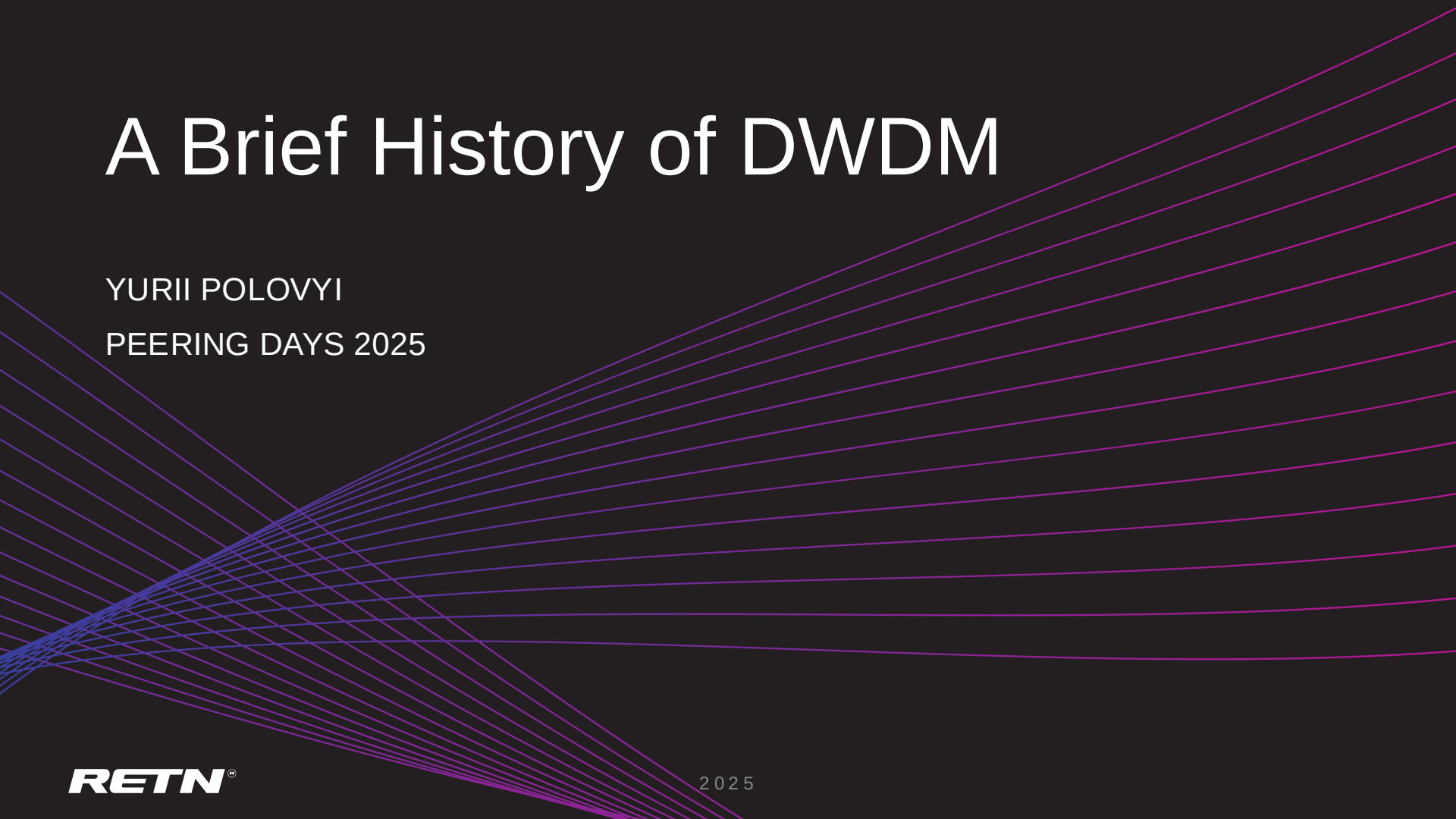
A Brief History of DWDM

YURII POLOVYI

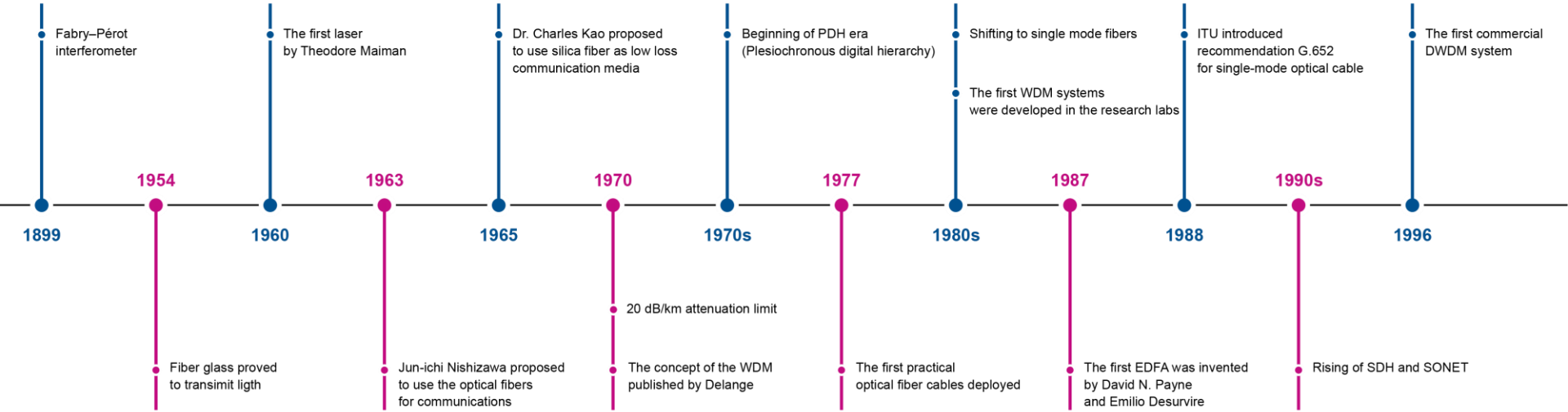
PEERING DAYS 2025



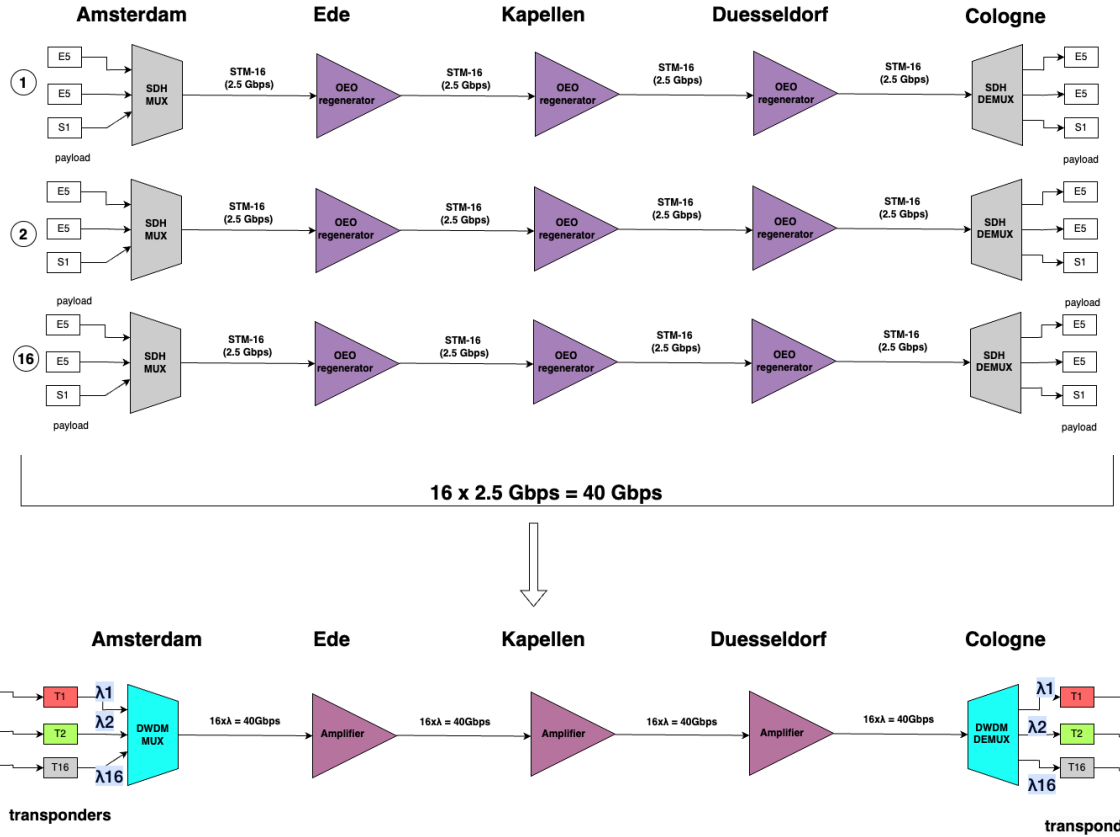
