Spatial Division Multiplexing
A New (Subsea) Cable Paradigm

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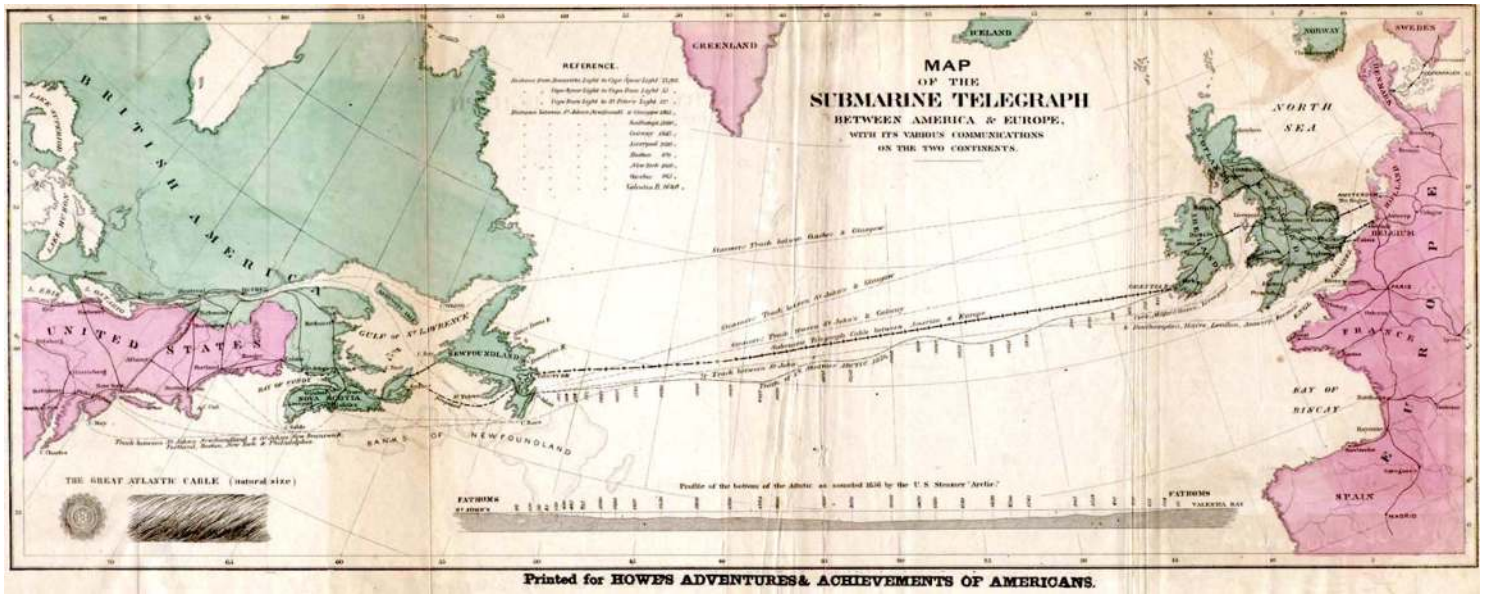
HISTORY



- Submarine cables have been in operation since 1866.
- Fibre optic submarine cables began carrying traffic in 1956 (TAT-1).
- Submarine cables are carrying 1.5Pbps annually, as of 2023.

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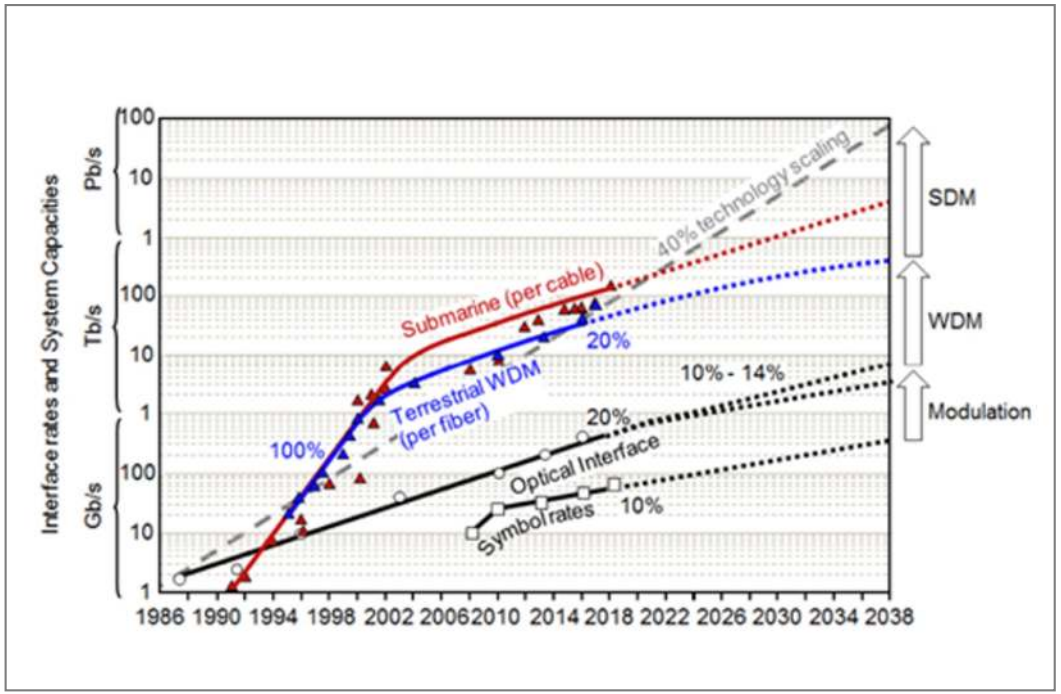
EVOLUTION

