



Maximizing Network Capacity, Reach and Value
Over land, under sea, worldwide

Submarine Upgrades: What is the Limit?

Bertrand Clesca, Tony Frisch, Joerg Schwartz

ECOC 2011 – Geneva, Switzerland

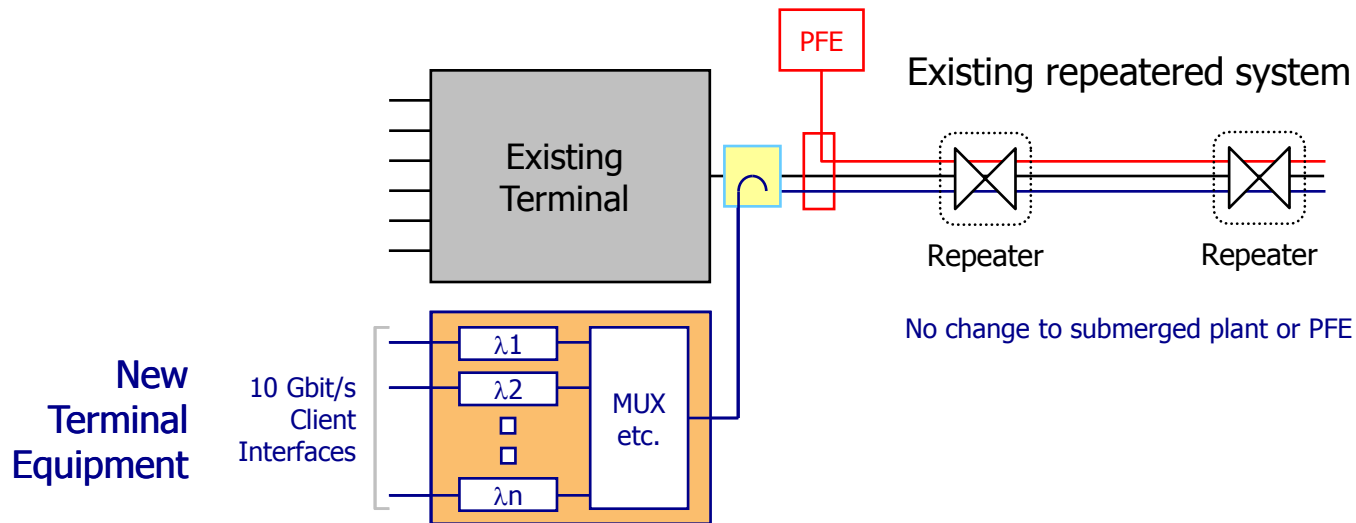
22 September 2011

Symposium On Undersea Systems: Technologies And Applications

- Upgrades: What are the Drivers?
- Channel Rate \neq Line Capacity
- Legacy System Challenges
- DSP and Coherent Detection
- Non-Linearities in Repeated and Unrepeated Submarine Cable Systems

Why Upgrades?

- Increase capacity of existing submarine systems
 - To extend the lifespan of system
 - Reduce cost of bandwidth
- Faster and simpler than completely new installation
- Can be performed in different ways:
 - In parallel with existing terminal equipment (dark fiber or overlay)
 - Replacing existing terminal equipment
 - Connecting to existing terminal equipment if optical port available



Channel Rate \neq Capacity



Popular myth: Increasing CHANNEL RATE “automatically” increases capacity, e.g. moving from 10G to 100G channels offers 10x more capacity

Long repeatered systems have a fixed repeater output power

Unrepeatered systems are limited by span loss, launched power, and receiver sensitivity

