High capacity optical transmission for science applications

SKA Workshop

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Optical Networks

Nokia Siemens Networks

Increasing network traffic …

… driver for 40G/100G in Core and Metro

Super Hi-Vision (UHDTV) with 16x pixel resolution of HDTV, BW >500 Mbit

Social networking, always connected

SKA

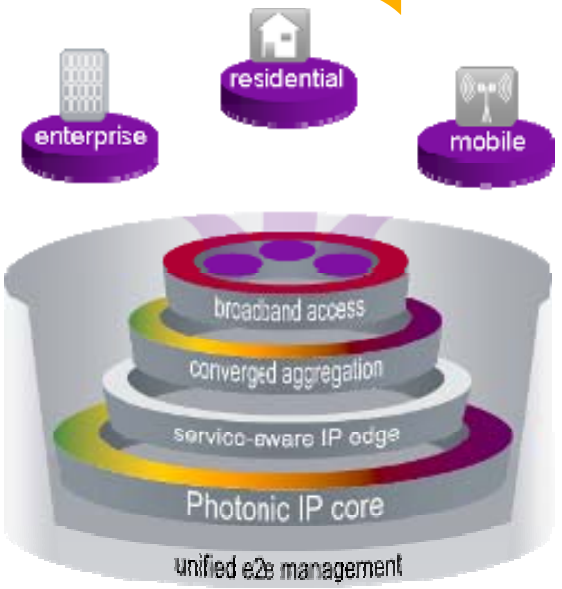
VOD, VoIP, Streaming, Cloud Storage

HDTV download speed 60Mbps

Data centers drive aggregation of 10G servers and clients

Online gaming 2-20Mbps bidirectional

network bandwidth growth of 50-100% per year



0.4-1T

100G

40G

10G

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Status Quo 100G

To 400G… and beyond

Modulation formats: from 10G to 100G

Channel data rate

622M

2.5G

10G

40G

100G

OOK is the de-facto choice for data rates up to 10G

- Simple Tx/Rx configuration
- Cost effective
- Robust against nonlinearities

… but it does not scale to high data rates!

Spectral efficiency (SE)

SE is limited to ~0.4b/s/Hz (0.8 b/s/Hz with Duobinary)

Chromatic dispersion (CD)

CD tolerance reduces with square of the symbol rate

Pol-mode disp. (PMD)

PMD tolerance reduces linearly with the symbol rate

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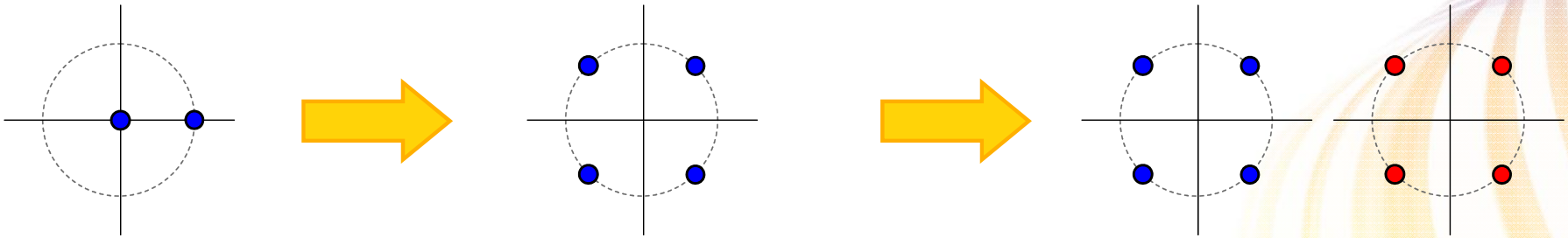
Solution for 40Gb/s and higher…

Spectral efficiency (SE)

Scale to higher signal constellation sizes



On-Off Keying (OOK)
1 bit/symbol

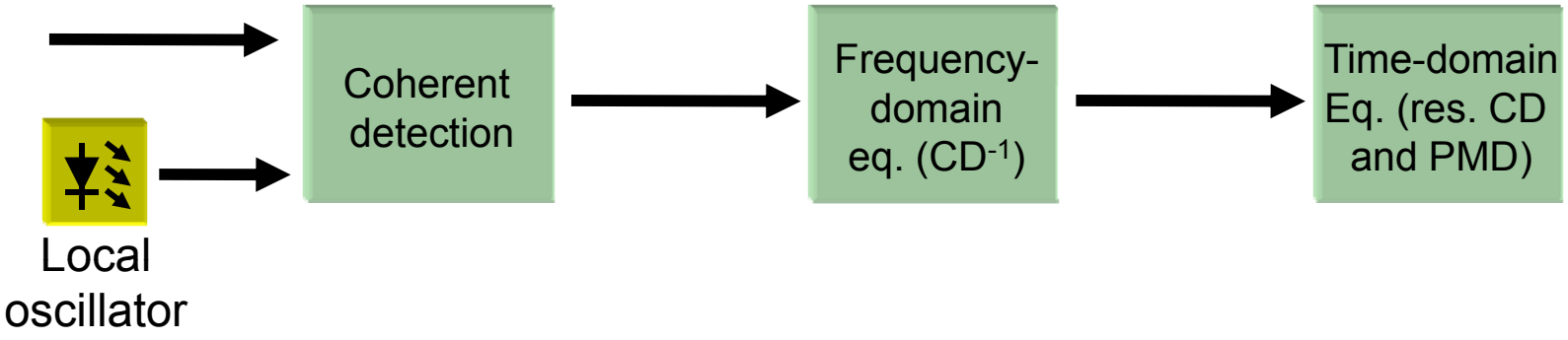
Quadrature phase shift Keying (QPSK) - *2 bit/symbol*

Polarization-multiplexed QPSK - *4 bit/symbol*

Chromatic dispersion (CD)

Pol-mode disp. (PMD)

Apply coherent detection and digital signal processing at the receiver.

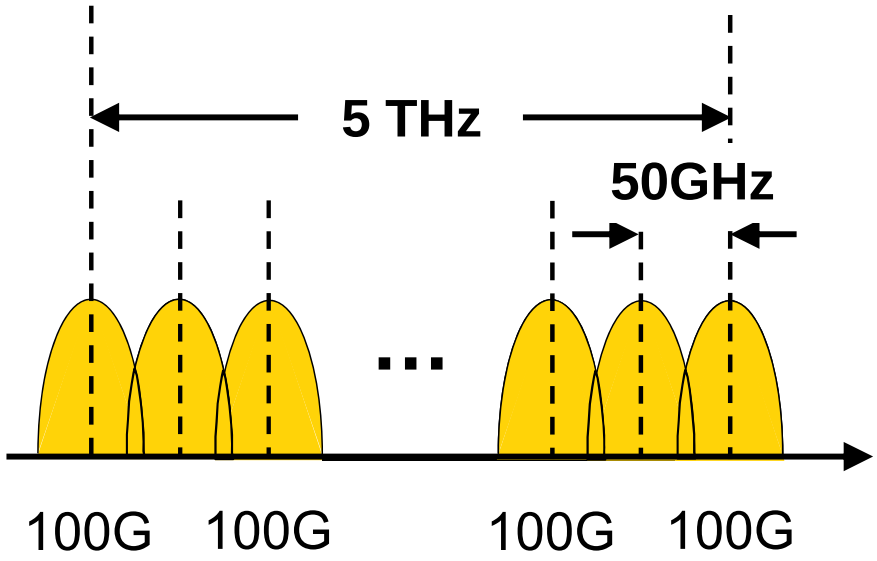


Status Quo 100G

To 400G… and beyond

High Capacity Optical Transmission
Beyond 10Tb/s Capacity

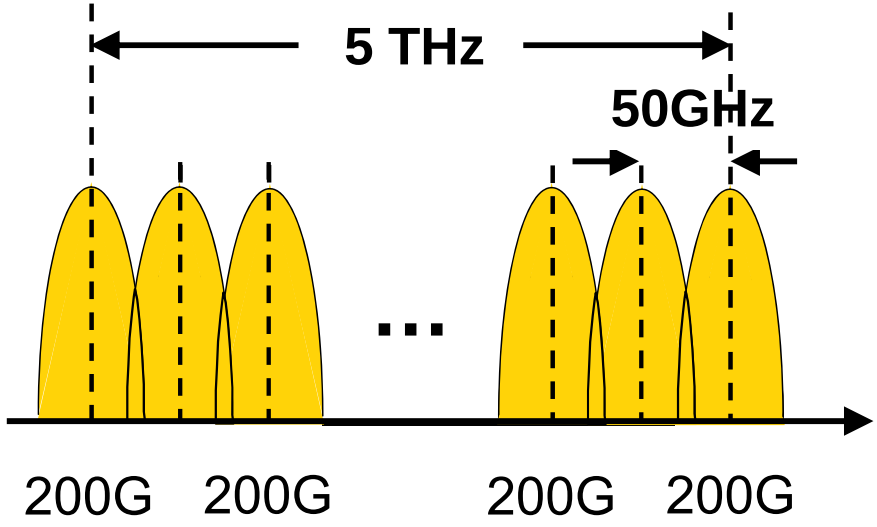
“Physical” measures:



High Capacity Optical Transmission
Beyond 10Tb/s Capacity

“Physical” measures:

