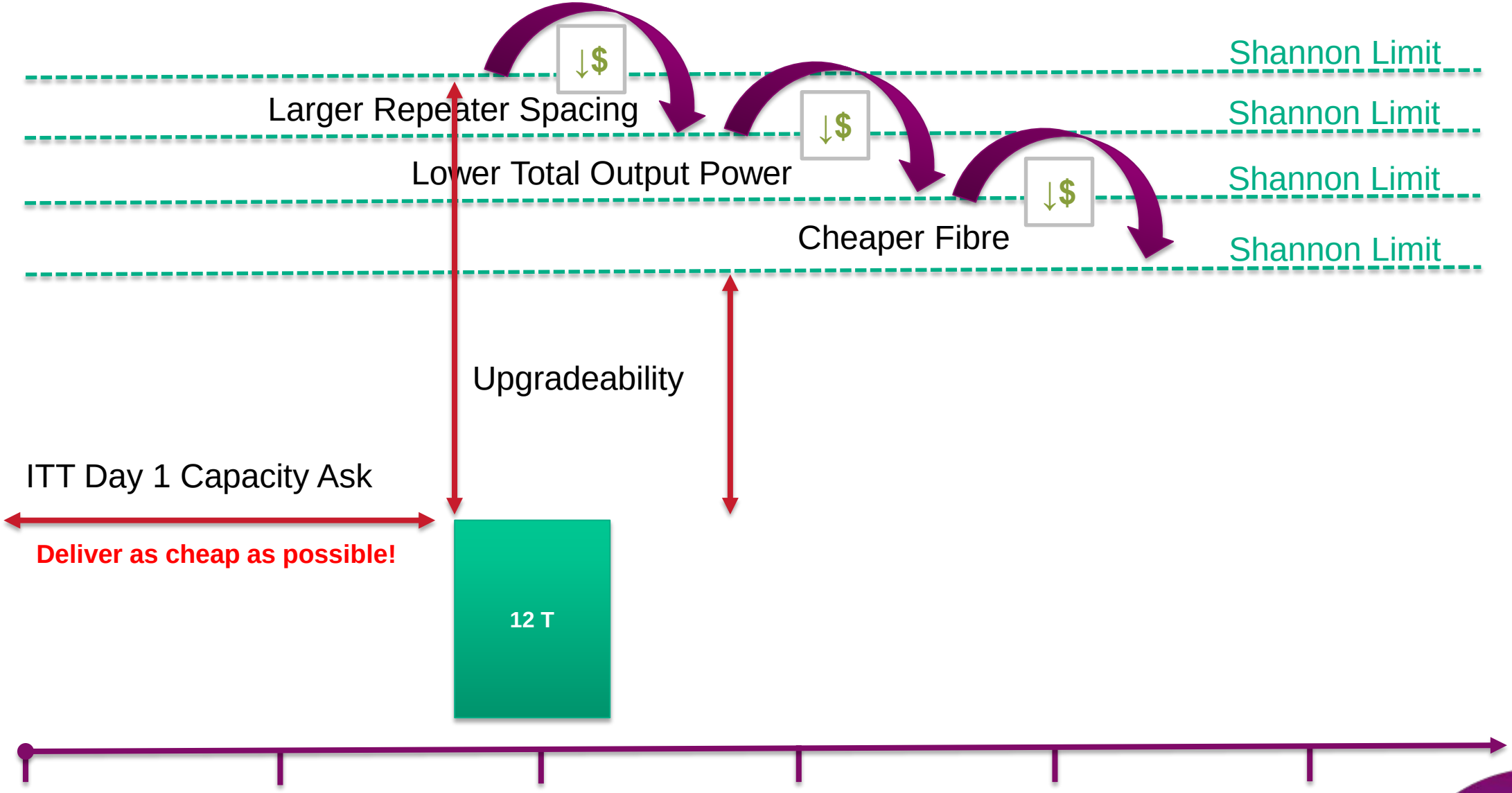
Submarine cables are unique: bandwidth & SNR are fixed at beginning of life → Shannon Capacity is also fixed!