RETN®

2025

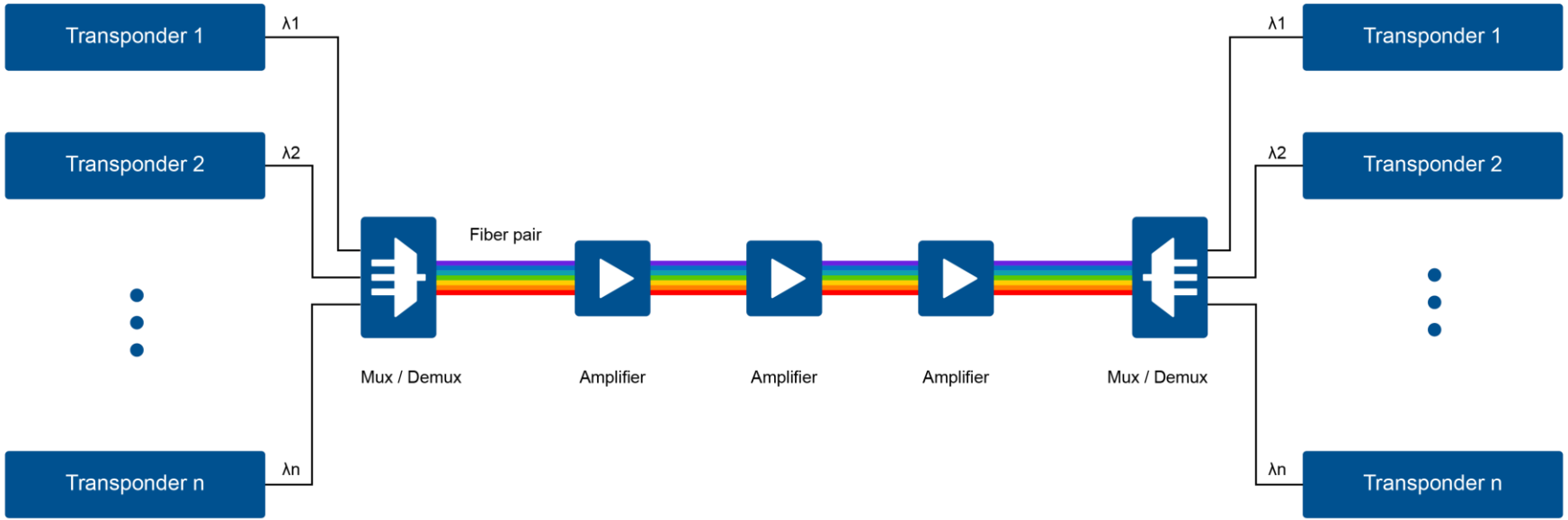
Early days of the fiber optic communication



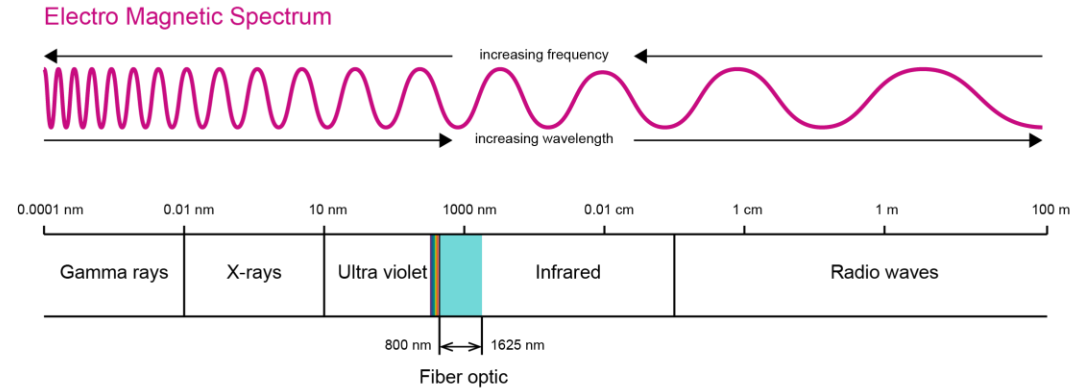
40G SDH vs DWDM (1996)