- **Option 1: Increased channel data rate – 100Gb/s, 200Gb/s, … , 1Tb/s**



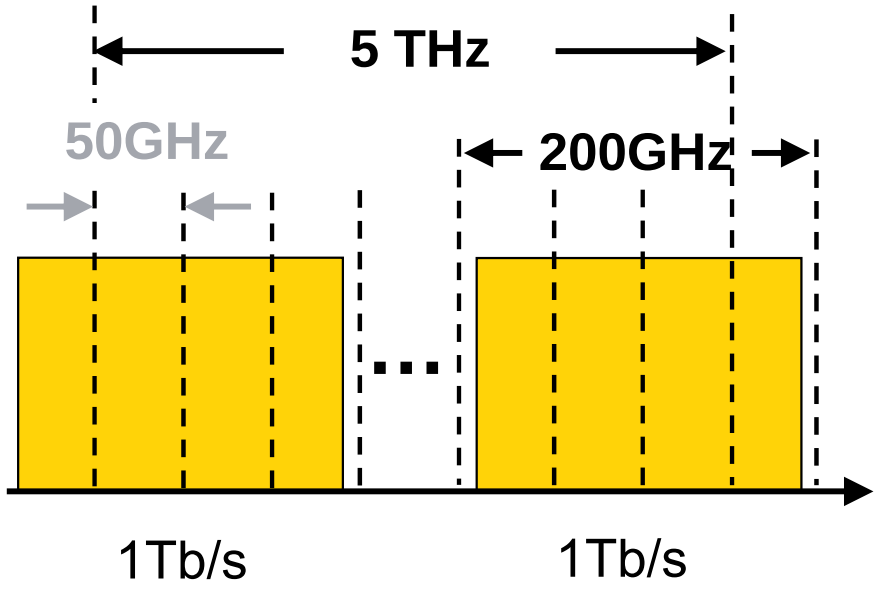
Example: 200Gb/s per channel

Total capacity: ~ 20 Tb/s

High Capacity Optical Transmission
Beyond 10Tb/s Capacity

“Physical” measures:

- **Option 1: Increased channel data rate – 100Gb/s, 200Gb/s, … , 1Tb/s**
- **Option 2: Enhanced spectral occupancy – Optimize grid: 50GHz,…, 250GHz**

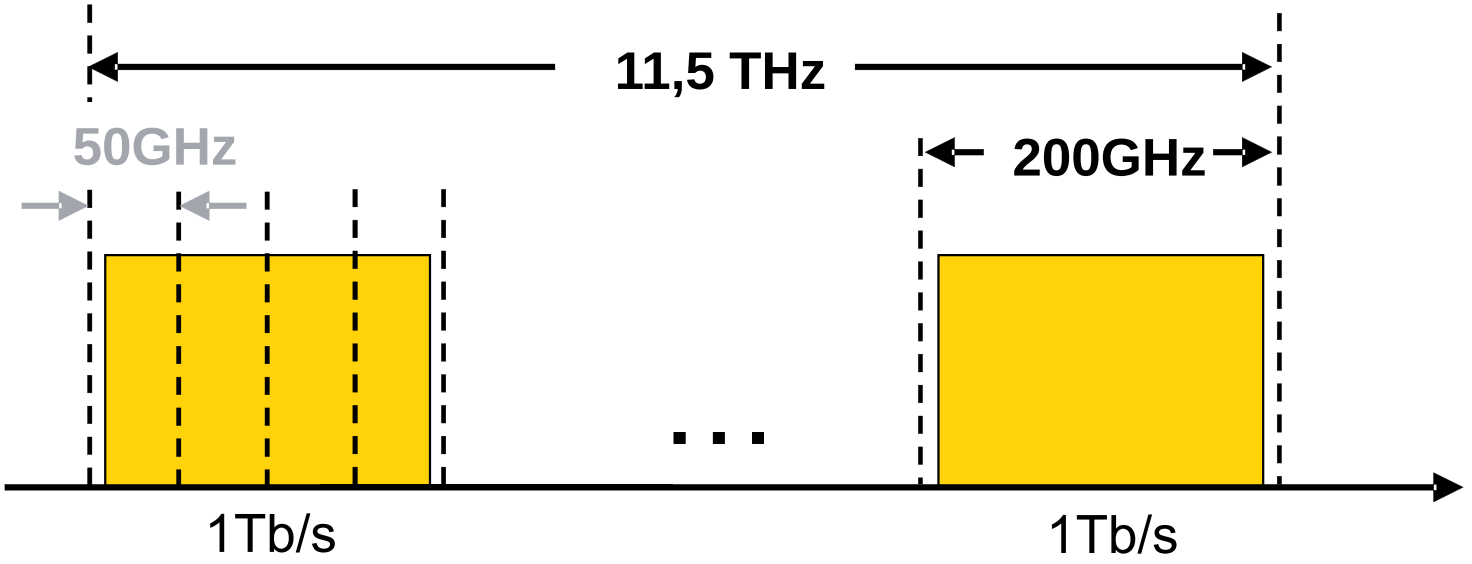


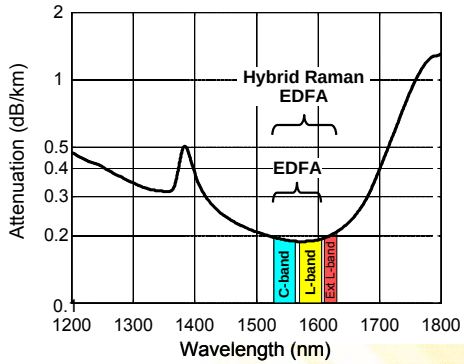
Total capacity: ~ 26 Tb/s

High Capacity Optical Transmission
Beyond 10Tb/s Capacity

“Physical” measures:

- **Option 1: Increased channel data rate – 100Gb/s, 200Gb/s, … , 1Tb/s**
- **Option 2: Enhanced spectral occupancy – Optimize grid: 50GHz,…, 250GHz**
- **Option 3: Bandwidth boost – Extend utilized fiber bandwidth**





Total capacity: 60 Tb/s

NSN is working on all 3 options

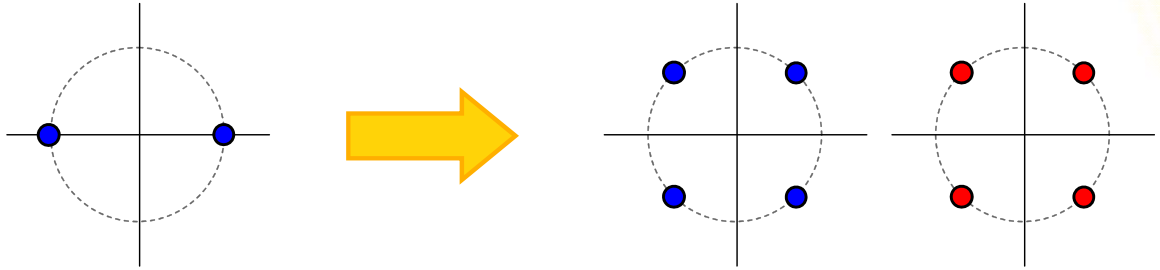
Option 1: Increased per-channel data rate
To infinity … and beyond?

Progress in optical transmission technologies has enabled us to scale DWDM systems efficiently to higher line rates

- Line rate, spectral efficiency and maximum feasible transmission distance have been increased at the same time.

Most recent example: 100G CP-QPSK compared to 40G DPSK.

- Both modulation formats have a close to identical OSNR requirement and high nonlinear tolerance (for 100G CP-QPSK over DCM-free transmission links).



43-Gb/s DPSK
Direct-detection, 7% FEC

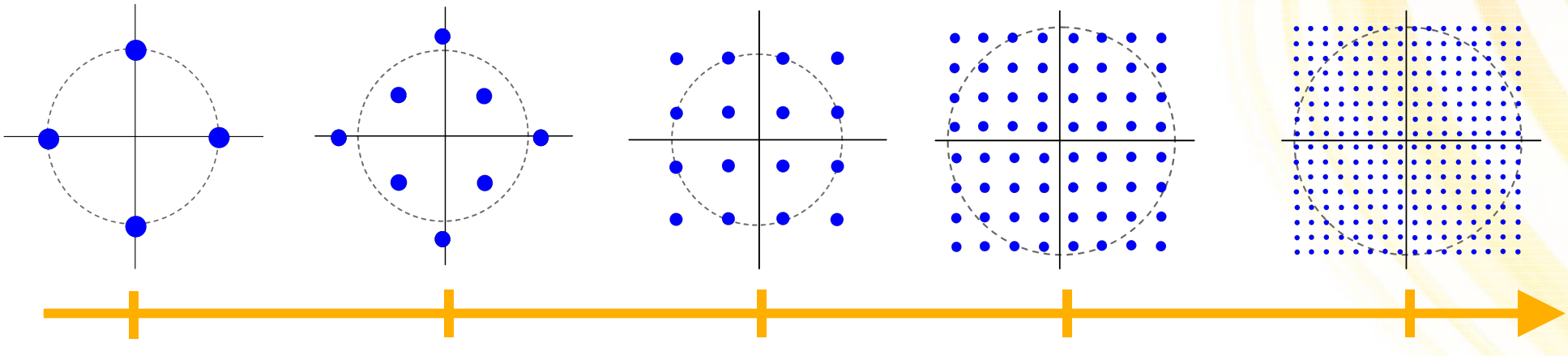
125-Gb/s CP-QPSK
Coherent-detection, 20% FEC

Can we extrapolate this trend to even higher line rates?

What is the reach at 400G or even 1T line rates?