Evolution Snapshot



- Initial transmission technologies were based on modulation.
- The next phase was Wavelength Division Multiplexing (WDM).
- The future is Space Division Multiplexing (SDM).

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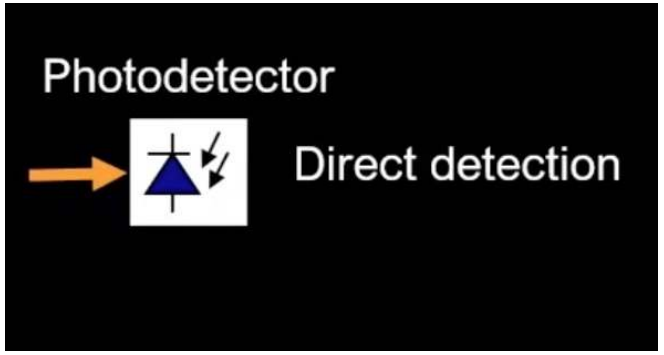
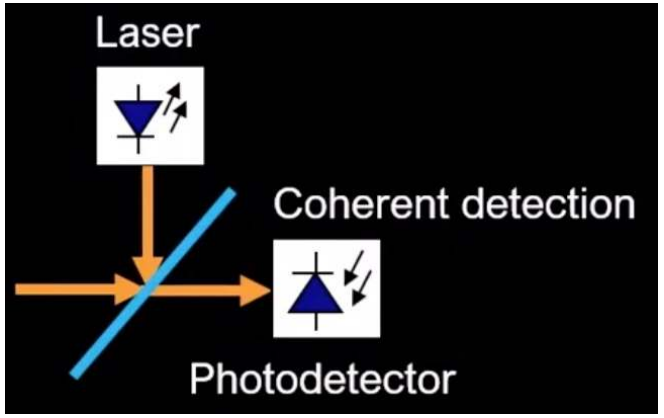
OPTICAL TECHNOLOGY

Direct Detection



- Direct Detection has been the technology, until 2010.
- Uses only amplitude to transmit data.
- 1 for high power. 0 for low power.
- Maximum capacity is 10Gbps.
- Prone to linear impairments.

Coherent Detection



- Coherent came on the scene in 2010.
- Uses amplitude and phase to transmit data.
- Allows for 100Gbps – 800Gbps (as of 2022).
- Permits great distances at lowest power consumption possible.
- Inherently compensates for linear impairments.

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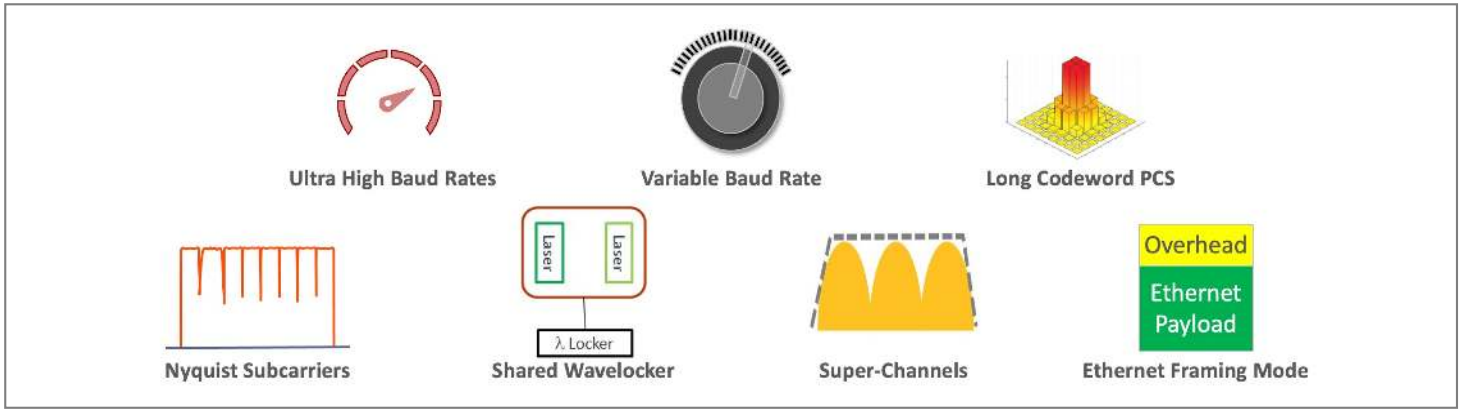
COHERENT EVOLUTION

