High-Capacity Optical Networks
With or Without Repeaters

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The Data Center Opportunity in Norway

- Cool climate and supply of cold water → natural free cooling
- Green power → Europe’s largest producer of hydroelectric power
- Surplus of renewable, tax-friendly energy → lower costs

Opportunity for High Capacity and Cost-per-Byte efficiency
Cloud and video are driving data center builds...

DCI is the fastest growing application for optical networking...

Most Content Providers are securing fiber and building their own networks...

...and changing how networks are constructed...

...DCI revenues grew 16.2% in 2014, surpassing US$2.5bn, and projected to grow at 10.5% CAGR...

...as opposed to lease managed capacity services from Carriers.

Source: Ovum 2015
Optical Networking Requirements for DCI and International Connectivity

- **High Capacity**
  - Maximize # of Tbps per Fiber

- **Long Spans & Reach**
  - Minimize # of Intermediate Sites
  - Reach out Longer Distances

- **Low Latency**
  - Minimize # of Regeneration Sites

- **Over Land & Under Sea**
  - Converged Terrestrial and Submarine Optical Solutions
  - Cost-efficient also across Short Distances
Driver for Longer Single-Span Optical Systems

- **City A**: Optical Equipment
- **City B**: Optical Equipment

- **PoP or DC**
- **Cable Landing Station**
- **Submarine cable**
- **Terrestrial extension**
Direct PoP-to-PoP: Better Cost/Bit and Latency
Removing CLS Equipment

Requires Superior Optical Technology
1. Fiber
   - Lower attenuation fiber is always better ➞ Ultra low-loss (G.652B, G.654B)
   - Type ➞ Fibers with large effective area tolerant to higher launched power

2. Electro-Optics Silicon
   - Line rate 100G, 150G, 200G, 300G, 400G and Beyond
   - Modulation format
   - Pulse shaping
   - Channel density and flex grid
   - Wavelength of transmission (fiber attenuation lower in L-band)
   - Detection (Coherent)
   - Forward Error Correction (Soft-Decision FEC)

3. Power Management
   - Launched power; power in the line fiber
   - Non-linearities mitigation
4. Raman amplification

- Results from the interaction of an optical radiation ("pump") with molecular vibrations of the glass
  - Maximum gain at a shift of ~100 nm in the 1550 nm window
- In any fiber types
- The more pump power the more gain
- Raman gain improves with lower fiber attenuation (larger $L_{\text{eff}}$)

Thus the NF and OSNR improvements due to Raman will be larger in lower attenuation fiber at the same Raman pump power.
Raman Amplification
Power Profile along the Span (Backward Raman)

Gain from backward Raman pumping

Fiber attenuation

266 km (61.2 dB); G.652D

15x100G
Raman Amplification
Power Profile along the Span (BWD & FWD Raman)

Gain from forward Raman pumping
Fiber attenuation
Gain from backward Raman pumping

288 km (65.5 dB); G.652D

15x100G

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5. Remote Optically Pumped Amplifier (ROPA)
   - Passive sub-system, made up of a few optical components (housed in an enclosure jointed to the cable) and pumped from one end of the span (typically, receive end)
   - Basically, performs the function of a mid-span EDFA

   - More pump power allows ROPA to be located further away from the terminals
Example of ROPA Enclosure for Subsea Applications

Splice tray
Fibre coiling tray
Component tray
Cable anchoring
FO cable

Courtesy of Nexans
**ROPA**

Power Profile along the Span

Gain from forward Raman pumping

Fiber attenuation

Gain from backward Raman pumping

Gain from ROPA

373 km (76.1 dB); G.652B

15x100G

107 km

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410 km (68.2 dB), 150 x 100G Unrepeatered Transmission over G.654B Fiber

LRA (Discrete Raman amplifier)  289 km  ROPA  121 km  LRA

\( <P_{\text{out}} > = -2.8 \text{ dBm/ch} \)

\( <\text{OSNR}> = 14.2 \text{ dB} \)
557 km (90 dB), 1 x 100G Unrepeatered Transmission over G.654B Fiber

- Corning® Vascade® EX2000 (G.654B), $A_{\text{eff}}=112 \ \mu\text{m}^2$
- Backward AND forward ROPAs – No use of extra fiber for pumping

**Graph:**
- Per channel power (dBm)
- Gain from forward Raman pumping
- Gain from backward Raman pumping
- Fiber attenuation
- Gain from ROPA

**Diagram:**
- 133 km transmission distance
- 291 km transmission distance
- Direction of transmission
- Forward Raman pumping
- Backward Raman pumping
- EDFA

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Most Recent Unrepeatered Results by Xtera

10 Gbit/s

100 Gbit/s
Raman for Multi-Span Applications
100G across Ultra-Long Spans over 2,266km OPGW

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Google (ECOC – Sept 2014): Spectrum efficiency (bit/s/Hz) is now close to the Shannon limit... Need to either:

1. Increase the # of fibers: too expensive
2. Increase the # of cores: too long term (10+ year) solution
3. Expand the spectrum width (without compromising the reach)

Option #3 is the one developed and field-proven by Xtera
More Capacity in Long Haul applications for 100G, 400G and Beyond

- **3x Capacity**
  - 240 channels
  - 150 channels
  - 80 channels

- **2x Reach**
  - Raman + (4,500+ km)
  - Raman (4,500+ km)
  - EDFA (2,000 km)
World-first Raman Repeater for Subsea Cable Systems

- 50% more optical bandwidth and longer spans
- Down to 8,000m, up to 12kV
- Titanium alloy: as strong as steel, yet 45% lighter
- Very compact for easy seabed burial through plough
Xtera Product Portfolio

Maximizing Capacity and Reach For Optical Networks

In-House Developed

- Nu-Wave Optima
- NMS
- Repeater
- Branching Unit
- ROPA

Partners Ecosystem

- Vessel
- Cable

Single DWDM & SLTE

Submerged Equipment

Turnkey Solutions

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Unified Terrestrial and Submarine Networks
Xtera Portfolio and Application Example

Transoceanic Repeatered

Regional Repeatered

Unrepeatered

Terrestrial fiber

Subsea fiber

DWDM optical systems

Repeater

Branching Unit

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Conclusion

- **Field-proven Raman optical unrepeatered transport technologies can offer today:**
  - Up to 600+ km unrepeatered reach
  - Up to 15 Tbit/s capacity per fiber pair

- **Optical unrepeatered transport technologies can be applied to multi-span links:**
  - Key to minimize the number of intermediate sites
  - Long-span capabilities required for OPGW cable in utilities power grids

- **Raman-based optical subsea repeaters are now in commercial service for wider spectrum and/or longer repeater spacing.**