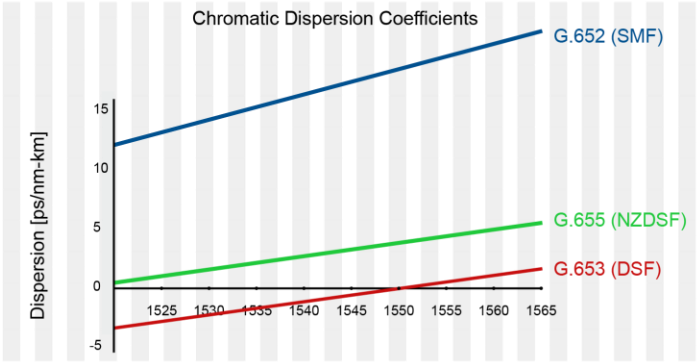


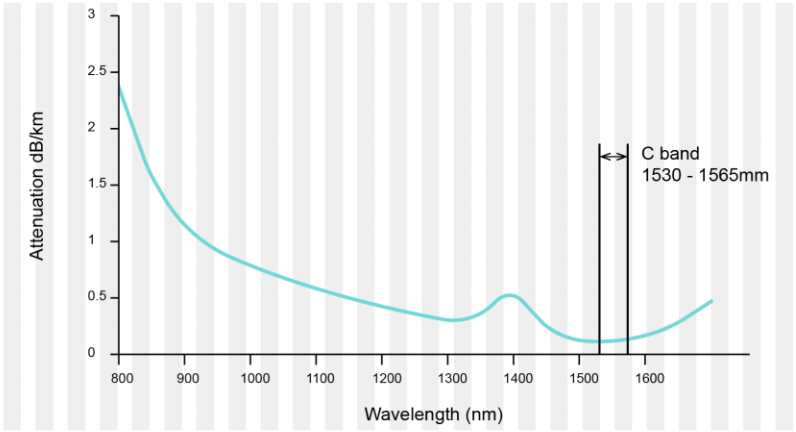
Key elements of a DWDM system

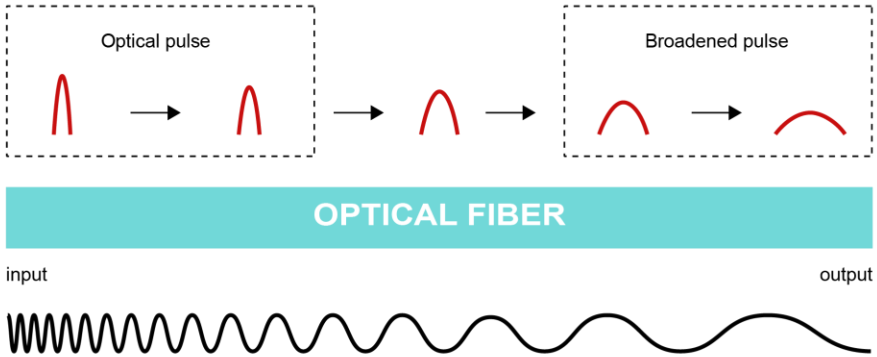


Media - a single mode fiber

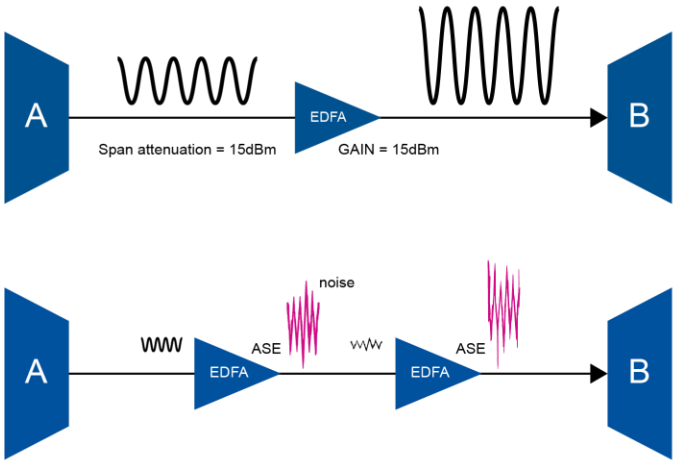






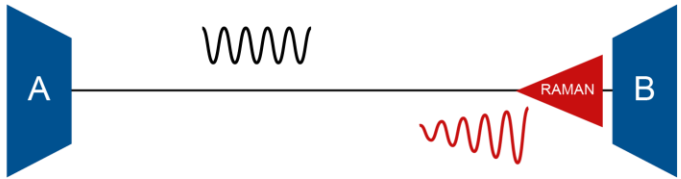


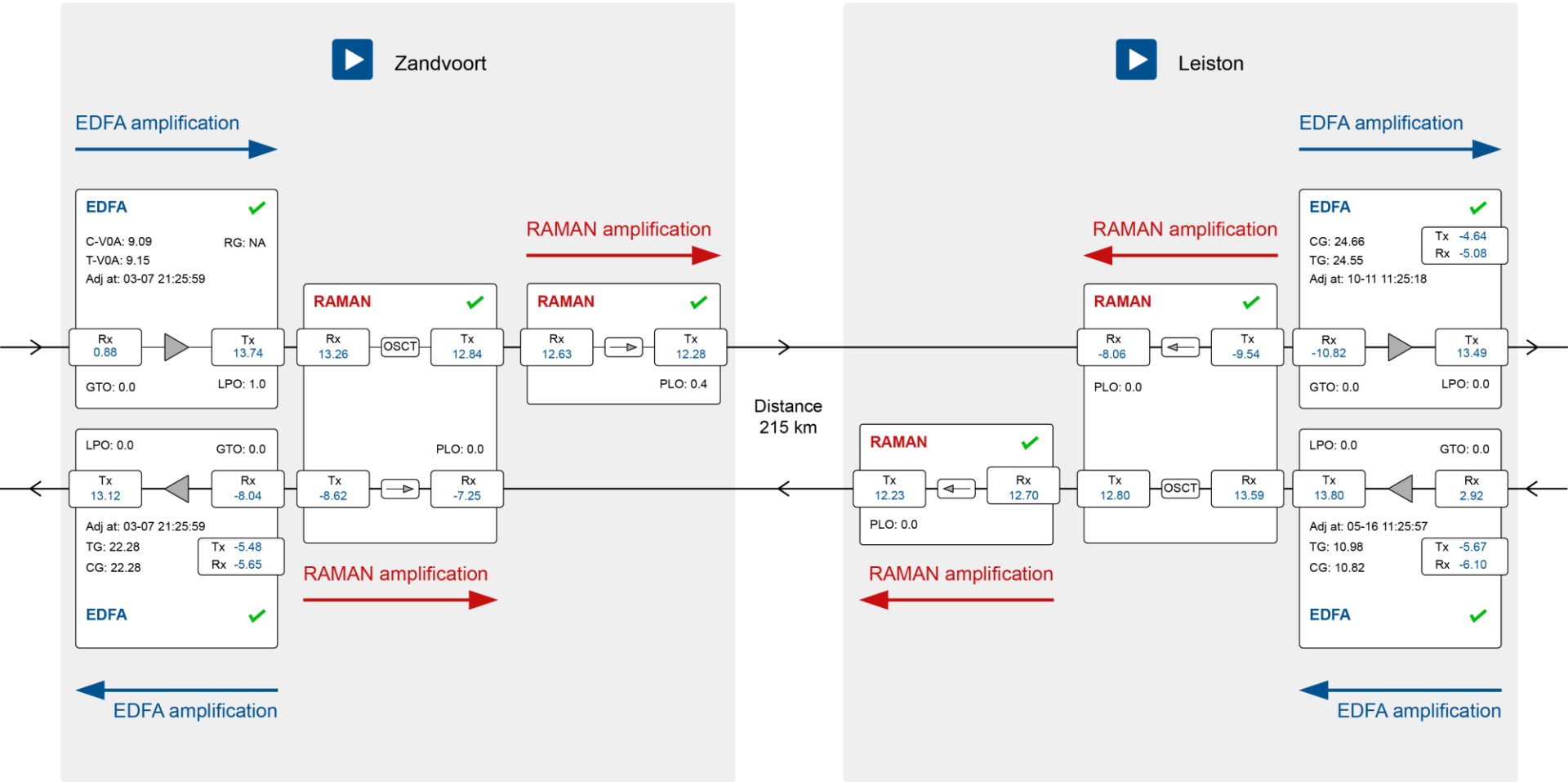
Erbium-doped fiber amplification (EDFA)