Coherent Detection Development Milestones & Roadmap



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COHERENT EVOLUTION

100G Coherent ZR Optics

- Industry's first 100Gbps coherent ZR optic.
- Developed by Adva and Coherent Corp. (formerly II-VI).
- In-house DSP.
- Up to 120km unamplified, and over 900km amplified.
- DWDM, so is tunable.
- Tx launch power can be configured.
- QSFP28 interface, so <5W of power, maximum.
- Vendor-neutral.

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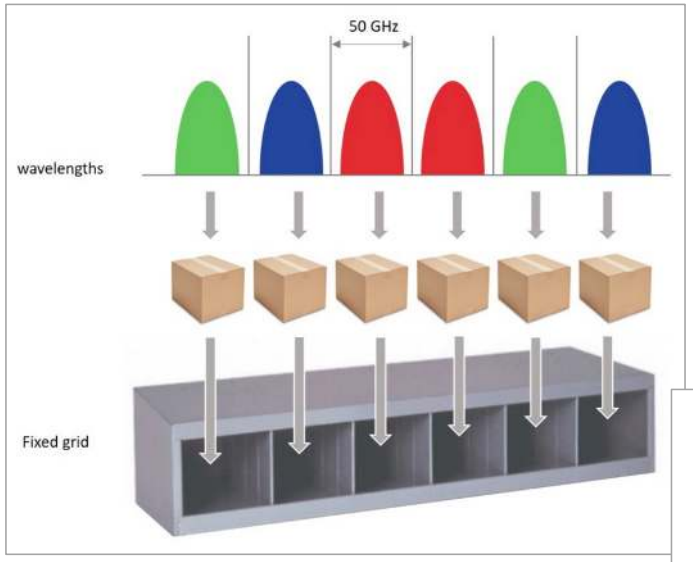
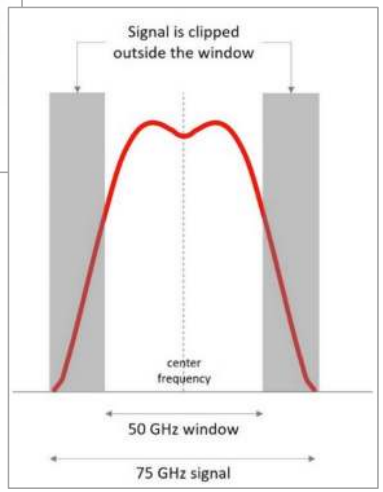
DWDM GRID SYSTEMS: FIXED-GRID

Fixed DWDM Grid



- Most DWDM systems today use a fixed-grid layout.
- Ideal when transponders use the same baud rate per wave.
- Today, transponders can run at various baud rates.
- Increasing baud rate increases bandwidth capacity per wave.
- But higher baud rates require wider grid frequencies.



- The edges of the 75GHz signal are clipped in the 50GHz channel.
- Leads to poor signal and/or transmission errors.