Higher bitrates need higher Signal-to-Noise Ratio

Higher bitrates need higher sensitivity receivers

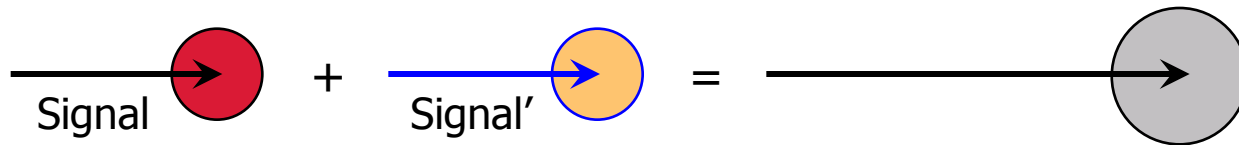
Available power to be shared between fewer channels

NOT always net LINE CAPACITY gain

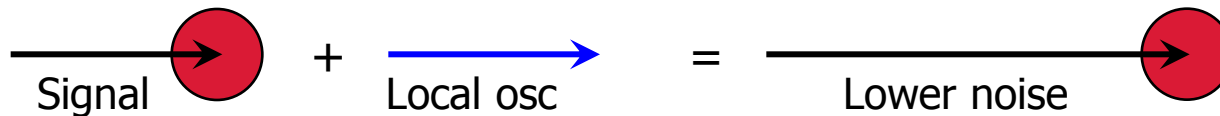
- Capacity gain can be achieved by:
 - Transmission technologies requiring less photons per bit
 - Higher tolerance to nonlinear effects
 - Better FEC
 - ...

DPSK Compared with Coherent Detection

- Differential PSK effectively adds two phase-related signals, each of which has noise



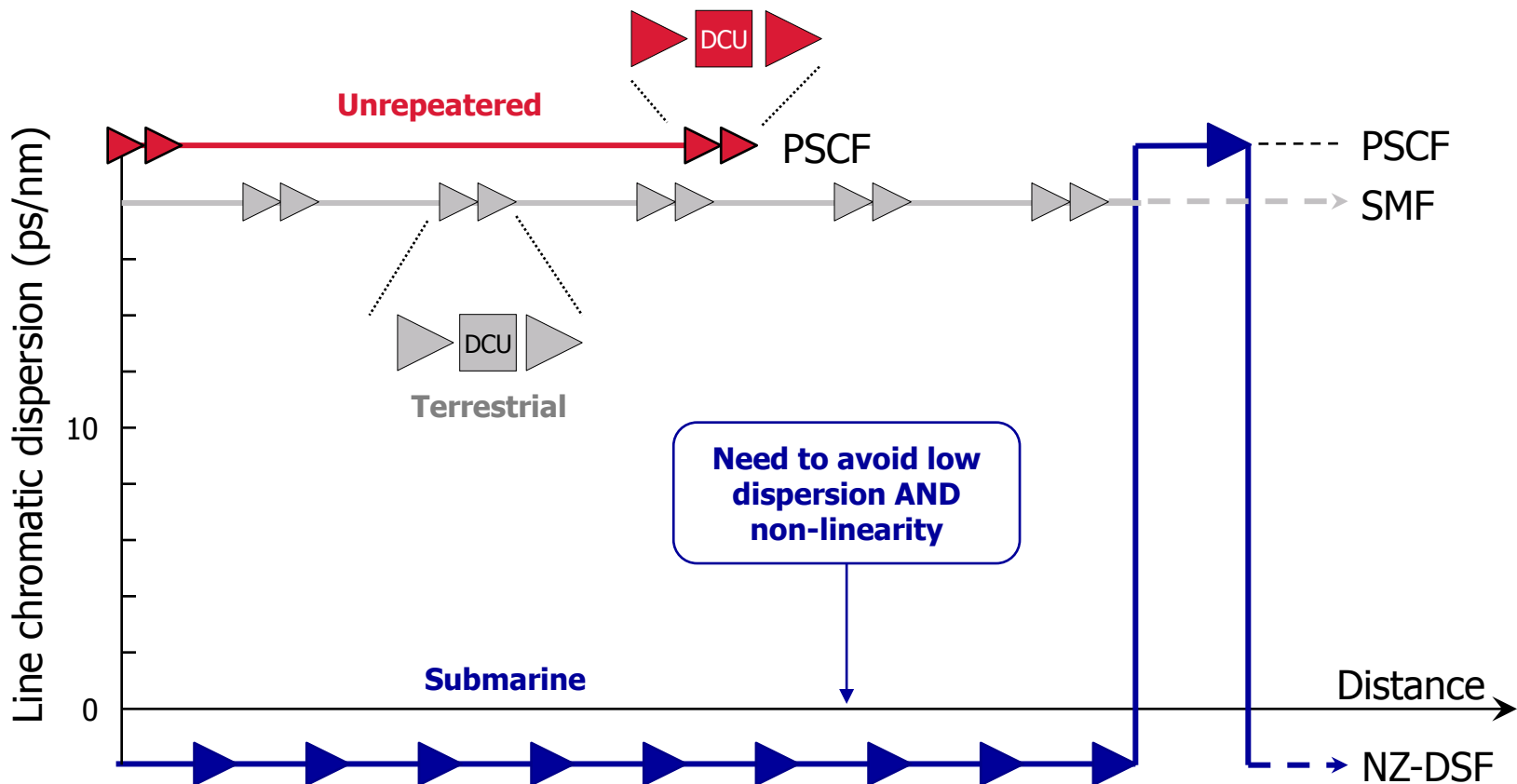
- Coherent PSK effectively adds two phase-related signals, only one of which has noise