ASE - Amplified Spontaneous Emission

RAMAN amplification

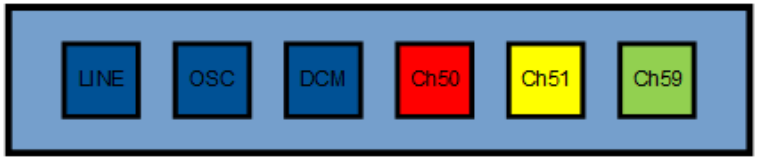



Zandvoort
Leiston
EDFA amplification
EDFA amplification
EDFA
C-V0A: 9.09
T-V0A: 9.15
Adj at: 03-07 21:25:59
RG: NA
Rx 0.88
Tx 13.74
GTO: 0.0
LPO: 1.0
RAMAN
Rx 13.26
OSCT
Tx 12.84
RAMAN
Rx 12.63
Tx 12.28
PLO: 0.4
RAMAN amplification
RAMAN amplification
RAMAN
Rx -8.06
Tx -9.54
PLO: 0.0
EDFA
CG: 24.66
TG: 24.55
Adj at: 10-11 11:25:18
Tx -4.64
Rx -5.08
Rx -10.82
Tx 13.49
GTO: 0.0
LPO: 0.0
Distance
215 km
LPO: 0.0
GTO: 0.0
Tx 13.12
Rx -8.04
Adj at: 03-07 21:25:59
TG: 22.28
CG: 22.28
Tx -5.48
Rx -5.65
EDFA
PLO: 0.0
Tx -8.62
Rx -7.25
RAMAN amplification
RAMAN
Tx 12.23
Rx 12.70
PLO: 0.0
RAMAN amplification
Tx 12.80
OSCT
Rx 13.59
LPO: 0.0
GTO: 0.0
Tx 13.80
Rx 2.92
Adj at: 05-16 11:25:57
TG: 10.98
CG: 10.82
Tx -5.67
Rx -6.10
EDFA
EDFA amplification
EDFA amplification

Multiplexing and demultiplexing
Fixed Optical Add-Drop Multiplexers (FOADM)

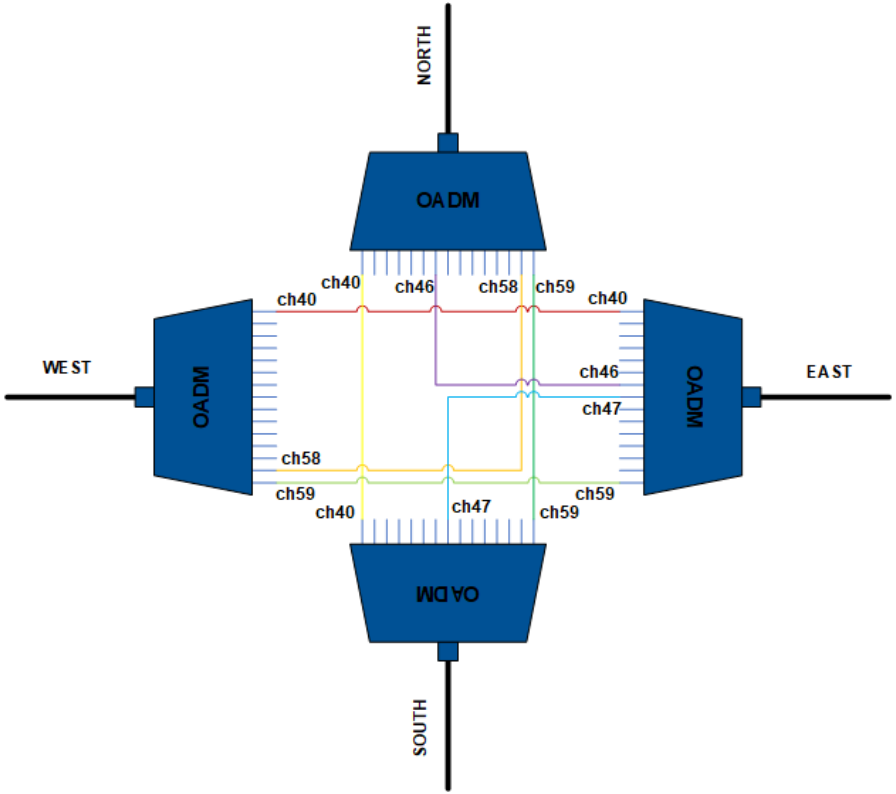
Early OAMD

- Fixed wavelength grid
- Manual add-drop only
- Fixed signal width
- Vendor lock