Option 1: Increased per-channel data rate
Scaling constellation size

Higher data rate and increased spectral efficiency can be realized by scaling the constellation size

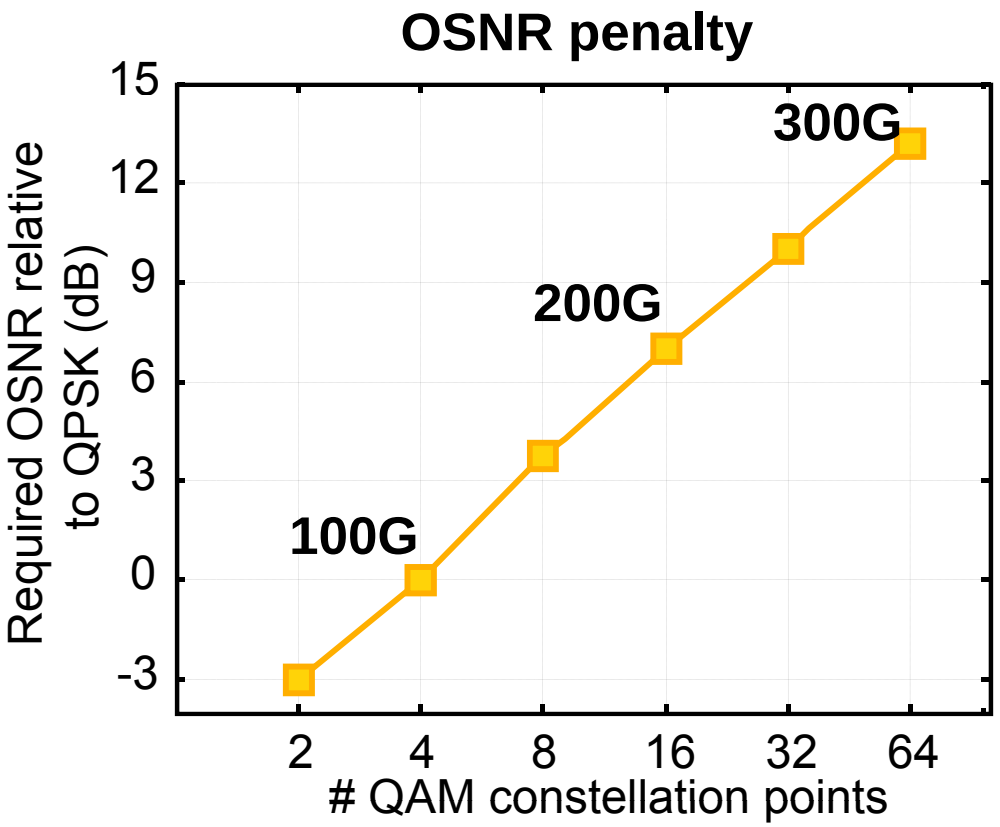


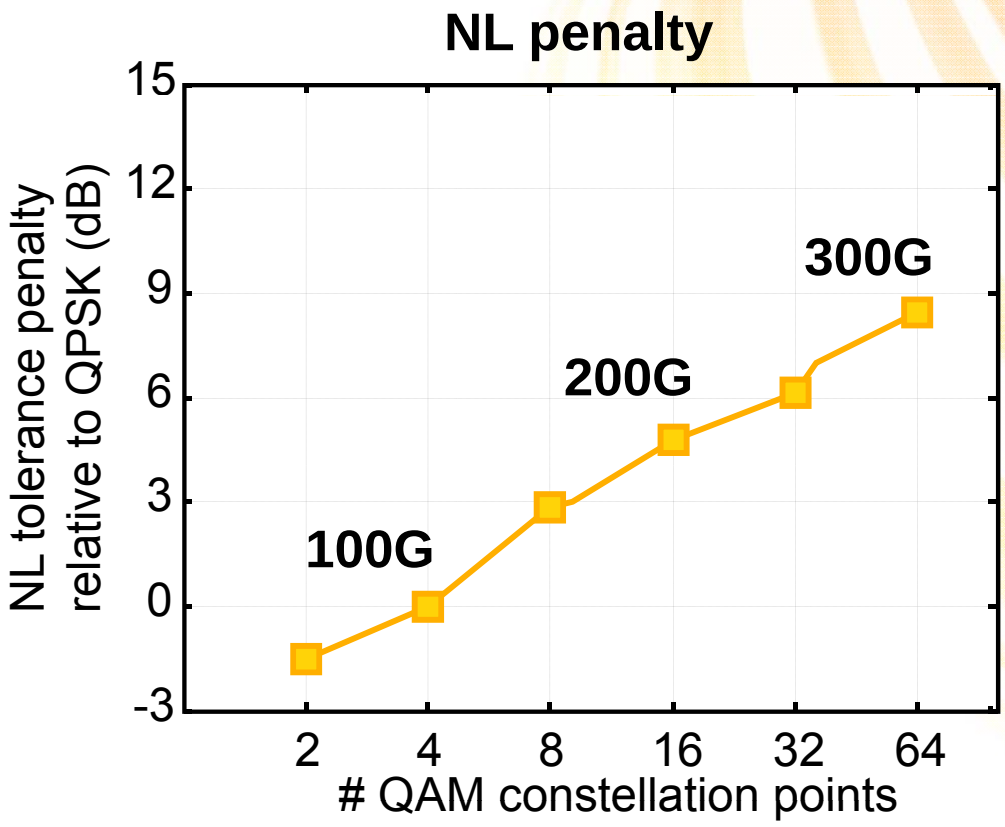
Bits per symbol (Constellation size)

Option 1: Increased per-channel data rate
Optical performance

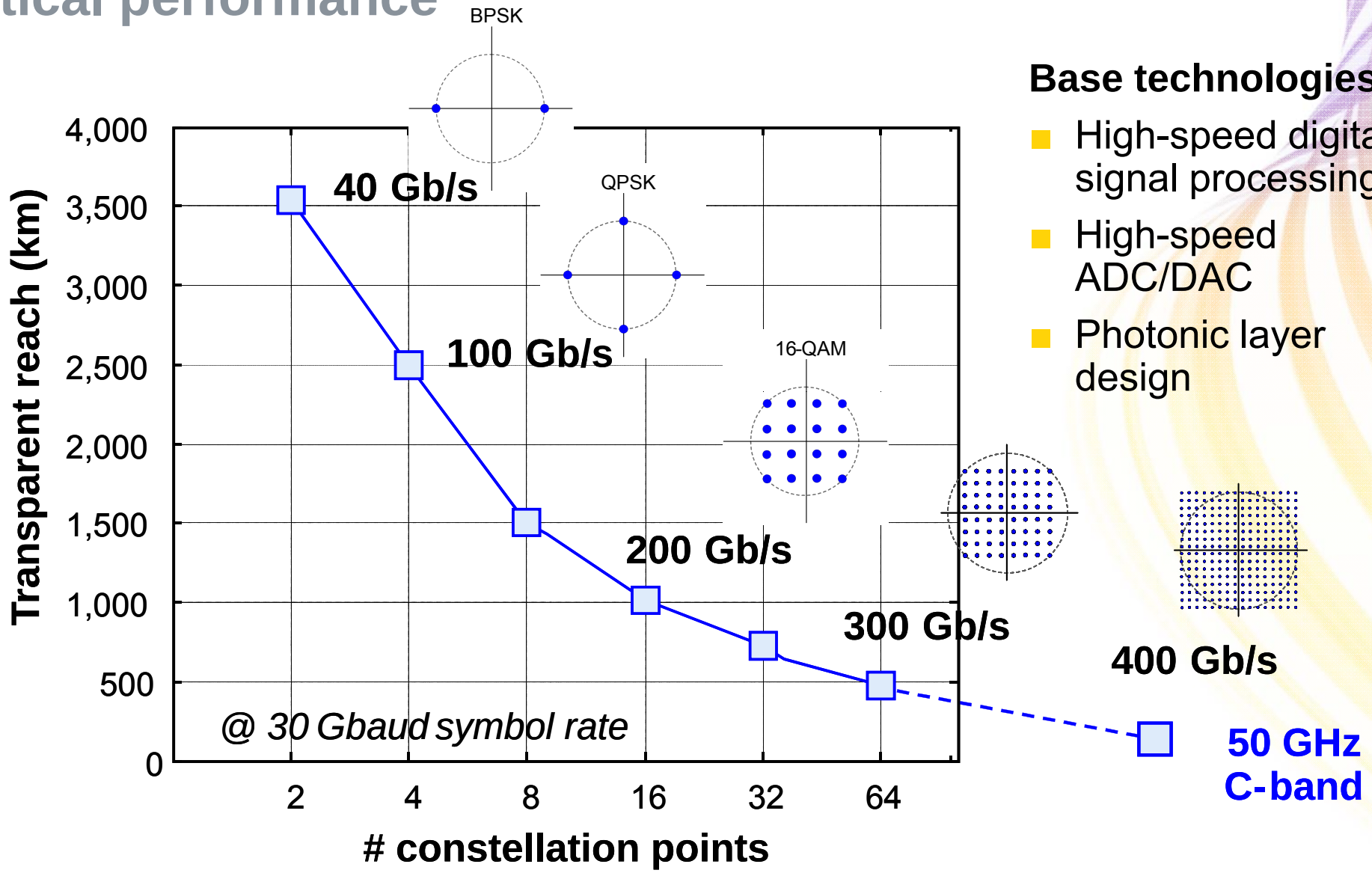
Scaling beyond CP-QPSK modulation to more dense formats will require a significantly higher margin:

- Requires a higher received OSNR at the end of the link.
- Results in a reduction of the nonlinear tolerance.





