The future of Submarine Systems 
Where Do Upgrades Fit?

Tony Frisch and Sumudu Edirisinghe, Xtera Communications
Contents

Focuses on Third Party upgrades of Long-span Repeatered submarine systems

• Background
• Upgrade Issues for legacy systems
• Constraints for increasing the data rates
• Potential advances for future cable systems
• Potential upgrade opportunities on new cables
• Conclusions
Where do Third Party Upgrades fit?

- **What?** Modification of the system to add capacity/functionality
- **When?** After the initial construction of the system
- **Why?** Opportunism
  - Better features from the competitor
  - To create competitive pressure
- **Why not?** Submarine-specific requirements/features
  - E.g. terrestrial suppliers generally cannot monitor submerged repeaters
- **Who?** Anyone other than the original supplier
  - Providing they can offer the correct solution – so far mainly submarine specialists

... Recently several non-specialists e.g. Nortel, Infinera, Huawei are showing interest in this market
Why Third Party Upgrades work

• Surely the initial supplier is best positioned?
  – Knowledge
  – Footprint
  – Simple installation
  – Upgrade needs to be coupled
    Unless it's on a dark fibre

• Exceptions are:
  • Initial supplier may be out of business
  • Existing equipment may no longer be supplied
  • Upgrade may be of low interest to initial manufacturer
  • Upgrade supplier may offer more
    – Better capacity
    – Better features
    – Better price / delivery
What about System Warranty?

- Usually expires after 5 years, so may not apply
- Risk is low because:
  - Submerged plant is very reliable
  - Terminal equipment is electrically isolated from the power feed
  - Terminal equipment produces relatively low power at the repeater

- Bad business to seek to void warranty without a good reason ...
Transatlantic Capacity Growth

Two targets:
- Upgrade existing systems
- Upgrade new systems

Source: Telegeography
Growth – the major driver

- Total capacity increased ~12x
- Capacity per fibre increased ~3x
Anatomy of a submarine system

- Cable
- Powering
- Monitoring

- Amplifier: larger bandwidth, more output power
- Fibre: larger core, different dispersion maps
- Terminal: higher line-rates, improved FEC, adjustable dispersion compensation, DPSK...
Initial Design Constraints

- Wet parts are very expensive to develop
  - Reluctance to change the design without a compelling reason
- Wet parts are very expensive to replace
  - Need to be reliable
  - Reluctance to replace them as part of an upgrade
  - Fault location a critical need
    - Simple for cable breaks using DC fault location
    - More difficult for amplifier faults needs a specialist solution

How can one detect which amplifier is faulty?
Upgrade Constraints

- Wet parts are very expensive to access
  - Changing repeaters: VERY expensive
  - Adding equalisers: Expensive, but more realistic? yet to be done ...
  - Disrupts traffic

- Moving the complete system: Quite popular
  - Cheaper than buying a new system

- Most cost-effective is to replace terminal equipment
  - Low / no disruption to traffic
  - May be able to retain existing terminal equipment

- Station by-pass: Increasing popularity
  - Provides more flexibility to carriers

- Needs a good understanding of the line characteristics
Line Characteristics

- **Amplifier**
  - Bandwidth / Gain shape
  - Power out
  - Noise factor
  - Supervisory type

- **Fibre map**
  - Attenuation
  - Dispersion
  - Dispersion slope
  - Lengths

- **Existing traffic**
  - Wavelengths
  - Power levels
  - Rate / Format
  - Performance
Line Shaping

- **Equalisers**
  - Passive
  - Active (adjustable)

- **Branching Units**
  - Fibre-splitting
  - Wavelength Selective
  - Coupler based

- Trend is towards simplicity?

- Need to understand
  - Wavelength Selectivity
  - Control
  - Monitoring
• Different solutions for handling chromatic dispersion

• Longer spans make non-linear effects more significant
• Generally need different solutions for submarine and terrestrial
Dispersion as a barrier to competition

- Long spans make dispersion an issue
- Example of residual dispersion
  - $Cd' = 0.1 \text{ ps/km/nm}^2$
  - Length $= 6000 \text{ km}$
  - WL offset $= 5 \text{ nm}$

  Typical values

  $$= 3000 \text{ ps/nm}$$

- Different for different wavelengths / bands
- **Significantly more than for a typical terrestrial system**
Technical Differences

- 40 Gb/s, and higher, solution in all cases, using Dual Polarisations of lower rate signals

**Terrestrial**

- **Long Haul**
  - Noise
  - DPSK and Multilevel (DQPSK)