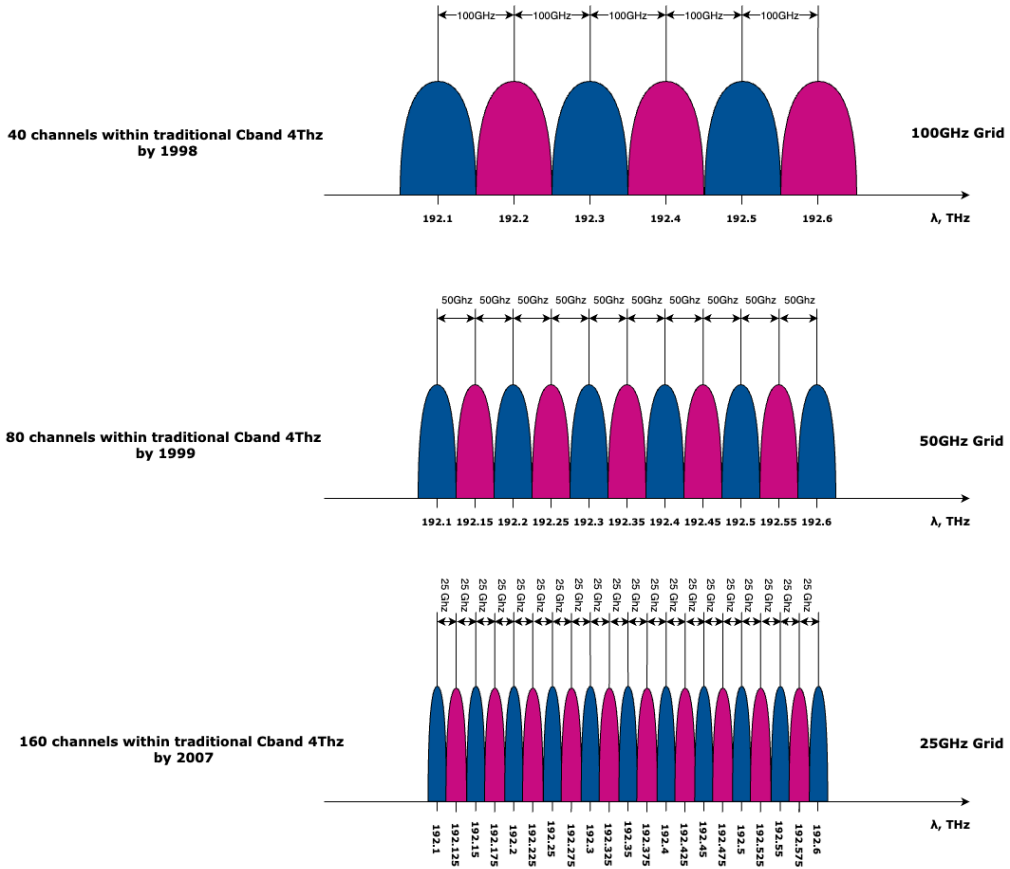


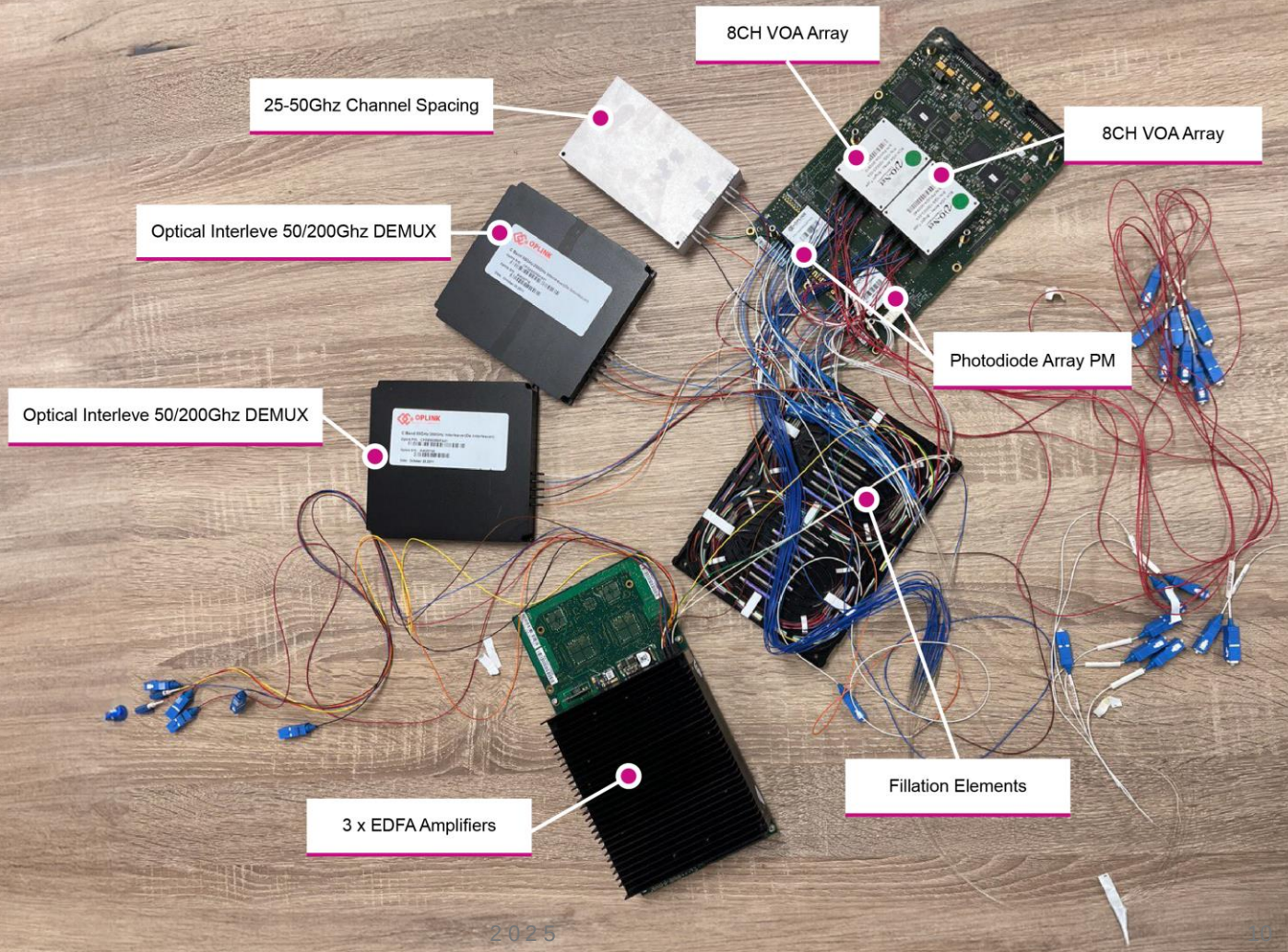
Powered by

- Athermal arrayed wave guide (AWG)
- Thin film filter (TFF)



Capacity increase by factor 4!