Option 1: Increased per-channel data rate
Optical performance



Base technologies:

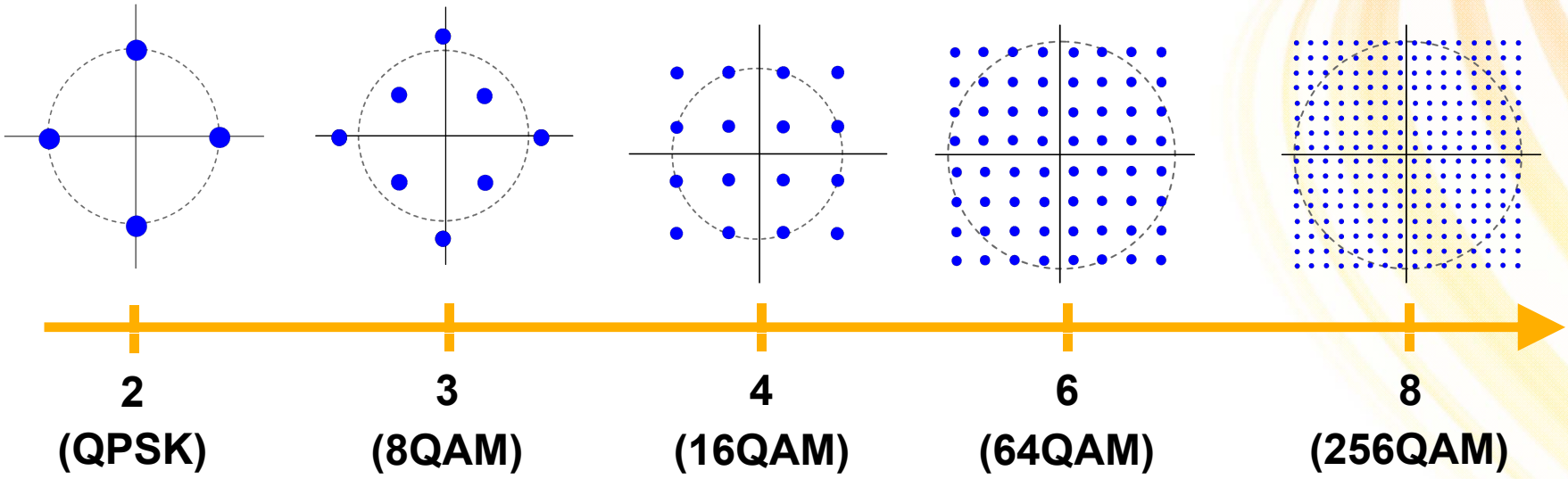
- High-speed digital signal processing
- High-speed ADC/DAC
- Photonic layer design

400G CP-256QAM is suitable for transmission distances up ~100km!

Option 1: Increased per-channel data rate
Flexi-rate optical transponders

Spectral efficiency (b/s/Hz)

Reach

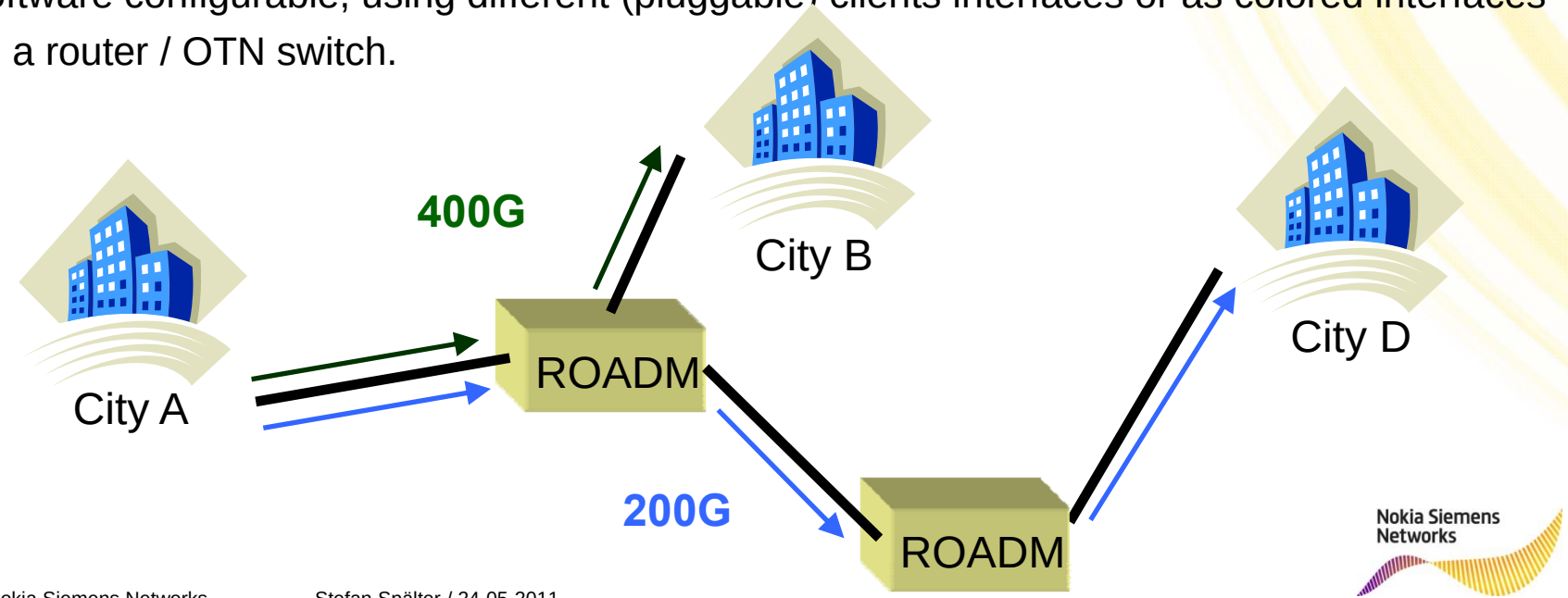


Network optimization using dynamic capacity allocation can significantly extend total network throughput!

Option 1: Increased per-channel data rate
Flexi-rate optical transponders

Flexi-rate transponders will likely use dynamic capacity allocation to address different transmission scenarios.

- 40G for ultra-long-haul transmission distances and submarine (>2500 km)
- 100G for long haul transmission distances (up to 2500 km)
- 200G for medium-haul transmission distances (up to 1000 km)
- 300G or 400G for intra-office and metro-core applications (up to 400 km)
- Software configurable, using different (pluggable) clients interfaces or as colored interfaces on a router / OTN switch.

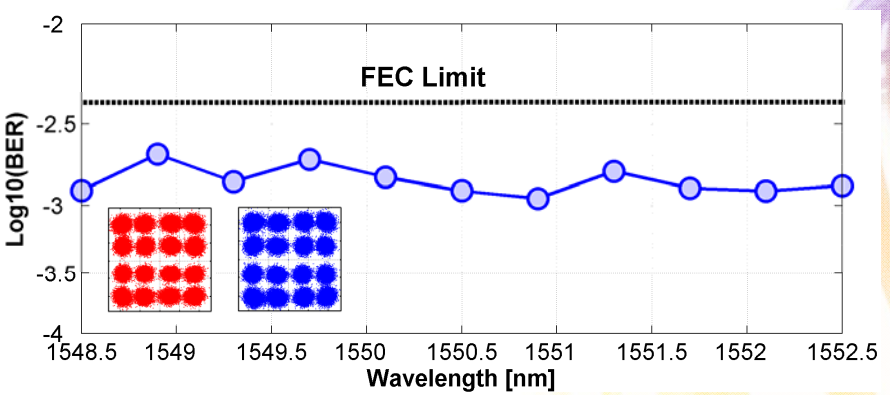


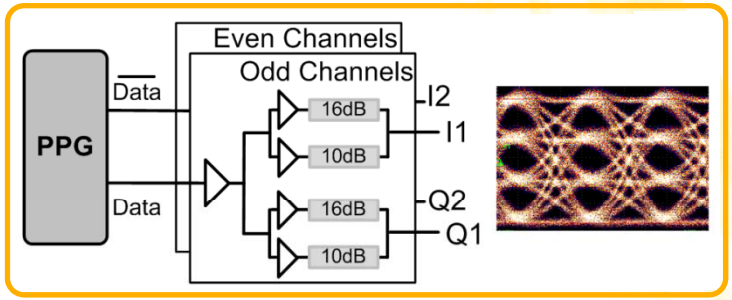
Transmission research beyond 100G (2010)

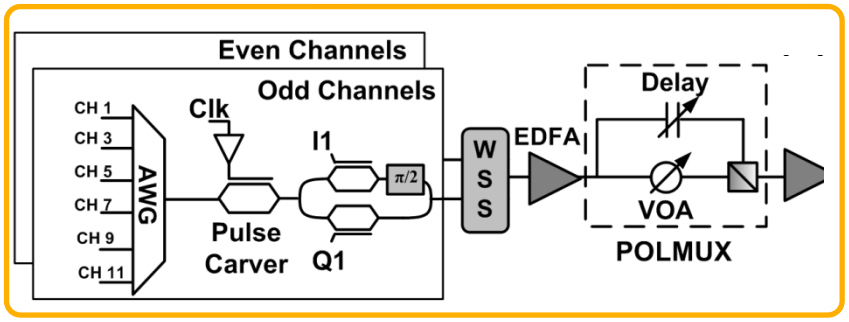
224-Gb/s CP-16QAM transmission over 650 km of SSMF

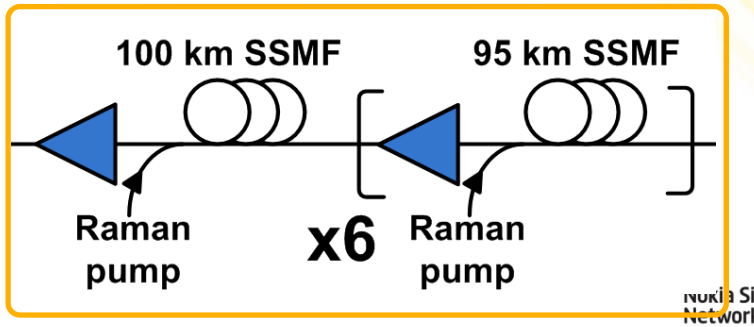
Experimental setup:

- 11 channels with 224-Gb/s CP-16QAM modulation (2 x 100GbE + EFEC)
- Standard 50GHz ITU grid with inline add/drop nodes
- 4 bits/s/Hz spectral efficiency
- Hybrid EDFA/Raman amplification
- 650km of standard single mode fiber (SSMF).