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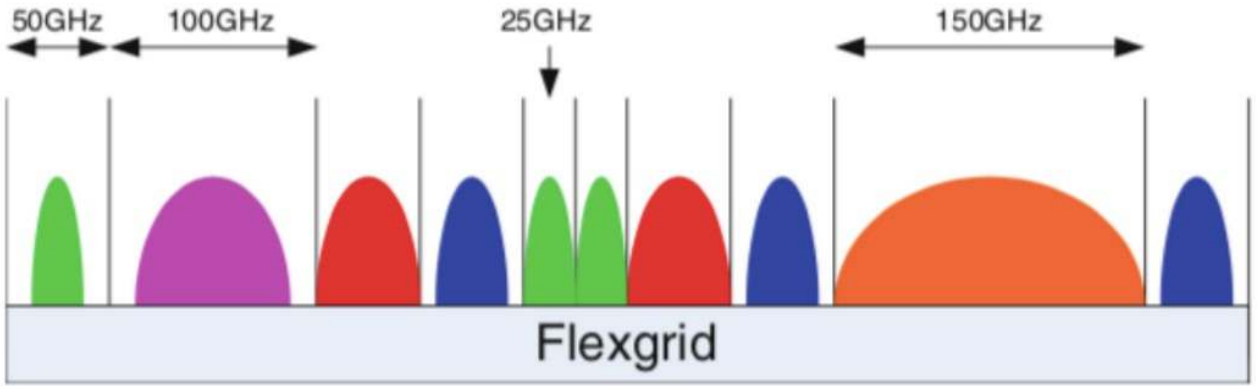
DWDM GRID SYSTEMS: FLEX-GRID

Flexible DWDM Grid



- Flex(ible) grids are the solution to the fixed grid limitations.
- Provides a continuous 4.8THz block of spectrum (C-Band).
- Operators can choose to assign spectral width per wavelength, as needed.
- It is granular, up to 12.5GHz per channel.
- You no longer have to strand capacity as in the case of fixed grid systems.
- More efficient use of the overall spectrum.
- More capacity can be carried across the entire system.
- Different services can be delivered without suffering spectral inefficiency.

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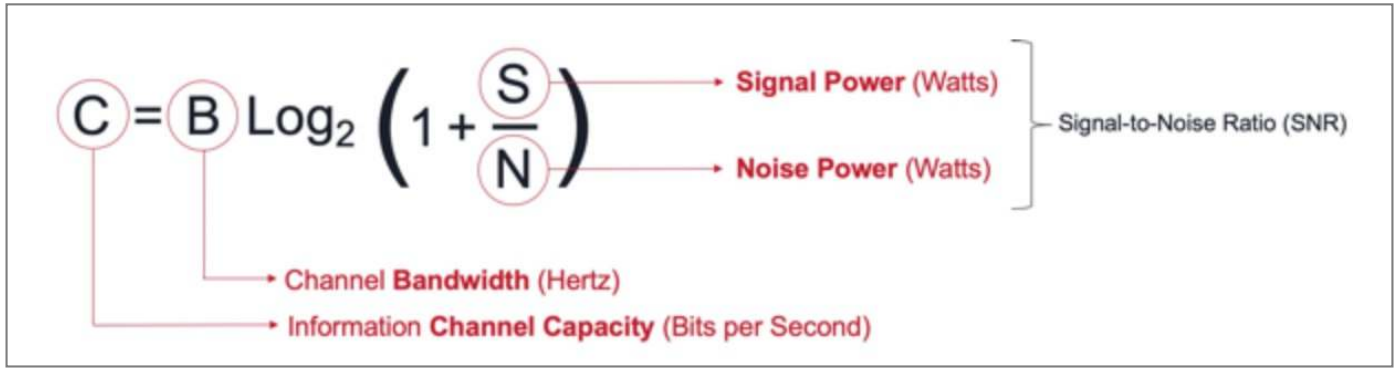
SHANNON'S LIMIT

Shannon's Limit Equation



- Once a submarine cable is laid, "B" is fixed based on the number of fibre pairs.
- The only thing to improve is the SNR to increase "C".
- In the last 12 years, we have done this with coherent detection.
- But we are nearing Shannon's limit.
- Time to go back to basics and build "hardware".