- ***Wet plant*** design ***sets*** Shannon Capacity, and cannot be increased after a cable is put in the water
- ***Modem*** technologies will ***approach*** the Shannon Capacity, but cannot exceed it



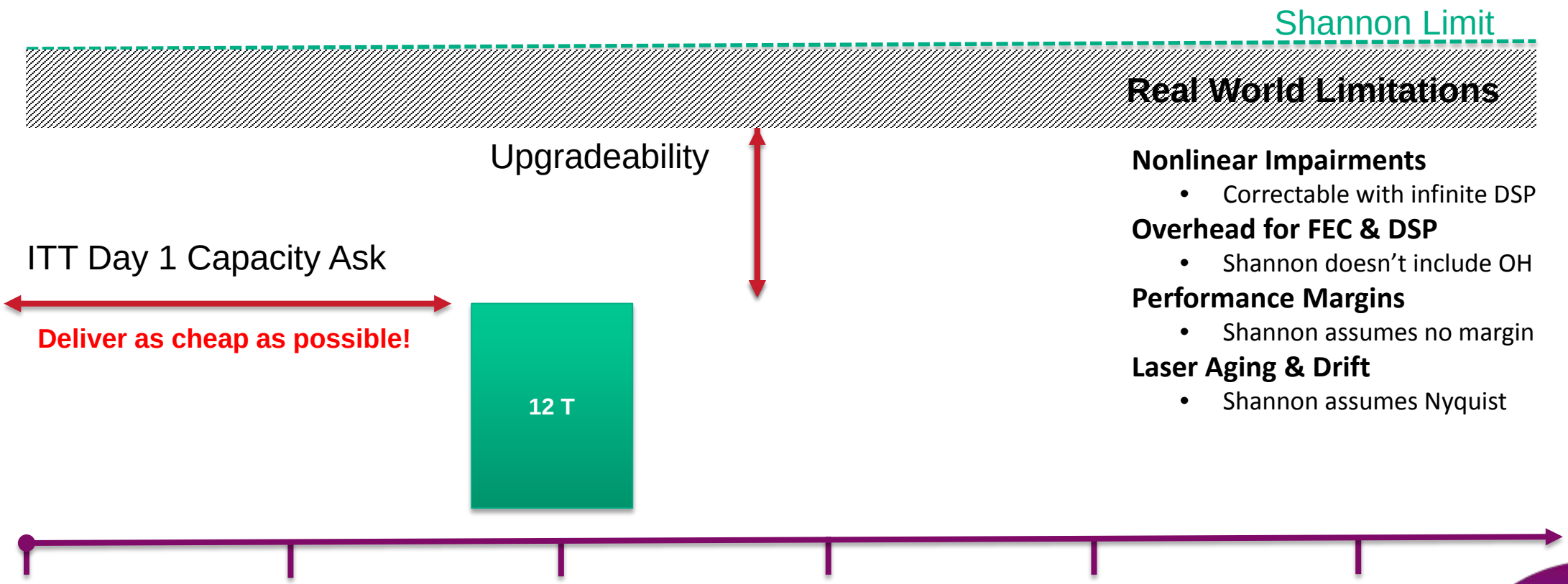
More Bandwidth & SNR = More Future Upgrade Capability