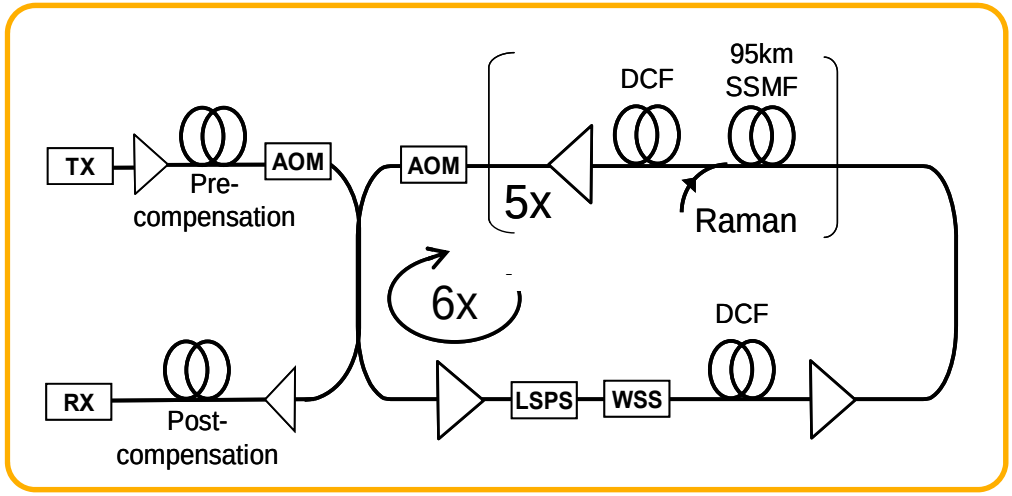


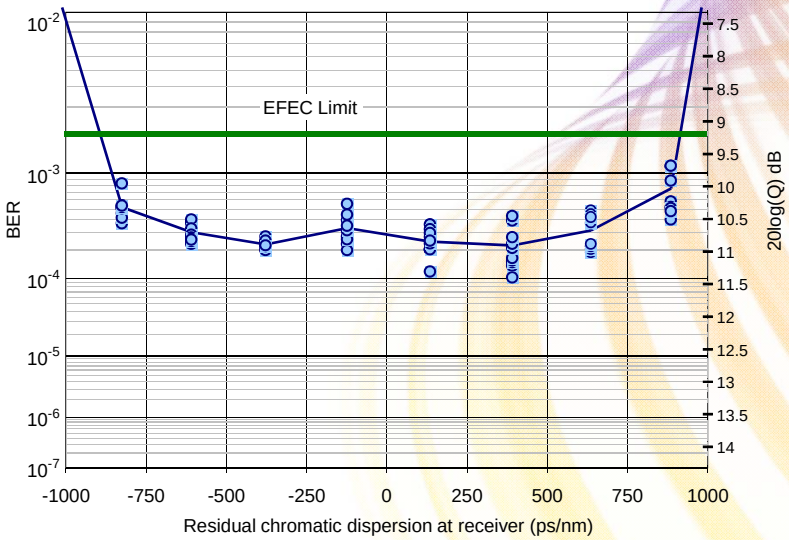
Transmission research @ 100G (2007)

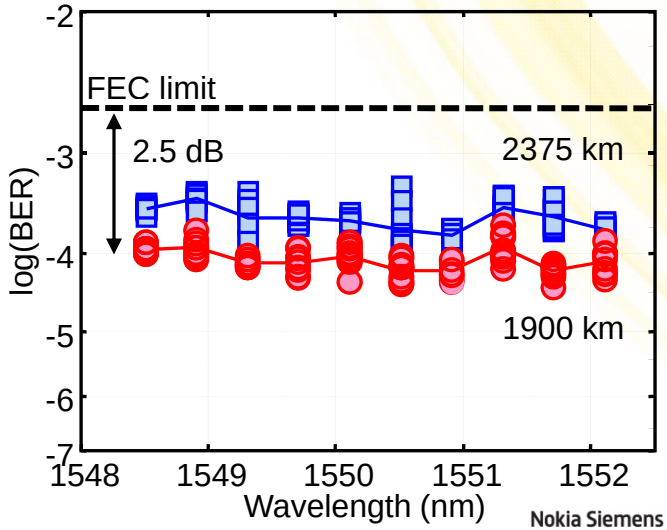
111-Gb/s CP-QPSK transmission over 2375 km of SSMF

Experimental setup:

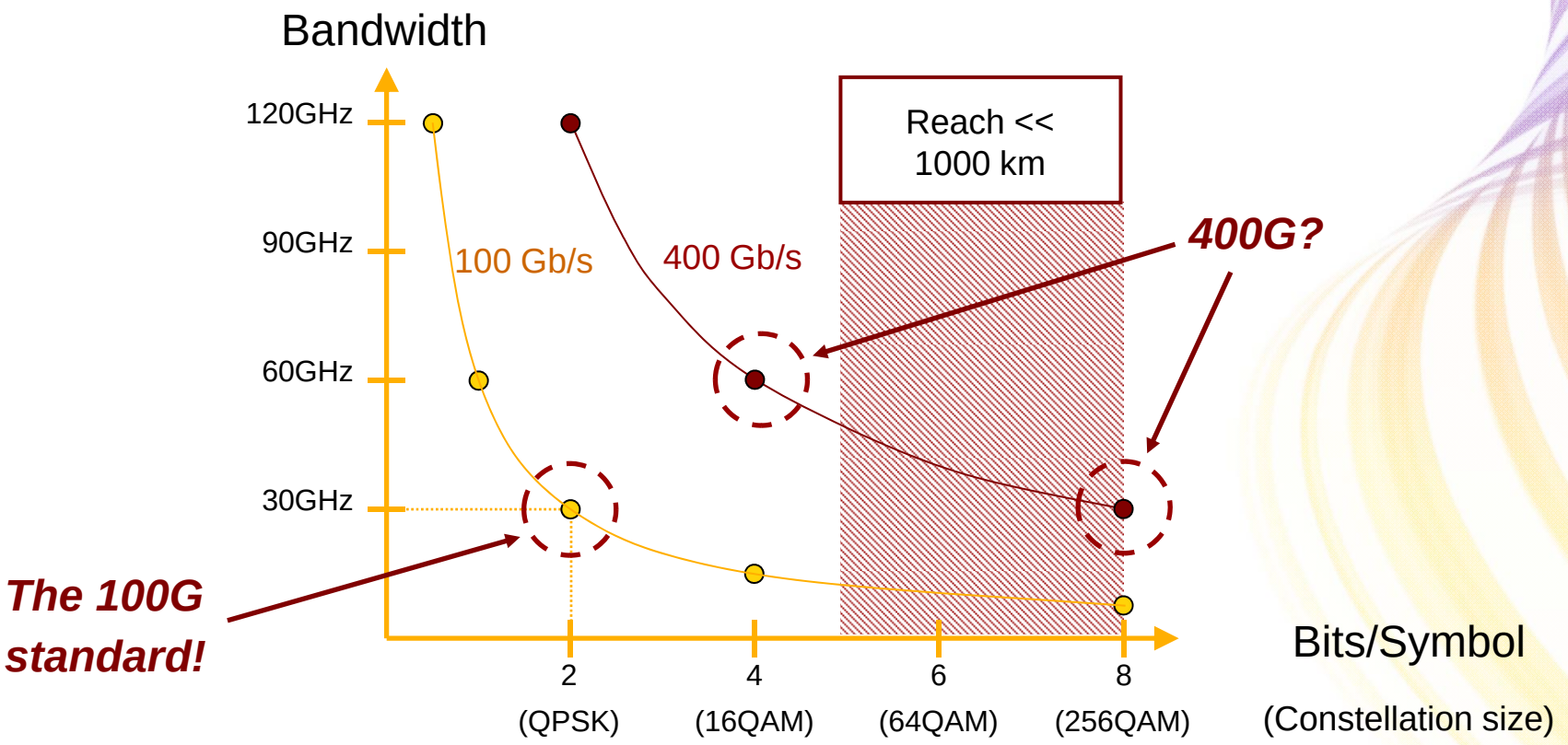
- 10 channels with 111Gb/s each on a 50GHz grid.
- CP-RZ-DQPSK modulation (100GbE + EFEC).
- 2 bits/s/Hz spectral efficiency.
- Hybrid EDFA/Raman amplification.
- 2375 km of standard single mode fiber (SSMF).







The trade-off between reach and spectral efficiency



For 100G the sweet-spot is a 30-GHz optical bandwidth and (POLMUX) QPSK signal constellation.

… but how will 400G look like?

** All formats assume polarization-multiplexing and 20% FEC overhead*

Are higher symbol rates the solution?