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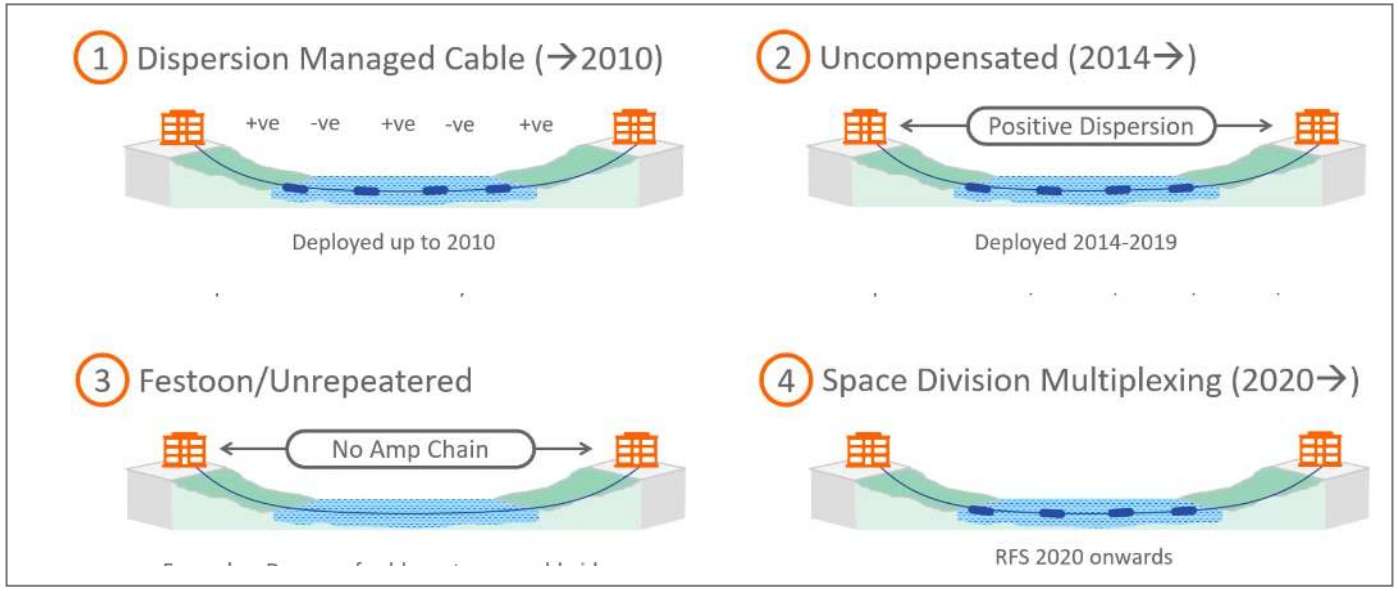
SUBMARINE CABLE TECHNOLOGY EVOLUTION

Evolution of Submarine Cable Design



- There is still room for Uncompensated cables, depending on use-case.
- Newer longhaul submarine cables will likely be SDM-based.
- Especially if content providers are involved in the build.

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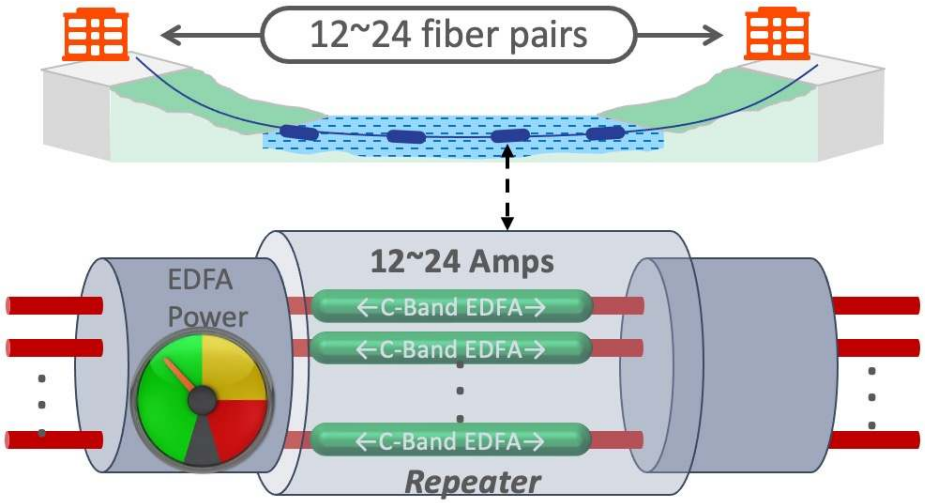
SDM: SIDE-STEPPING SHANNON'S LIMIT

SDM Submarine Cables



- We can be as clever as we have been, but at some point, we need to build things.
- SDM looks at adding more fibre pairs, as opposed to improving SNR.
- Rather than increase fibre pair capacity, we increase overall cable capacity.

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WHAT IS SDM?

Latest approach to maximizing the capacity of a subsea cable

SDM techniques (examples)	Consequences of SDM
Optimize repeater power and space • Longer amplifier spacing • Lower amplifier power • Pump sharing	• Lower launch power • Lower OSNR Lower non-liner penalties • Operation in linear regime

Lower fibre pair capacity but **more fibre pairs** delivering higher **total cable** capacity