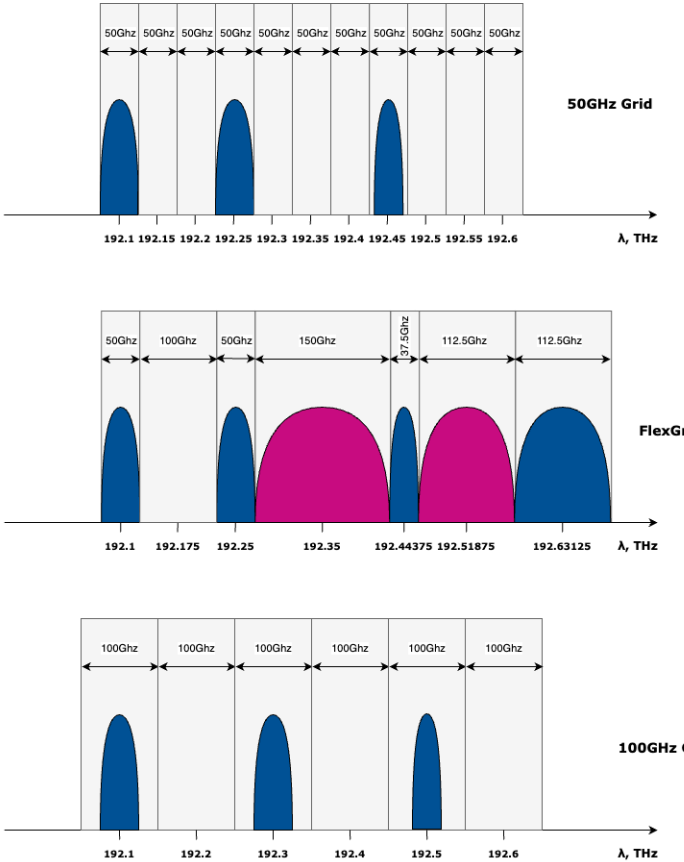

8CH VOA Array
25-50Ghz Channel Spacing
8CH VOA Array
Optical Interleve 50/200Ghz DEMUX
Photodiode Array PM
Optical Interleve 50/200Ghz DEMUX
Fillation Elements
3 x EDFA Amplifiers

Reconfigurable OADM (ROADM)

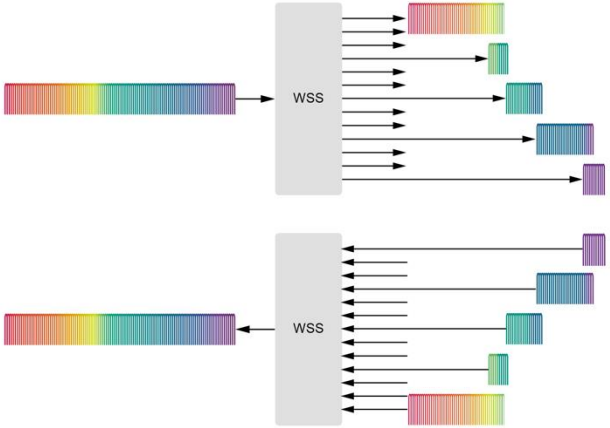
- Flexible wavelength planning
- Fully reconfigurable add-drops
- Flexible signal width (granularity)
- Open ROADM

Powered by

- light processing
- microelectromechanical systems mirrors
- liquid crystal
- liquid crystal on silicon