**Submarine**

- **Short Haul**
  - Noise + Low Dispersion
  - DPSK and Multilevel (DQPSK)
  - TDC or EDC

- **Long Haul**
  - PSK / DPSK + TDC/ EDC
  - Coherent detection (?)
  - Soft decision FEC
  - Non-linear Effects
  - Noise + Low Dispersion
# 40Gb/s Performance on legacy submarine systems

<table>
<thead>
<tr>
<th>Bitrate/Modulation</th>
<th>Channel spacing/ GHz</th>
<th>Performance</th>
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<tr>
<td>42.8 Gb/s DPSK, DD</td>
<td>100</td>
<td>Poor</td>
</tr>
<tr>
<td>42.8 Gb/s DQPSK, DD</td>
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<tr>
<td>42.8 Gb/s QPSK HD</td>
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<td>42.8 Gb/s POLMUX DPSK DD</td>
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<td>42.8 Gb/s POLMUX DPSK T/2 DD</td>
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<tr>
<td>42.8 G POLMUX DPSK T/2 HD</td>
<td>50</td>
<td>Good</td>
</tr>
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Over 6750km Submarine link with LEAF & LS fibre

DD = Direct Detection, HD = Homodyne Detection
Legacy verses future systems

• Upgrading long span legacy systems over 4000km to higher data rates seems challenging
  – Moving to 40Gb/s over trans-Atlantic distances will require 2 x 20Gb/s or 4 x 10Gb/s
  – Coherent detection may not work well with DSF and NZ-DSF links due to nonlinear effects

• However, for new builds there is increasing pressure to move to 40Gb/s and 100Gb/s data rates
  – Needs cables designed for large bandwidths and minimal non-linear effects
  – Modulation and detection schemes capable of delivering 100Gb/s would dictate the fibre types
  – Coherent detection would offer more functionality
    • Mitigation of propagation effects using DSP
    • Better coding gains through soft decision
More fibre pairs, more bandwidth

- Higher Bandwidth?
- C + L band EDFA
  - More complex
  - More pumps
  - More power needed

- Raman Amplifier
  - Complex control
  - More pumps
  - More power needed

- Is there a benefit compared with 2 fibres?
  - Economic?
  - Reliability?

- Power / reliability could be the key limit to capacity
• +D/–D reduces Cd and non-linear effects; expensive and makes repairs quite complex?
• All PSCF an even better solution?

Today (+D/–D)  Future? (all PSCF)

Large Area Core
All PSCF Fibre

- Long spans make dispersion very large
  - $C_d \sim 20$ ps/km/nm
  - Length 6,000 km
  - Dispersion 120,000 ps/nm
- Only practical with Electronic Dispersion Compensation (EDC)

- Most suppliers currently selling direct detection DPSK
  - High-speed ADC and DSP not trivial developments
  - Some questions regarding coherent benefit on long spans
FEC limits

- Simple binary codes are close to reaching the theoretical limits
- Soft-decision gives theoretical improvement of up to 3 dB
- Requires high-speed ADCs – more complex coding/decoding

Using 6 bit soft-decision decoding

Net coding gain (dB)

Overhead (%)

Hard coding

Using 6 bit soft-decision decoding
Higher level formats

- Needed to avoid the need for higher line-rates

- More levels = more power
- More levels + more power = problems with non-linear distortion

- More levels = more processing = more complexity
Will upgrades be viable in the future?

- If future systems evolve towards uncompensated PSCF systems then,
  - Coherent detection + DSP will be the most viable technique
  - The upgrade market will become very competitive
  - System design should be simpler

- The upgrade business will thrive if upgrade vendors offer
  - Compatible equipment providing 40Gb/s and 100Gb/s at competitive prices
  - With extra functionality and superior service

- Carriers interested in third party upgrades
  - To maintain a competitive environment
  - To stimulate innovative advances
  - To cover the possibility that a supplier goes out of business or a product becomes obsolete
Summary

• Moving to 40/100 Gbaud line rates on long submarine links proves to be challenging
• Higher capacity per fibre pair will use binary/quaternary formats rather than 40/100 Gbaud line-rates Also likely to use polarisation multiplexing
• Choice of format / line-rate depends on target system
• Single, low-loss, large area, high-dispersion fibre map appears attractive for future deployments
• ADC and DSP technology is likely to be a key enabler
  – Expensive development
  – Will not happen quickly

• A lot of potential changes, opportunities and challenges for upgrade suppliers as the target system evolves
Acknowledgements

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Thank you for listening

Any Questions?