- Coherent detection is inherently lower noise in theory
- Typically <1 dB improvement, even less on non-linear systems
- BUT coherent detection offers:
 - Chromatic dispersion and PMD compensations
 - Full analysis of optical field and ADC that enable soft decision FEC

Legacy Submarine vs. Terrestrial Systems

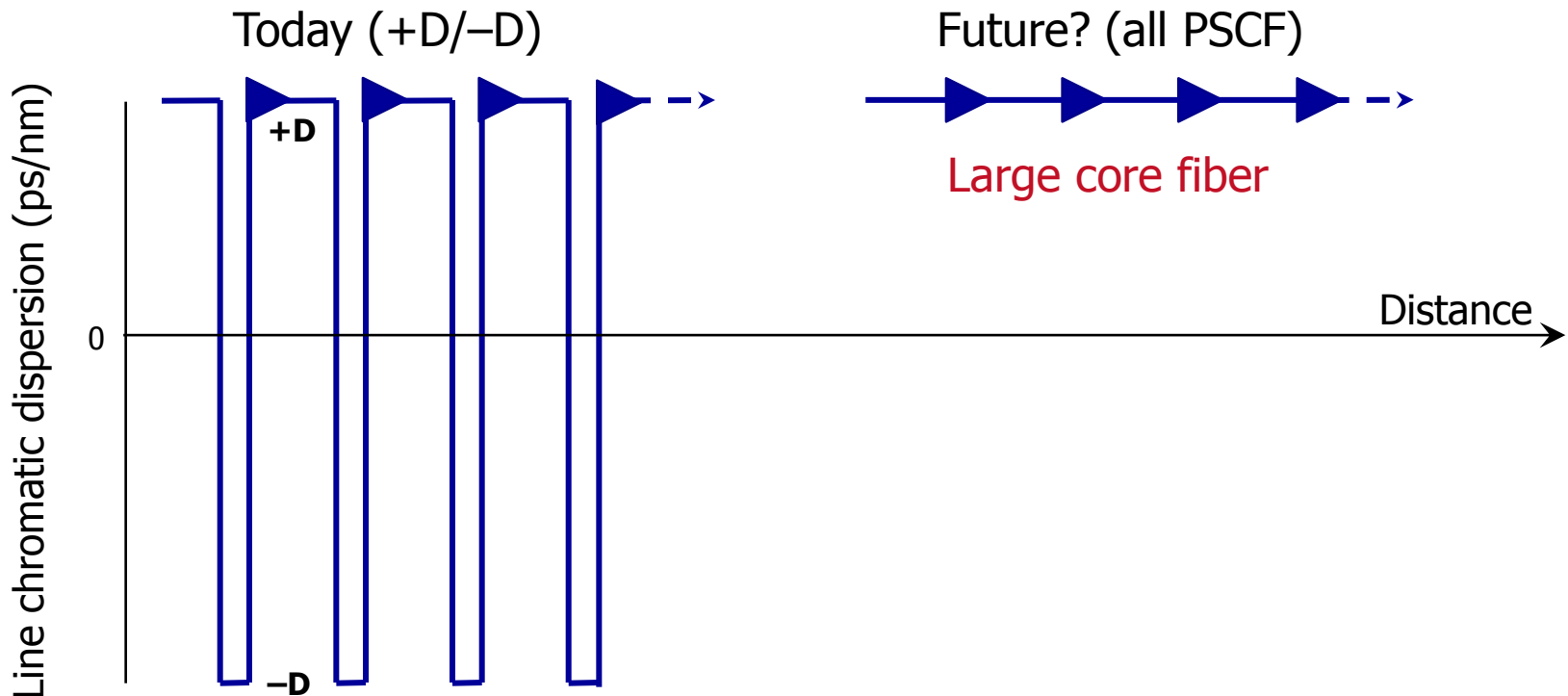
- Different solutions for handling chromatic dispersion:



- Longer spans make non-linear effects more significant.

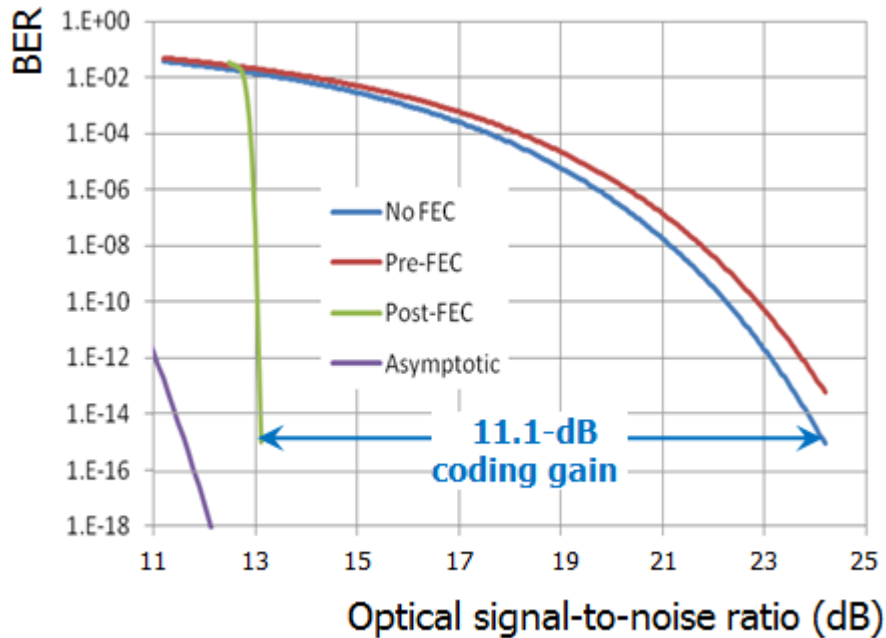
Newer Generation Submarine Systems

- Newer systems try to minimise non-linear effects over long spans:



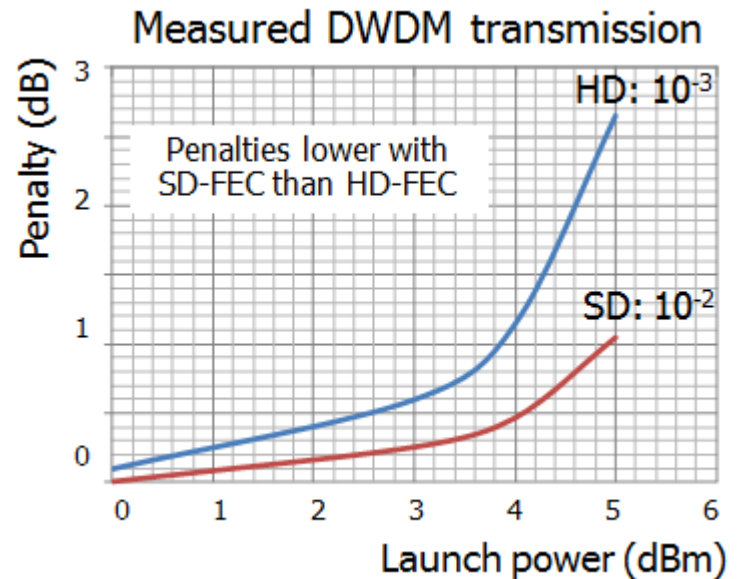
- +D/-D: expensive and makes repairs quite complex?
- All PSCF an even better solution – but needs a completely different terminal...

Soft-Decision FEC



Parameter	Turbo Product Code
Overhead	15%
Line Rate	120 Gbps
Net coding gain @ 10 ⁻¹⁵	11.1 dB
Error kink	<10 ⁻¹⁸
Latency	7.5μs
Burst error performance	> 2000

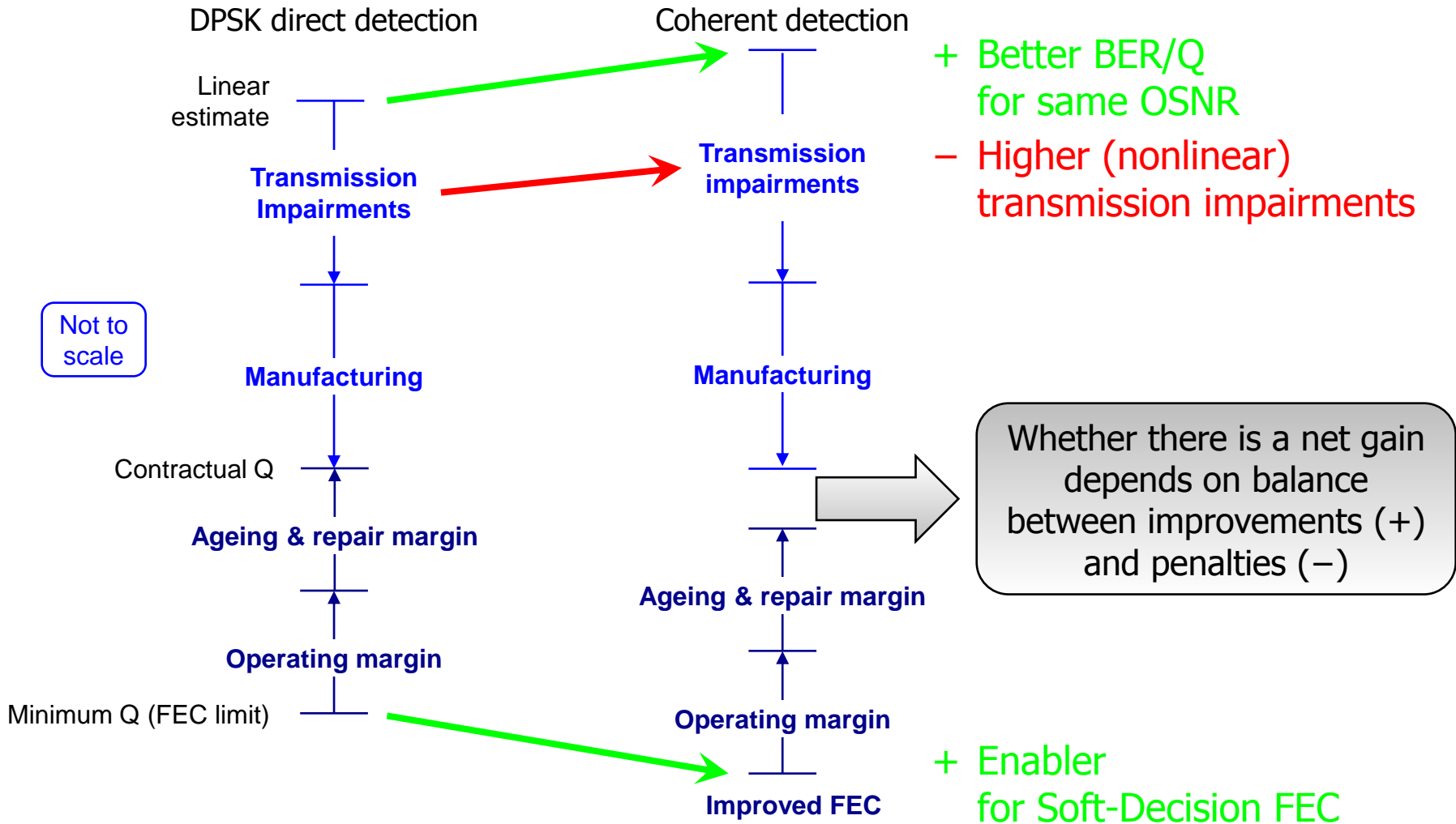
- SD-FEC provides 3-4 dB gain over HD-FEC
 - 2.5 dB better coding gain than 7% HD FEC
 - 1.5 dB better system margin (lower penalties) if there are non-linear impairments