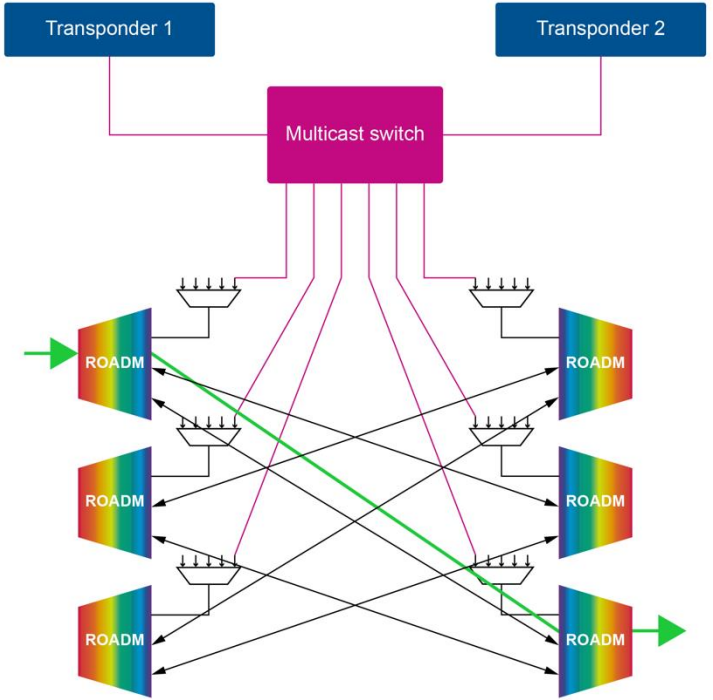


Flexible-grid WSS - a heart of modern ROADM

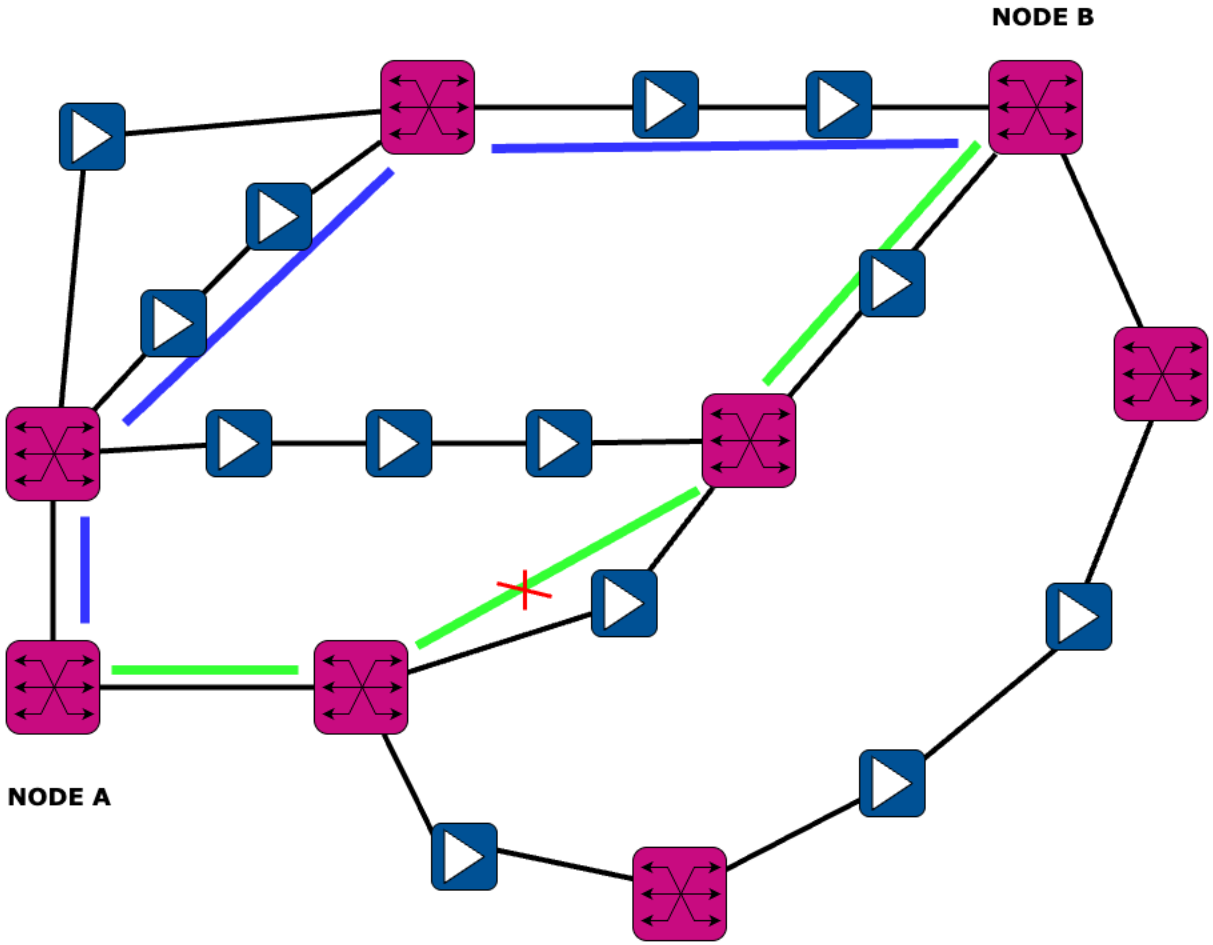


CDC ROADM

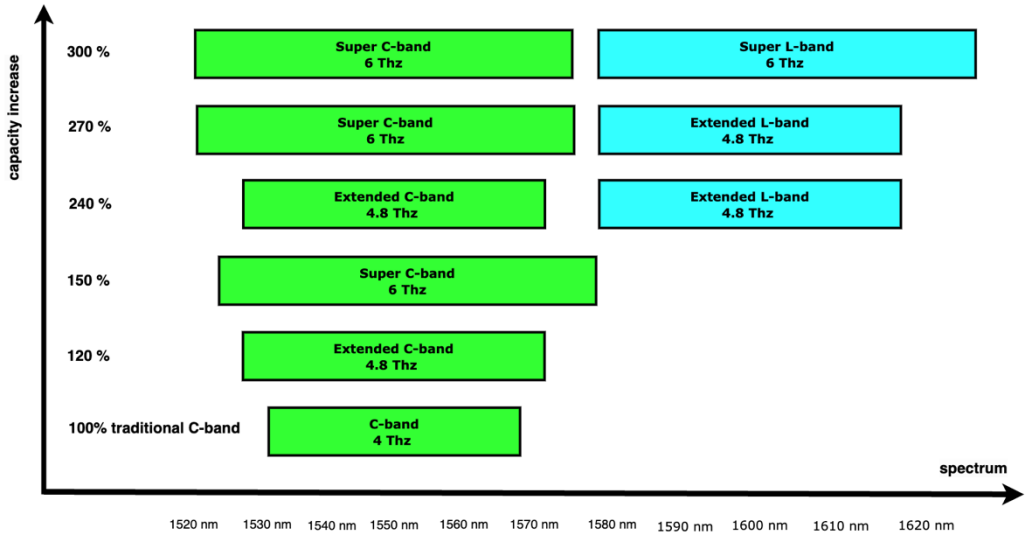
C - Colorless
D - Directionless
C - Contentionless

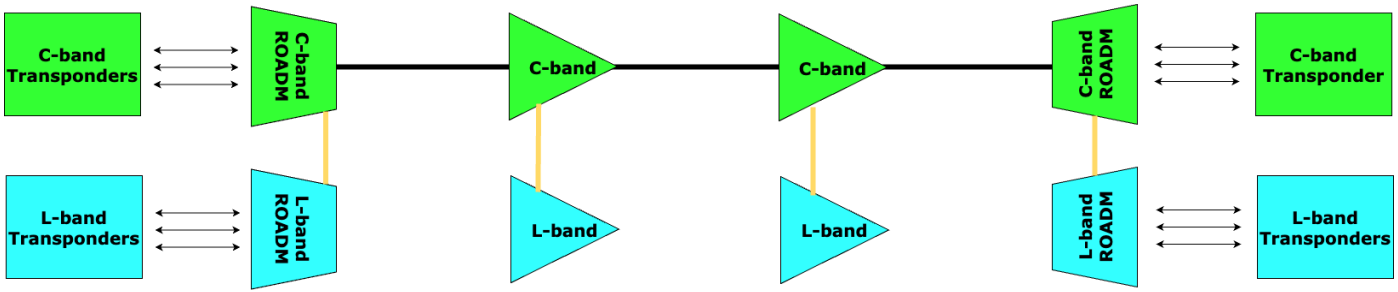


Power of Flexibility!

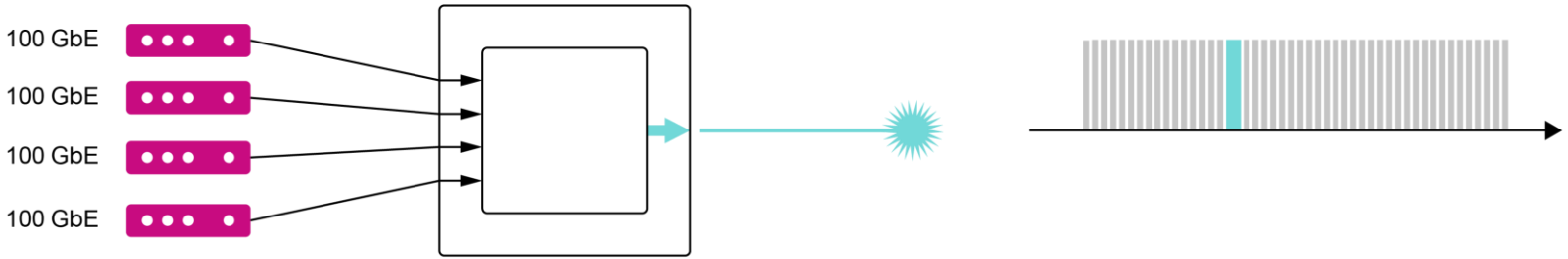


Spectrum extension and C+L band system





Transponder



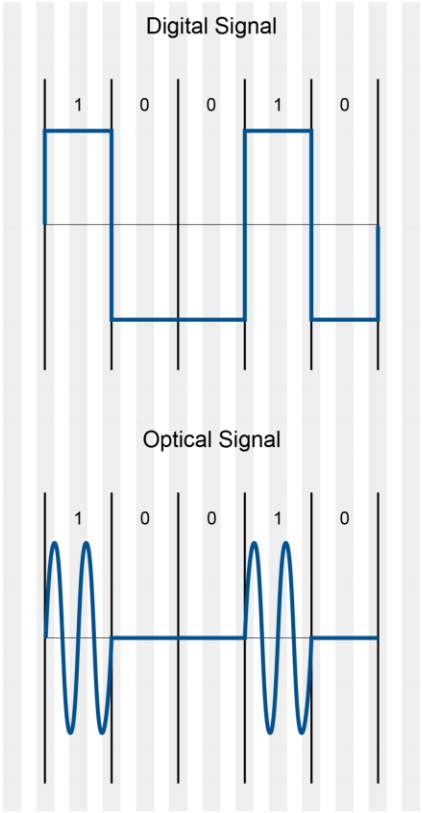
Transponder

Accept client signals
Convert to digital
OTN wrap and FEC
Modulate and Channelize