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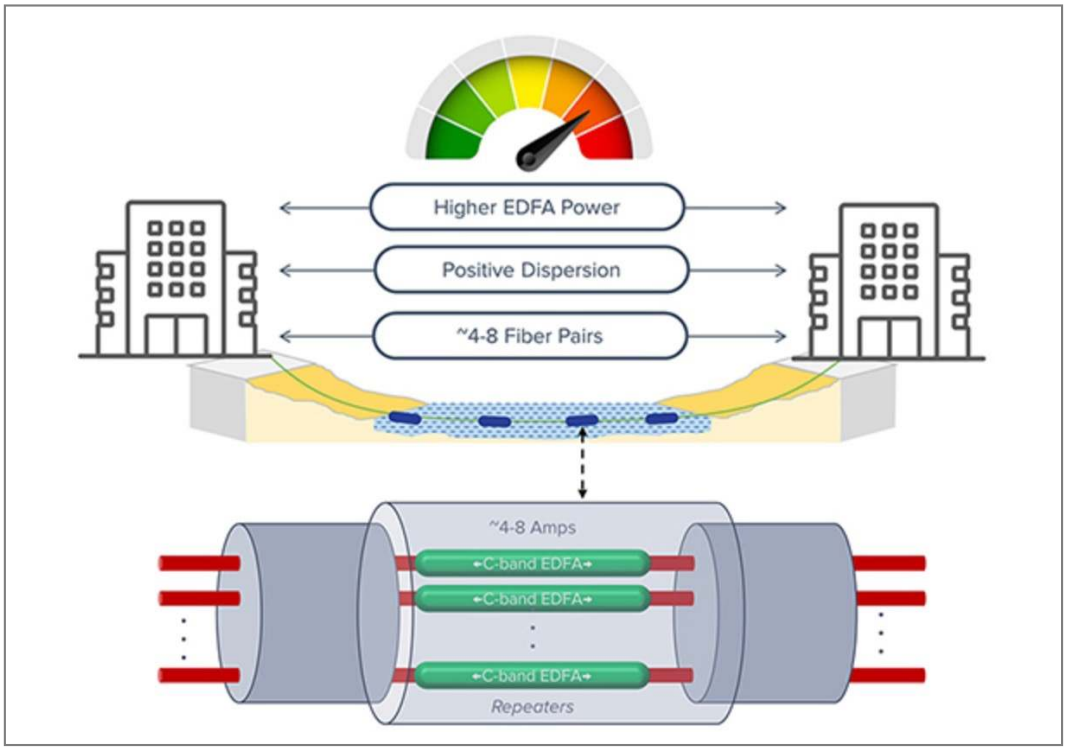
UNCOMPENSATED CABLES: HOW WE REACH MAXIMUM CAPACITY?

Uncompensated Cable Design



- Uncompensated fibre technology.
- First appeared in 2015.
- 2, 4, 6 or 8 fibre pairs in the cable.

- Maximize spectral efficiency per fibre pair.
- Maximize spectral capacity per fibre pair.
- (not the overall cable).

- High amplifier power.
- 100Gbps, 400Gbps, 800Gbps waves per fibre pair.
- Anywhere from 4Tbps – 24Tbps per fibre pair.
- 32Tbps – 192Tbps per cable system.

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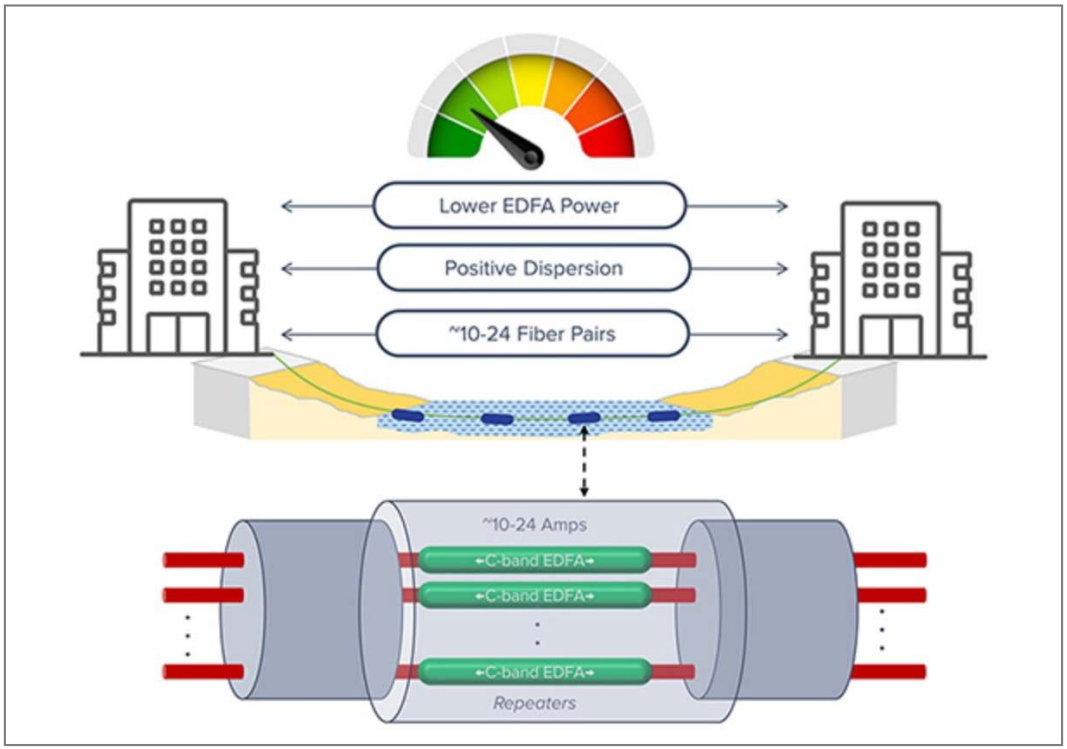
SDM: HOW WE REACH MAXIMUM CAPACITY?