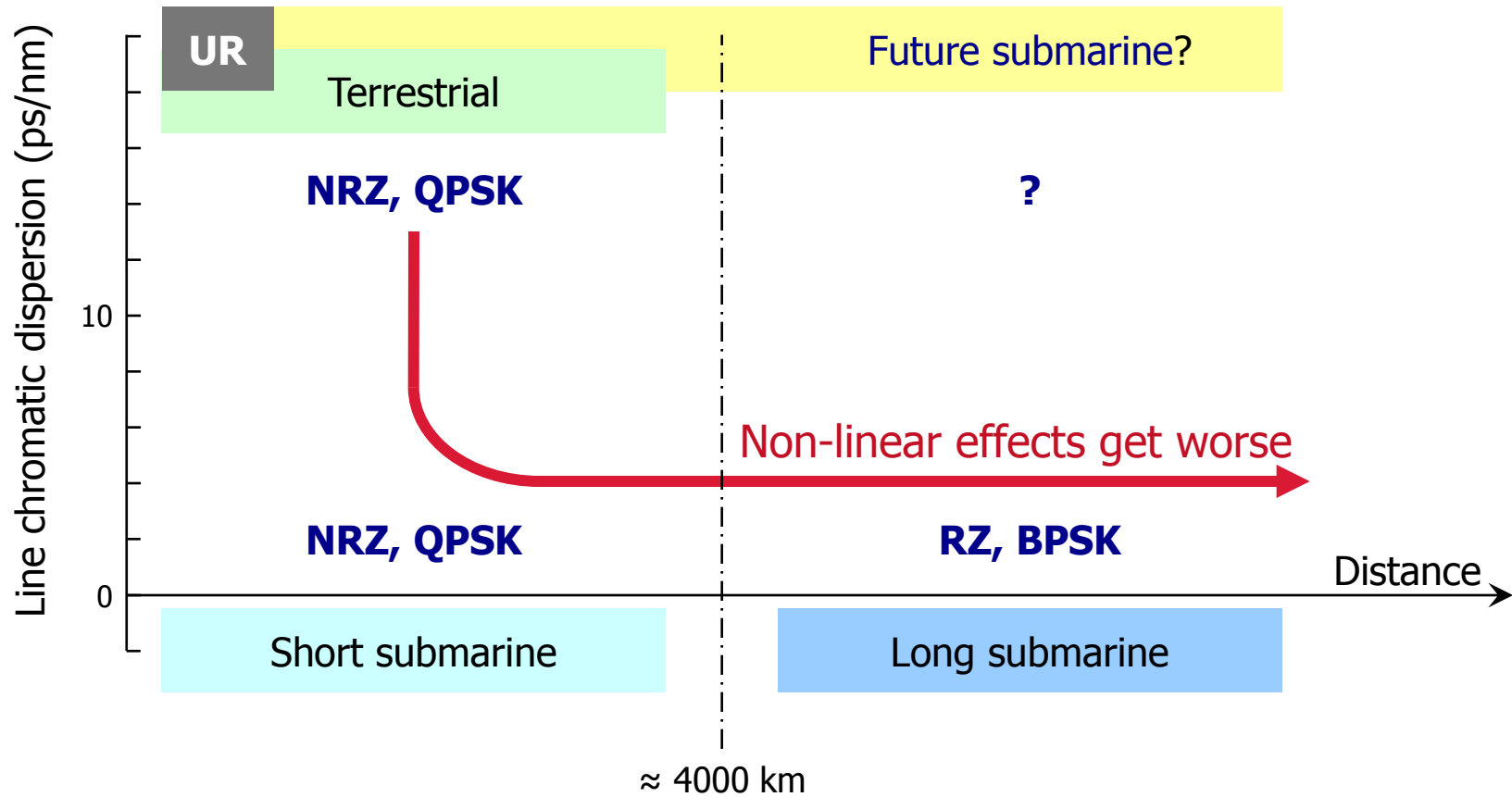
Coherent Detection for Legacy Upgrades