Shannon's Limit on a **New Coherent Cable**

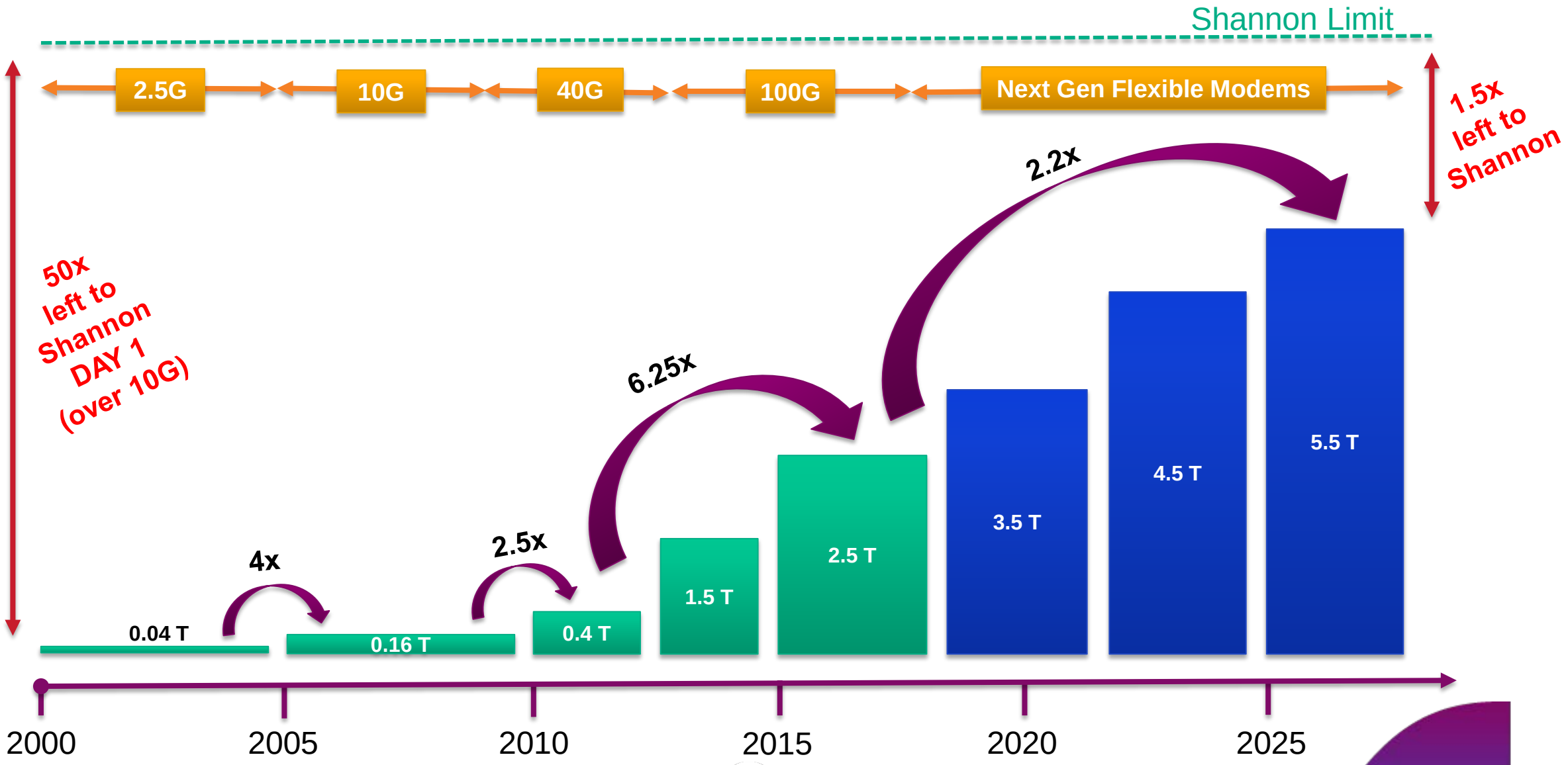


Shannon's Limit on a **New Coherent Cable**

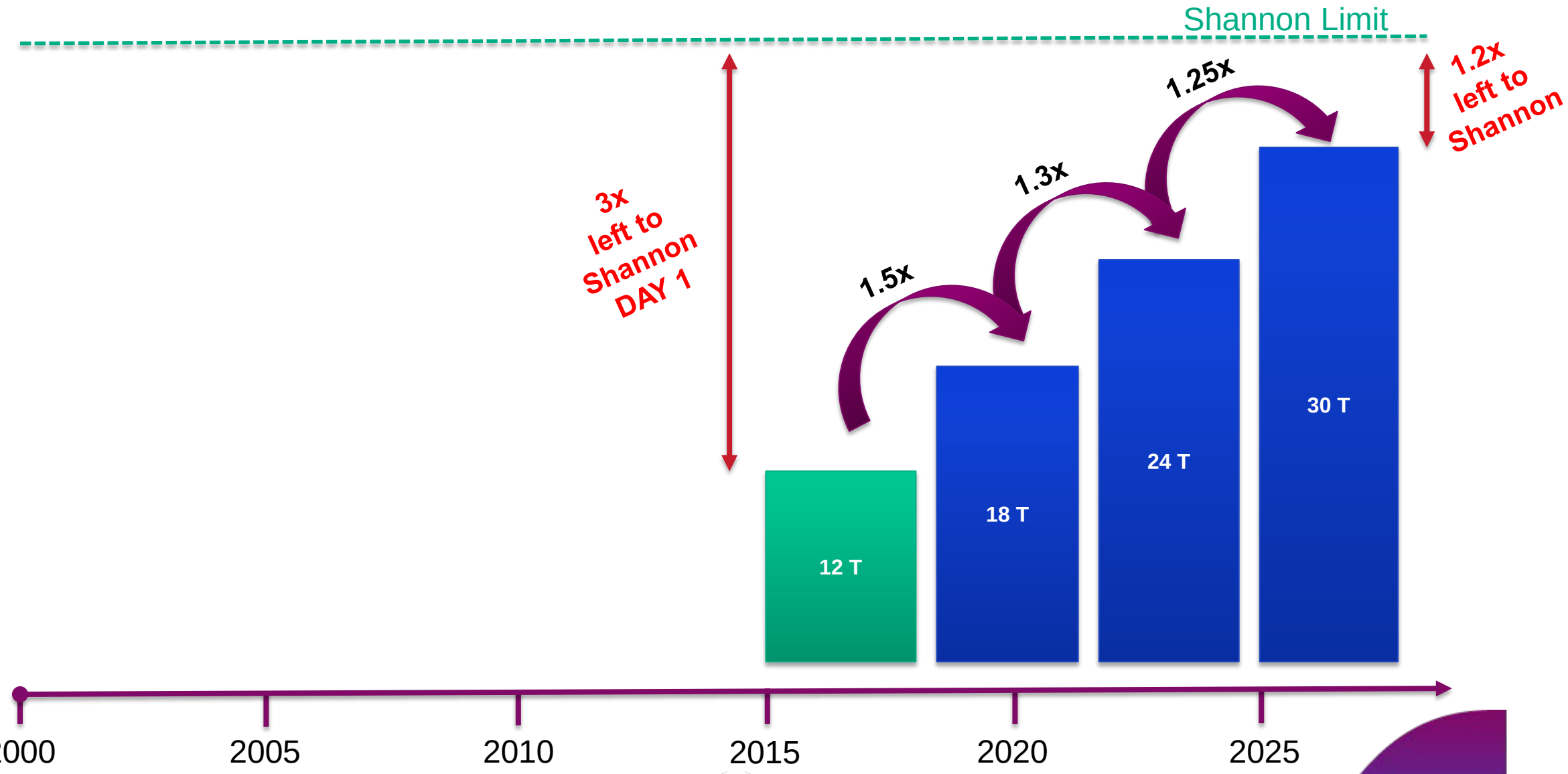