SDM Cable Design



- SDM fibre architecture.
- First appeared in 2020.
- 10, 12, 16, 18, 20 or 24 fibre pairs in the cable.

- Sacrifice spectral efficiency per fibre pair.
- Sacrifice spectral capacity per fibre pair.
- Compensate by increasing fibre pairs in the cable.

- Low amplifier power.
- 100Gbps, 400Gbps, 800Gbps waves per fibre pair.
- Anywhere from 4Tbps – 24Tbps per fibre pair.
- 40Tbps – 576Tbps per cable system.
- Lots more margin for future capacity.

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GENERATIONAL EVOLUTION OF TRANS-ATLANTIC CABLE SYSTEMS

Cable Design & Capacity Growth

	Dispersion Managed	*Uncompensated*	*SDM-1*	*SDM-2*
	Apollo	**MAREA**	**Dunant**	**Meta Cable**
RFS Date:	2003	2018	2021	Contract in Force
Fibre pairs:	4	8	12	24
FP Capacity:	10Tb/s	26.2Tb/p	25.2Tb/s	21Tb/s
Cable Capacity	**40Tb/s**	**210Tb/s**	**312Tb/s**	**504Tb/s**

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SDM BENEFITS

- SDM = lower capacity per fibre pair, BUT more capacity per cable.
- Lower wavelength power = low system SNR at receiver.
- Lower power requirements compared to previous cable technologies.
- Lower power = plenty of margin to adapt to new transponder technology.

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SDM CABLES

SDM Cable Build Projects

SDM Cable System	Fibre Pairs	RFS
Dunant	12	2021
H2HE	16	2021
Amitié	16	2022
Equiano	12	2022
APRICOT	16	2024
JUNO	20	2024
2Africa	16	2024
Bifrost	12	2024
MEDUSA	24	2024
Hawaiki Nui	12	2025
Caribbean Express	18	2025
SMW6	10	2025
CSN-1	?	2025

- For each of these, you are looking at 15Tbps – 20Tbps per fibre pair.
- Total system capacity in excess of 400Tbps - 500Tbps.

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SDM CHALLENGES

It's not all roses…

- Latest SDM cables are touted as being "open".
- So when is a cable RFS?
- How do you manage spectrum?
- Who operates the cable system?
- How do you perform testing quickly?
- How do you provision quickly?
- Who do you call when things go wrong?