≤ 40Gbaud

Electrical bandwidths ≤ 30 GHz

Surface-mount soldering

Re-use of 40G/100G technology

≥ 40Gbaud

Electrical bandwidths ≥ 30 GHz

High speed GPPO connectors

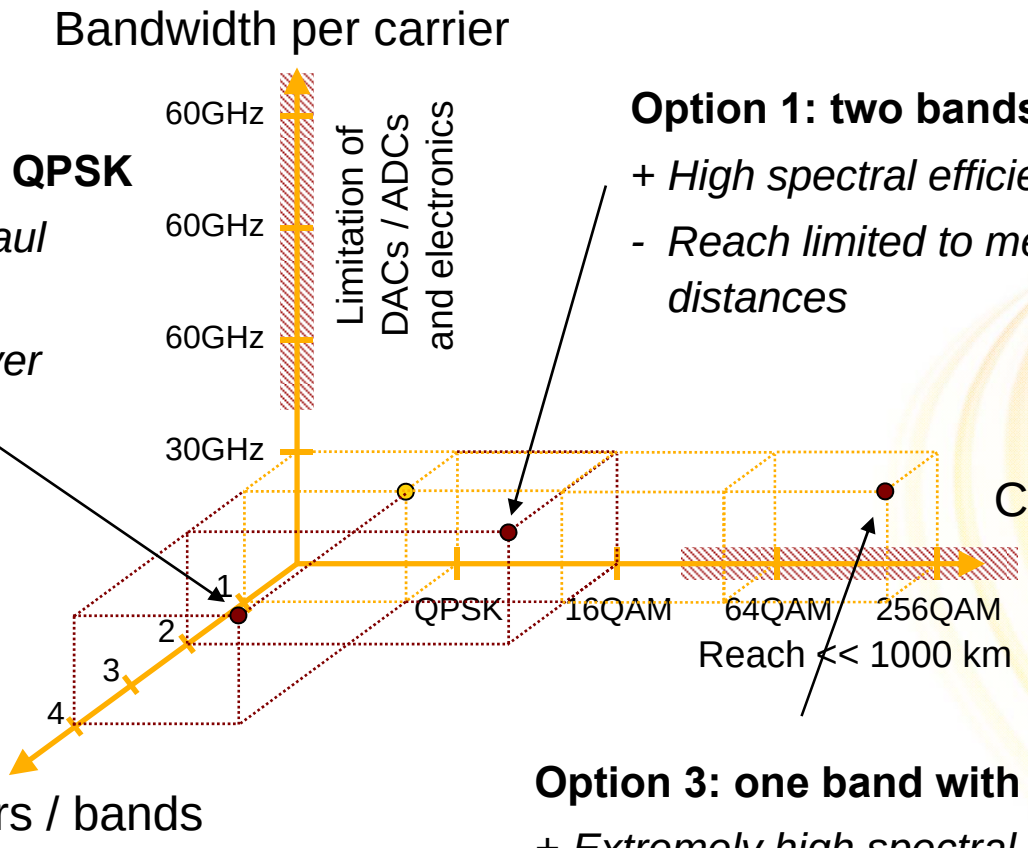
New high speed technology

And most importantly… a higher symbol rate does not improve the optical performance or maximum feasible spectral efficiency.

- The OSNR requirement increases linearly with symbol rate.
- On a DCM-free transmission link the nonlinear tolerance increases as well more or less linearly with the symbol rate.

Next-generation optical interfaces will have symbol rates comparable to 100G today

Towards 400-Gb/s



Option 2: four bands with QPSK

+ *Suitable for (ultra) long-haul networks*
- *No improvement in SE over 100G*

Option 1: two bands with 16-QAM

+ *High spectral efficiency (SE)*
- *Reach limited to metro / regional distances*

Option 3: one band with 256-QAM

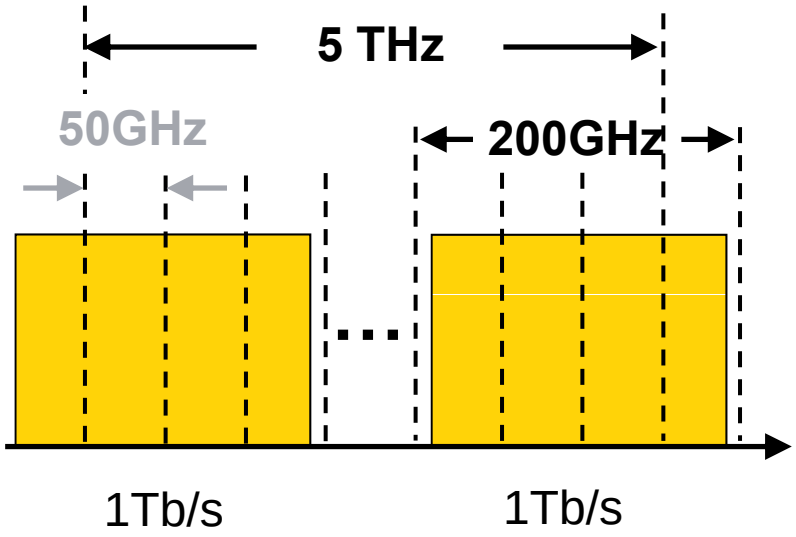
+ *Extremely high spectral efficiency (SE)*
- *Reach limited to ~100 km*
- *Optical components for 256-QAM are challenging to make*

A flexible photonic layer is the key technology to ensure compatibility with upcoming data rates.

High Capacity Optical Transmission
Beyond 10Tb/s Capacity

“Physical” measures:

- Option 1: Increased channel data rate – 100Gb/s, 200Gb/s, … , 1Tb/s
- **Option 2: Enhanced spectral occupancy – Optimize grid: 50GHz,…, 250GHz**

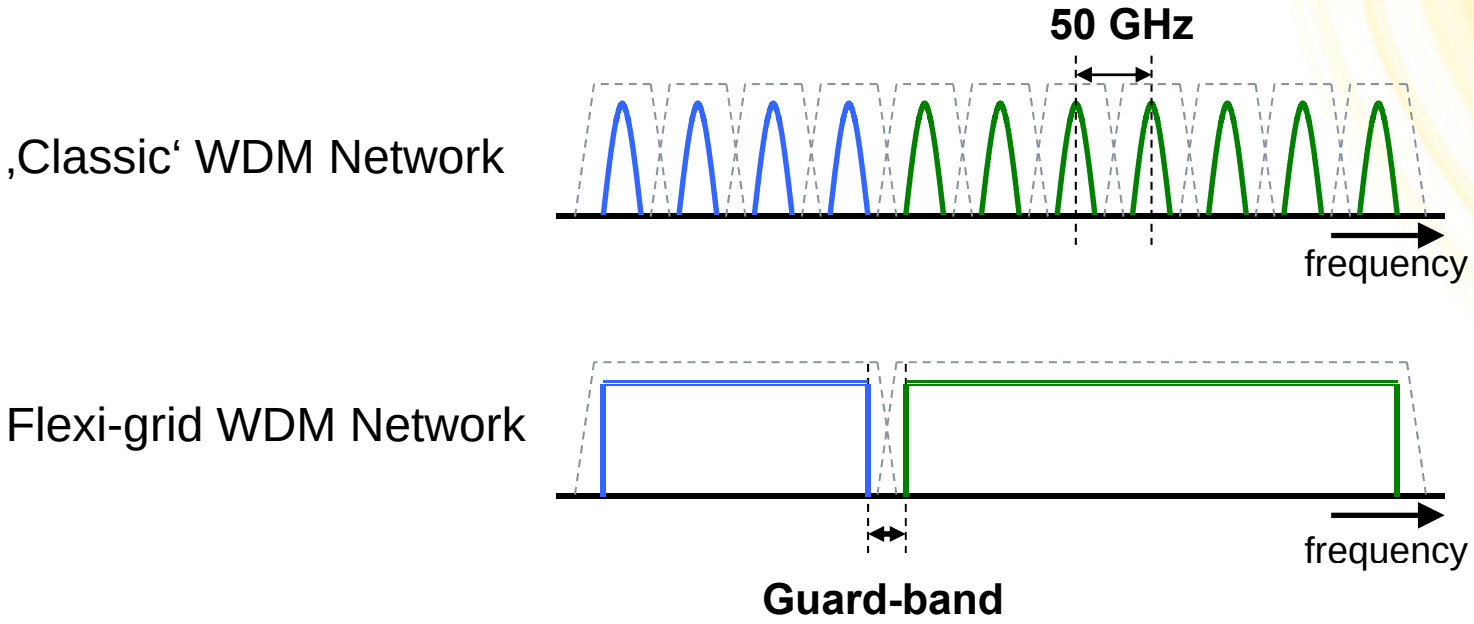


How to enhance spectral occupancy?

Option 2: Enhanced spectral occupancy
Flexi-grid optical networks (1/4)

How do we realize the next generation of 400G or 1T transmission systems with long-haul transmission reach?

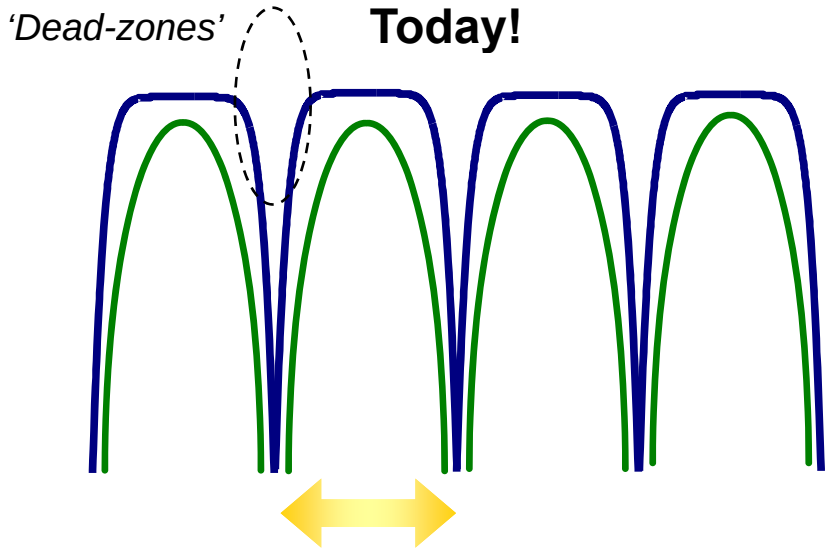
- Group individual WDM channels into ‘super-WDM’ channels.
- Together with grid-less WSS technology this enables agile switching that can be scaled to the actual traffic demand.

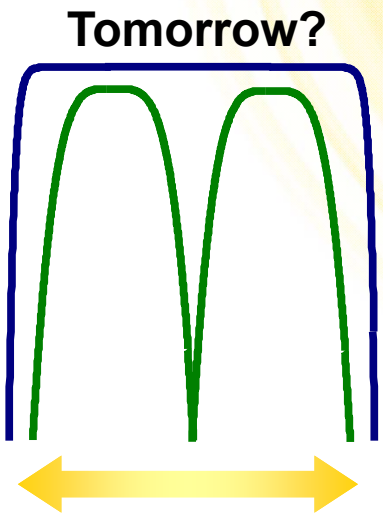


Option 2: Enhanced spectral occupancy
Flexi-grid optical networks (2/4)

Flexi-grid capacity allocation enables 400G or 1T over long-haul distances.