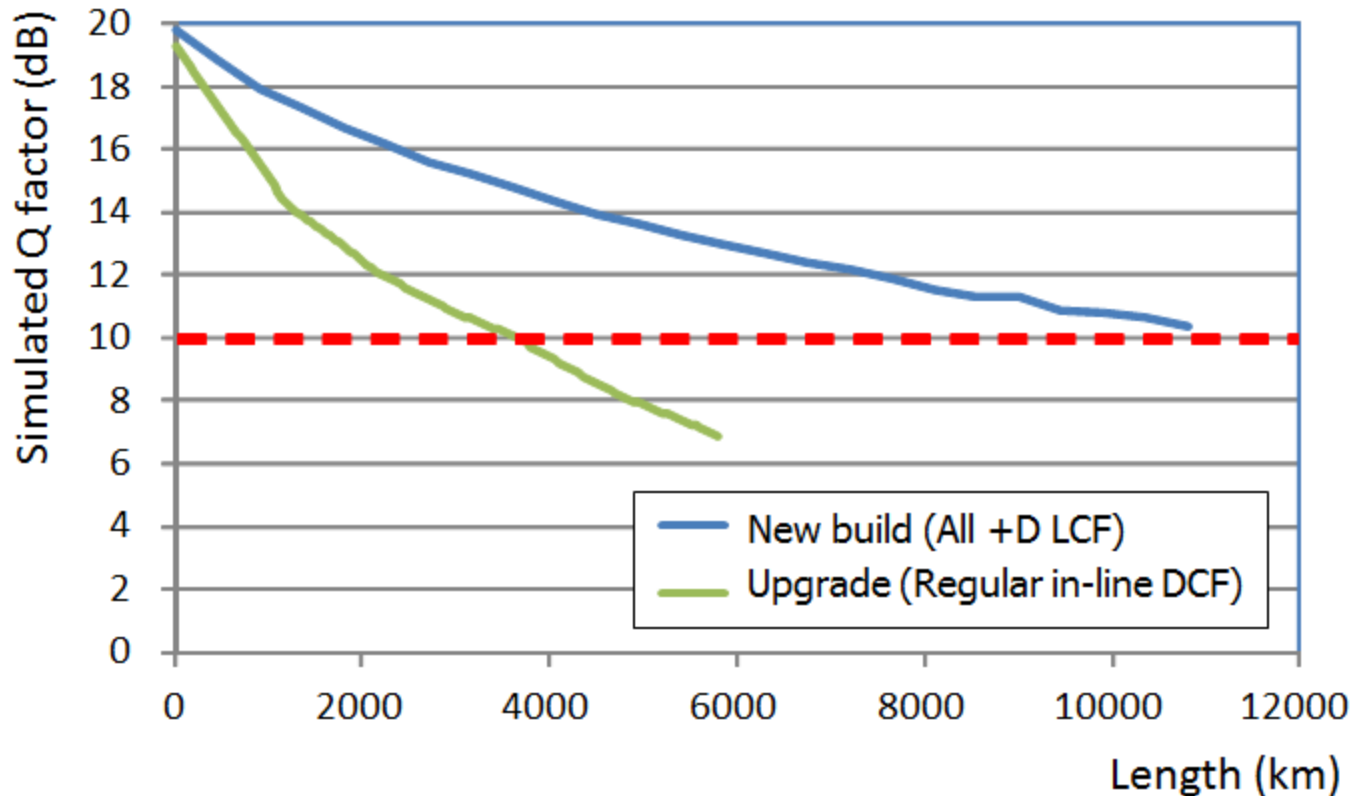
- “Power Budget” view: you win and you loose...