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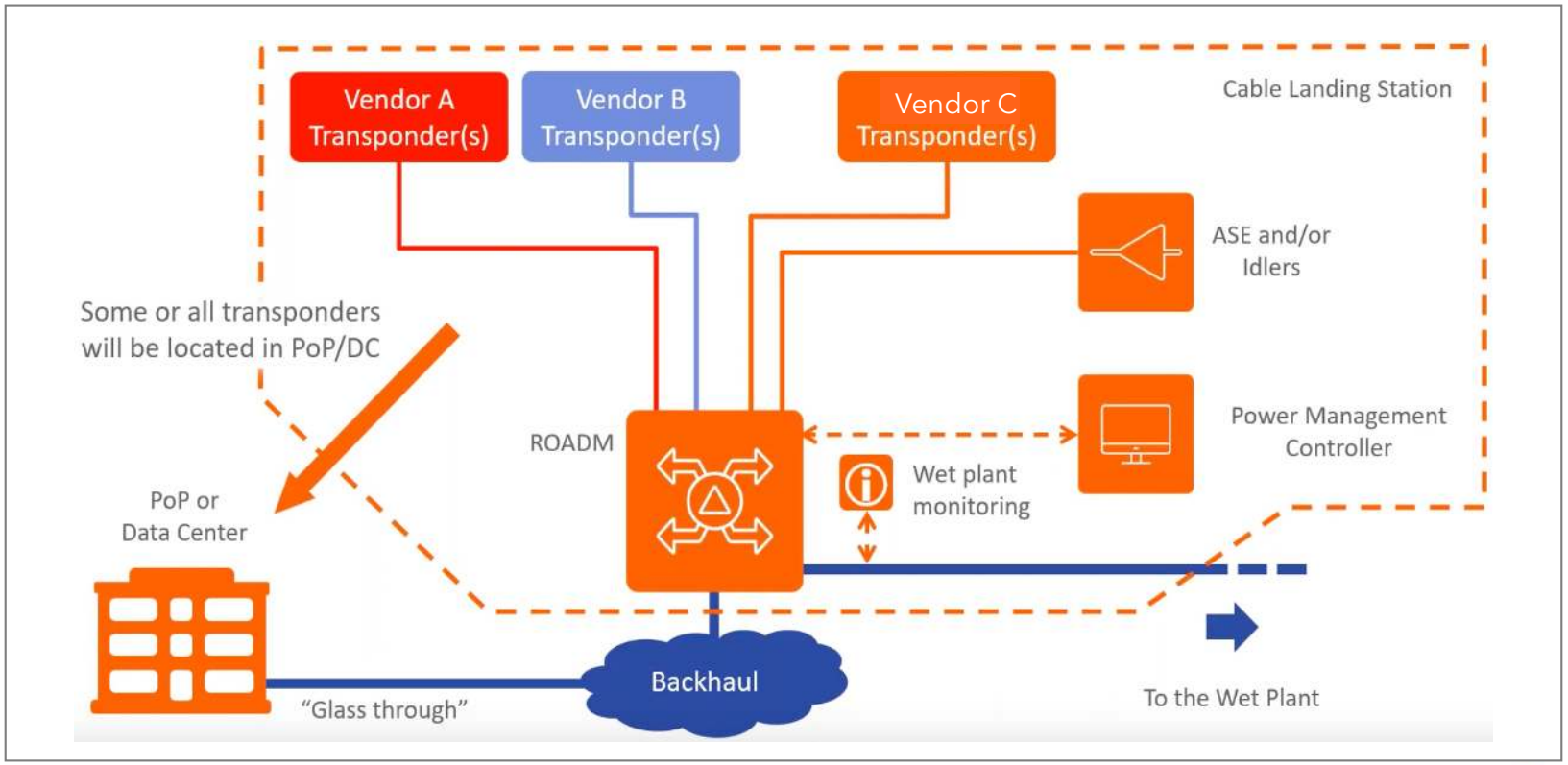
SDM CHALLENGES

It is rather logistical…



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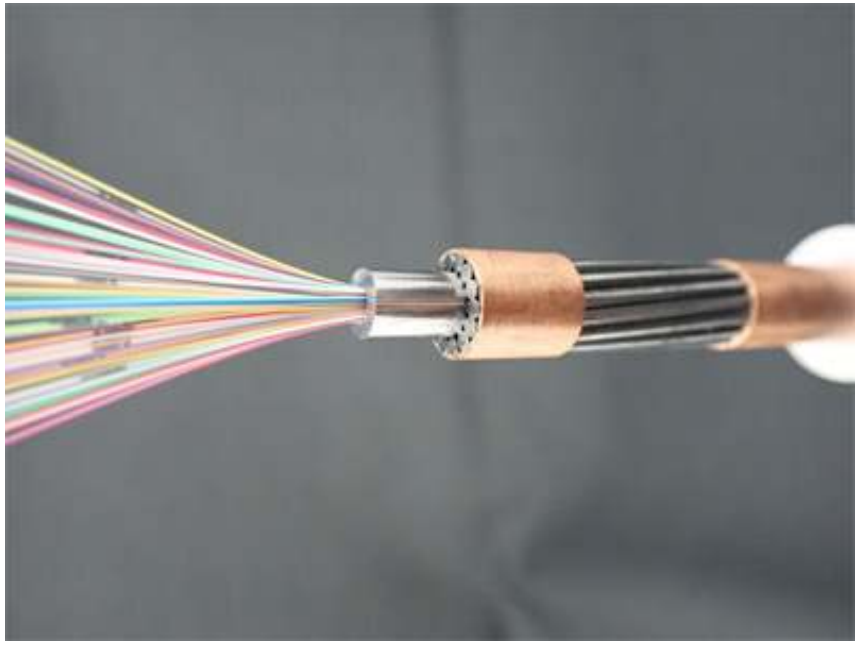
SDM FUTURE



- 32 fibre pairs is work currently under way for SDM cables.
- Later on, 40 fibre pairs is the target.
- Limitations for the # of fibre is the # of amplifiers and their spacing.

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Q&A

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