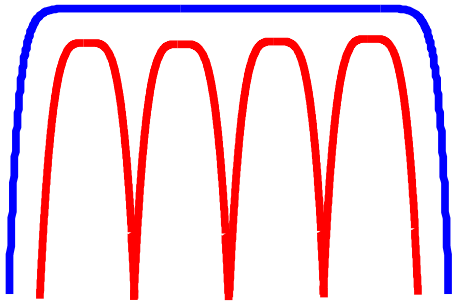
- Future high bit rate LH interfaces will no longer fit into a 50GHz WDM grid.
- WDM evolves from fix-grid to flexi-grid, and the channel spacing will become a dynamically (software-defined) configurable attribute of transport systems.
- This still requires significant progress in optical components (optical integration!).





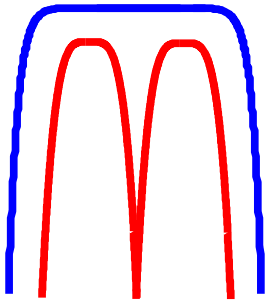
Option 2: Enhanced spectral occupancy
Flexi-grid optical networks (3/4)

Ultra long-haul (>2500 km on SSMF)



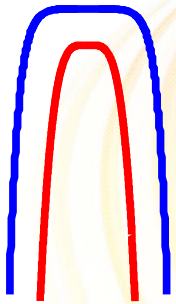
4 x CP-QPSK
150 GHz grid
(2.67 b/s/Hz)

Medium-haul (500 km on SSMF)



2 x CP-16QAM
75 GHz grid
(5.33 b/s/Hz)

Short-haul (100 km on SSMF)



1 x CP-256QAM
50 GHz grid
(8 b/s/Hz)

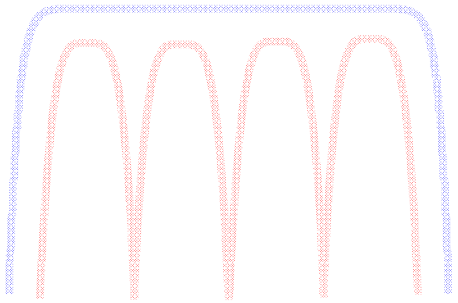
Spectral efficiency

Reach

Nokia Siemens Networks

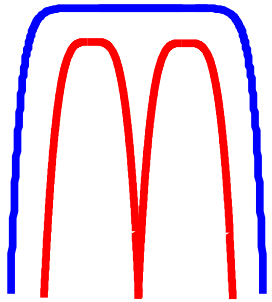
Option 2: Enhanced spectral occupancy
Flexi-grid optical networks (3/4)

Ultra long-haul
(>2500 km on SSMF)



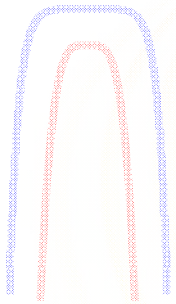
4 x CP-QPSK
150 GHz grid
(2.67 b/s/Hz)

Medium-haul
(500 km on SSMF)



2 x CP-16QAM
75 GHz grid
(5.33 b/s/Hz)

Short-haul
(< 200 km on SSMF)



1 x CP-256QAM
50 GHz grid
(8 b/s/Hz)

Spectral efficiency

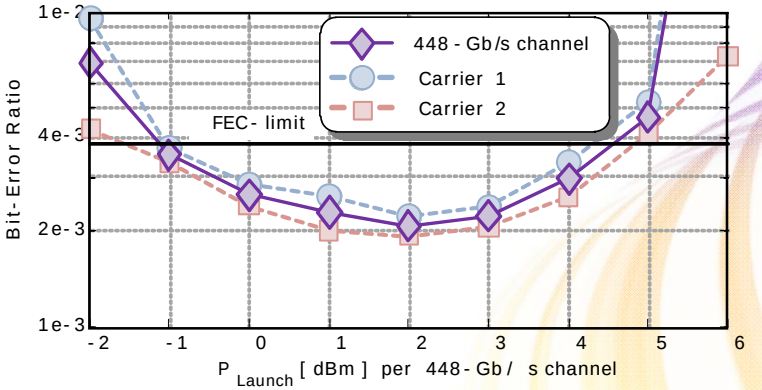
Reach

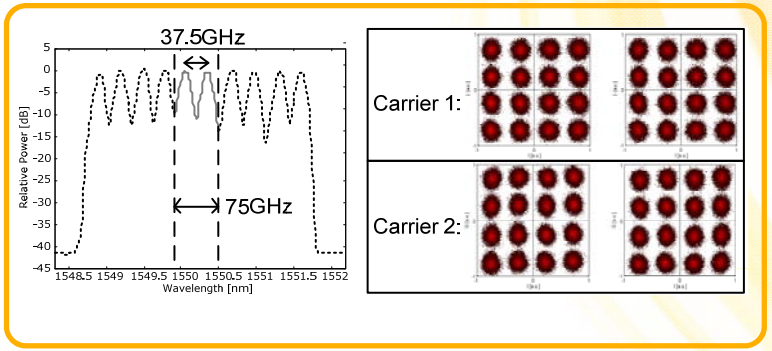
Transmission research @ 400G

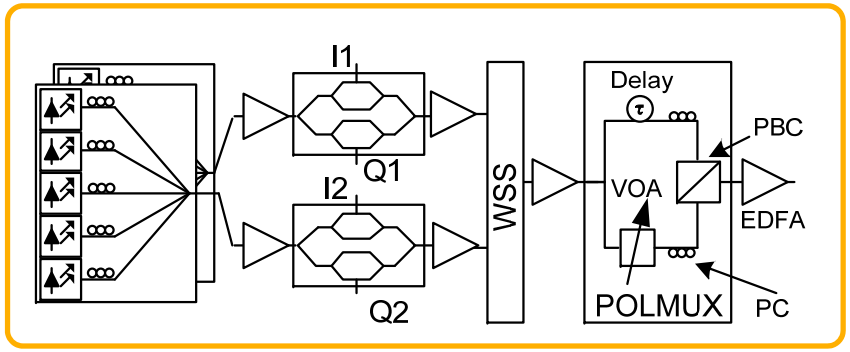
448-Gb/s dual-carrier CP-16QAM transmission over 656 km

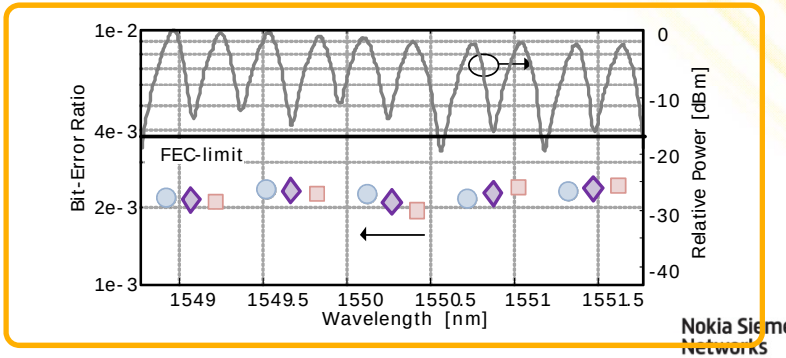
Experimental setup:

- 5 channels with 448-Gb/s dual-carrier CP-16QAM modulation
- 75-GHz grid based on flex-grid technology
- 5.33-bits/s/Hz spectral efficiency
- Hybrid EDFA/Raman amplification
- 656-km of large-core pure-silica fiber.

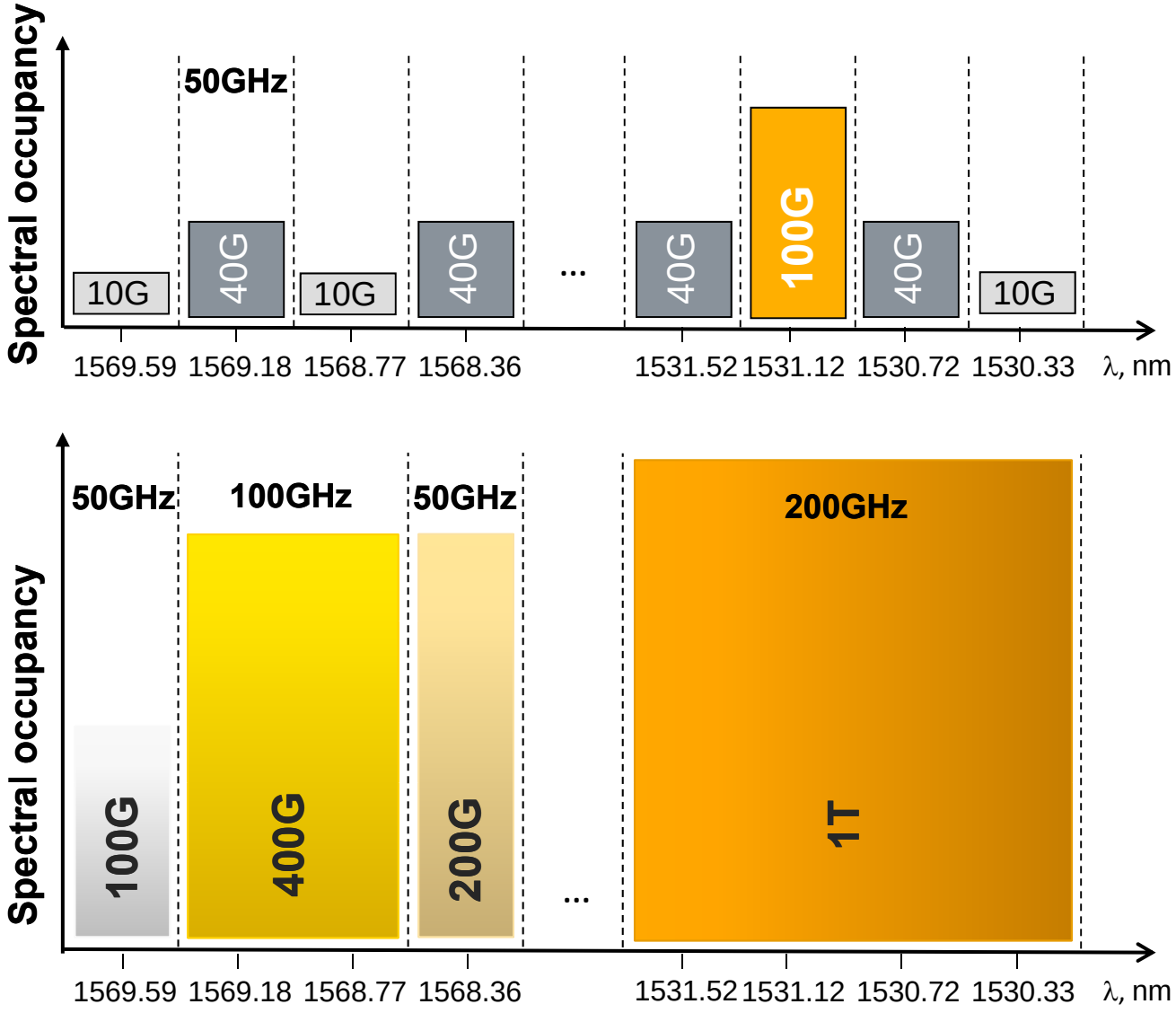








Option 2: Enhanced spectral occupancy
Flexi-grid optical networks (4/4)