Different Applications: Different Solutions



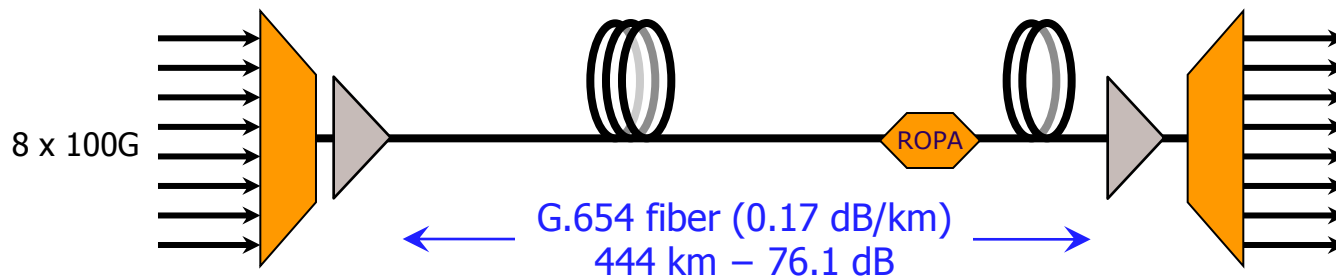
Coherent 100G for Repeated Upgrades



- Performance of 100G DP-QPSK on Upgrades (with in-line compensation) vs. New Build (all +D large-core fiber)
- Today's coherent products work for regional upgrades and longer new builds, but not for long repeated upgrades.

Coherent 100G for Unrepeated Upgrades

- Unrepeated transmission with Remote Optically Pumped Amplifier (ROPA)
 - 8 x 120-Gb/s transmission over 444 km



➔ Twice the capacity achievable at 10G (NRZ)

- Unrepeated transmission with no ROPA:
 - Around 71 dB of cable attenuation, the line capacity is about the same for 10G, 40G or 100G channel rates.
 - Beyond 71 dB, multiplexing 10G waves leads to the highest line capacity.

➔ 100G PM-QPSK offers advantage, but is limited today by nonlinearities.

- To date, there has been no fundamental limitation to pushing up the capacity of optically amplified submarine systems.
- We have been able to increase the capacity of systems via upgrade not only once, but several times.
- This has been largely facilitated by new technologies, such as advanced modulation or better Forward Error Correction, as well as better components.
- The advent of coherent detection and DSP offers a large potential to submarine upgrades, in particular by facilitating Soft Decision FEC.
- Due to the non-linear impairments present in legacy long-span systems with in-line dispersion compensation, standard coherent technologies are not suitable for upgrades of these systems.
- New approaches are required and are under development.
- They will push the limits for upgrades even further...



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