Shannon's Limit is "theory"
…what about other real world limitations?



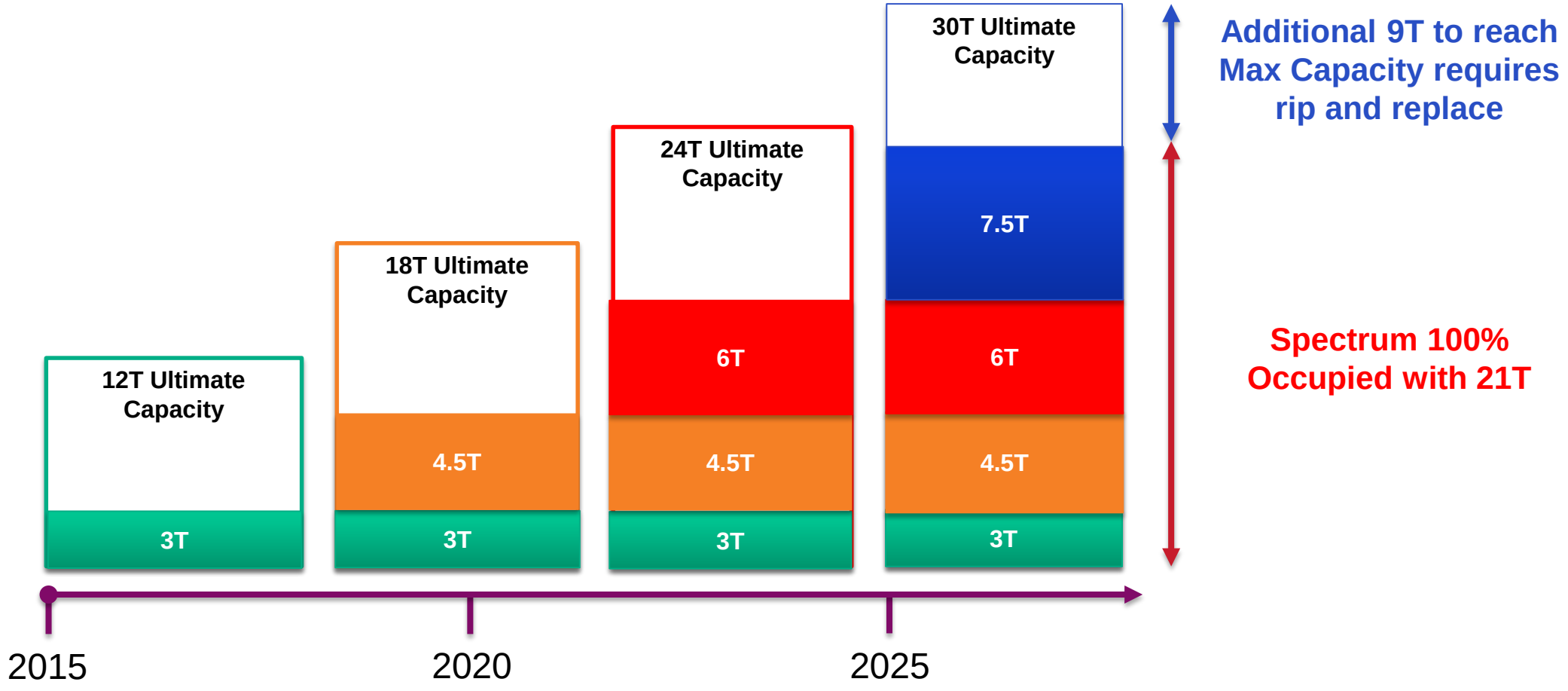
Shannon's Limit on Legacy Cables – Room to Grow!