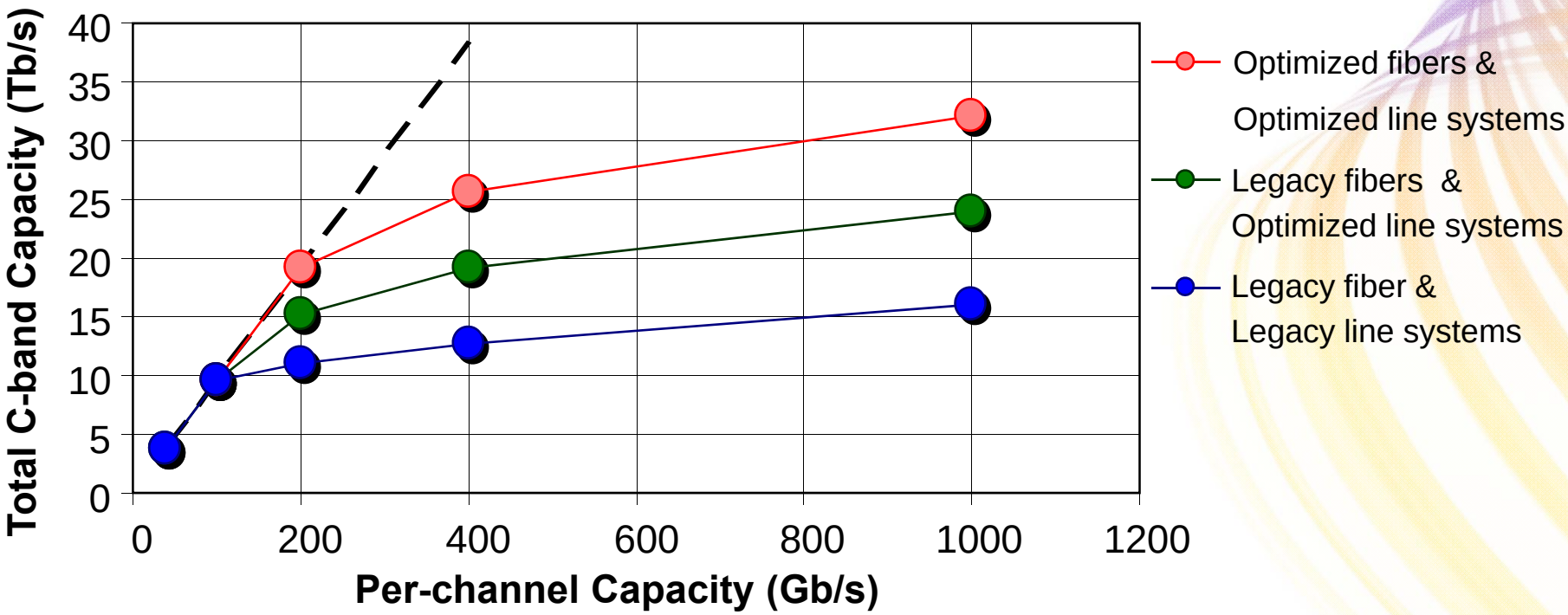
Legacy networks as deployed today:

50 GHz, fixed grid

Future networks:

50-250 GHz, flexible grid

Capacity limits in optical transmission



The total C-band capacity will start to saturate at data rates beyond 100G

** Minimum reach of 1000 km on SSMF*

Conclusions

Scaling transmission system well beyond 10-Tb/s will require a mix of new transponder technologies,

- Enhanced signal processing algorithms and coding formats are key to achieve transmission distances at high spectral efficiency.
- Flexi-rate transponder and flexi-grid technology will in addition enhance the flexibility of highly meshed optical transport networks.

The fiber capacity will ultimately increase to between 20 Tb/s and 40 Tb/s per optical fiber (40 Tb/s to 80 Tb/s for C + L – band)

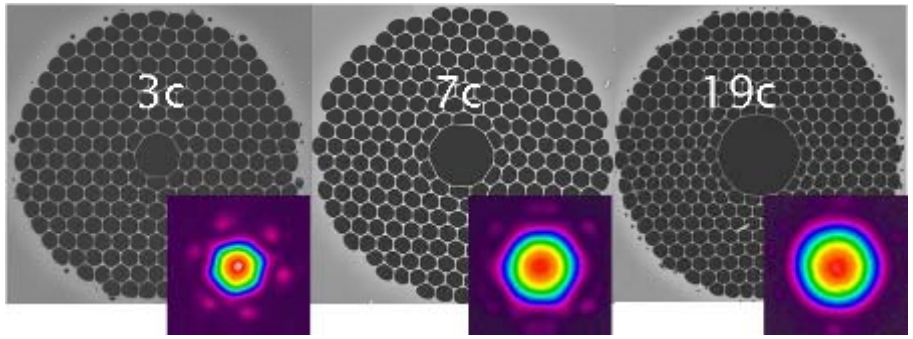
- Short-haul transmission (~100km) will support a spectral efficiency of up to 8 b/s/Hz and a total fiber capacity of up to 40 Tb/s.
- Long-haul transmission (up to 1200 km) will increase the spectral efficiency to 4-5 b/s/Hz and channel bonding of 100G to 250G sub-channels seems the most likely technology to realize 400G or 1T.
- In ultra-long haul transmission, the spectral efficiency will not increase much beyond 2-3 b/s/Hz, and only multi-band transmission can enable capacities of up to 20 Tb/s.

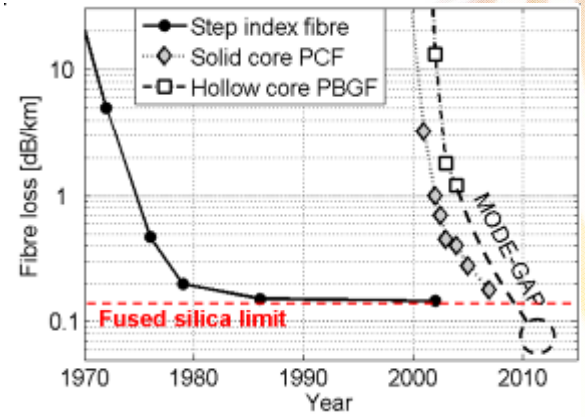
Nokia Siemens Networks

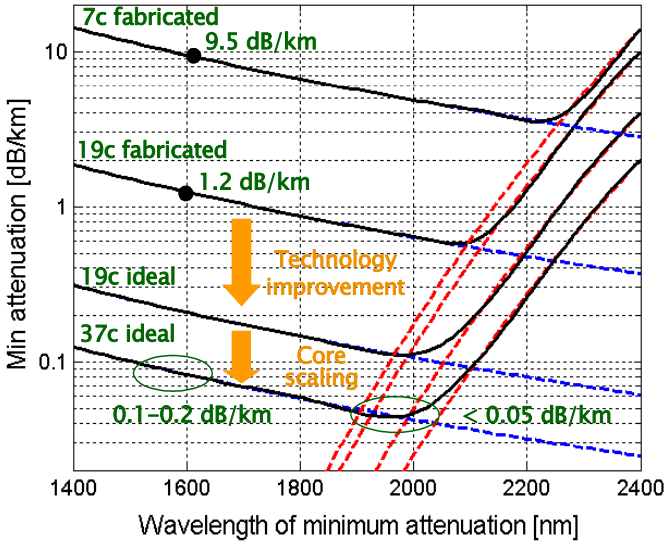
Or not

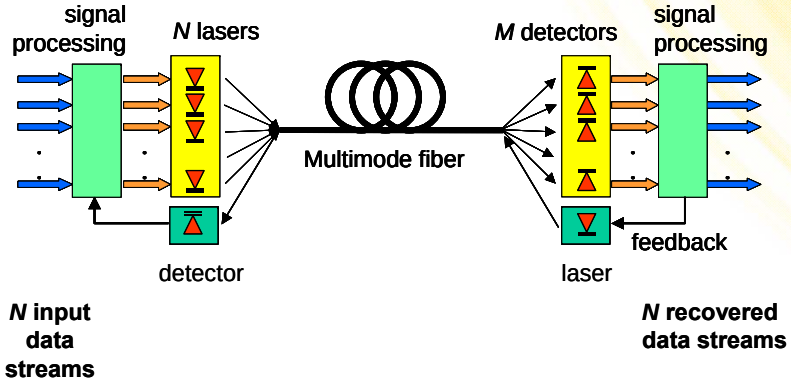
Beyond the capacity crunch

NSN is a partner in the EU-funded MODE-GAP project, which envisions to lay the groundwork for the next wave in telecommunications.









THANK YOU!