Shannon's Limit on **New Coherent Cables**



Upgrading 25% of Spectrum with Each Technology Generation



Real-World Terrestrial Coherent Transmission Experience

“ Highest spectral efficiency **per fibre pair** ever achieved…

30.4 terabits per second

23 January 2018

PRESS RELEASE
23 January 2018

Telstra, Ericsson and Ciena achieve world’s fastest speeds on the Telstra transmission network in Melbourne

Telstra, Ericsson (NASDAQ: ERIC), and Ciena (NYSE:CIEN) today announced they had successfully demonstrated 400 gigabit per second (Gbps) speeds over 61.5 GHz spectrum on Telstra’s transmission network in Melbourne. This demonstrates the highest spectral efficiency per fibre pair ever achieved in a live environment and enables up to 30.4 terabit per second (Tbps) bandwidth on Telstra’s transmission network in Melbourne.

This technology will be introduced as part of the upgrade Telstra is completing across its long haul, metro and regional optical network under the Networks for the Future program to deliver increased capacity, enhanced resiliency and fully programmable capabilities.

The achievement enables up to 30.4 Tbps per fibre pair – which is the equivalent to 1.2 million 4K Ultra HD videos being streamed simultaneously – the most capacity ever achieved, with the previous highest on record being 25.6 Tbps. It is made possible through the deployment of software programmable 400Gbps wavelengths using Ciena’s WaveLogic Ai modem technology on the 6500 Packet-Optical Platform, in combination with Ciena’s Blue Planet Manage Control Plan (MCP) and Liquid Spectrum applications.

Packet-Optical Leadership

“ Successful field trial delivering live **400Gbps** Ethernet traffic on a **single wavelength** … leveraged Ciena WaveLogic Ai

25 January 2018

Verizon marks milestone with successful 400G technology trial

Media contact(s)

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Interoperability field trial used standards-compliant Ciena and Juniper Networks equipment

NEW YORK – Verizon has achieved another industry first with the completion of a successful field trial delivering live 400 Gbps Ethernet traffic on a single wavelength between MPLS Core routers over its Packet-Optical network. This trial proved the interoperability of equipment from two different suppliers and the capability to quadruple the typical capacity carried on a wavelength.

This field trial marks an important step toward advancing 400 Gbps transmission and router technology – vital to the continued growth of services and applications such as video streaming, virtual reality and cloud computing.

This trial, held in December 2017 using the Verizon network in the Dallas area, validates the viability of carrying 400 Gbps traffic. This test traffic was transmitted between two Juniper Networks PTX 5000 routers across the Ciena 6500 Packet-Optical Platform, both used in Verizon's production network. This 400 Gbps interworking connection is compliant with IEEE Standard 802.3bs-2017, which was ratified in December 2017.

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