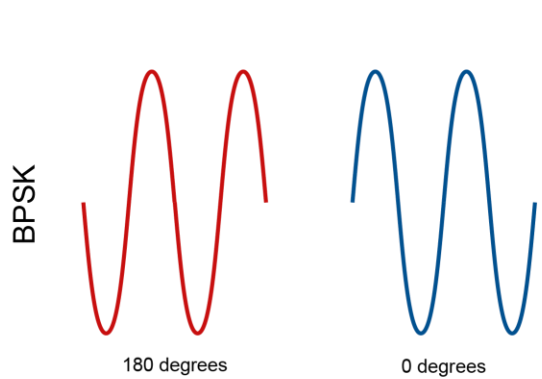
Direct detection for 10G modulation

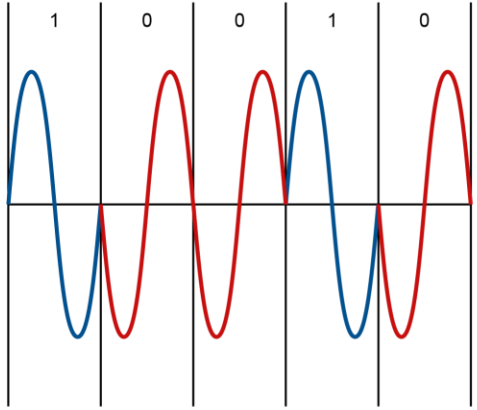
Coherent detection + Digital Signal Processing for higher order modulations.

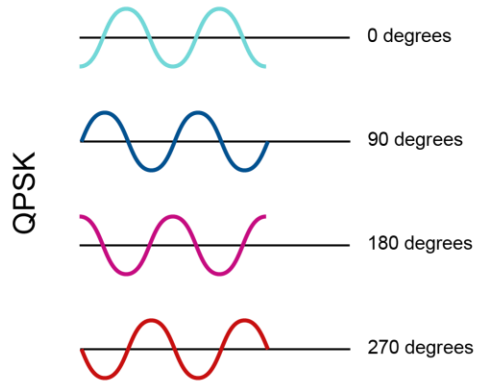
Amplitude Modulation On–Off Keying (OOK)

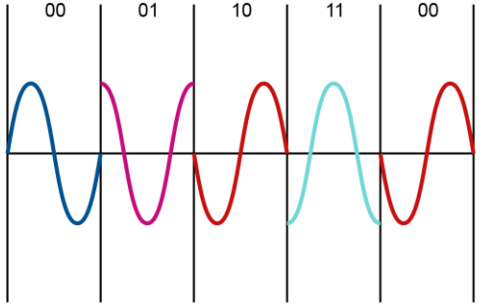


Phase Shift Keying Modulation

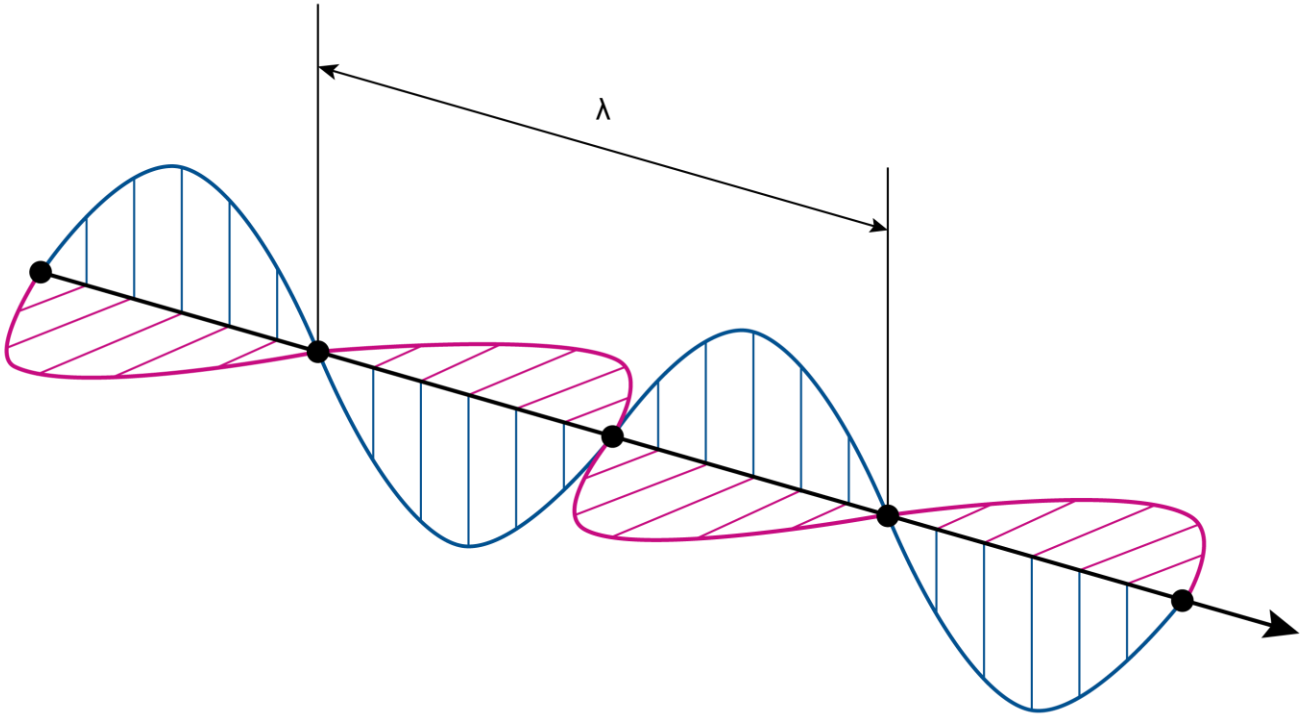




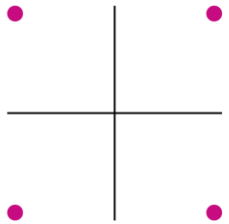
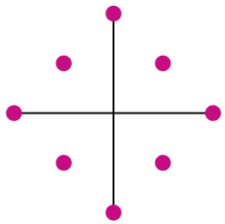
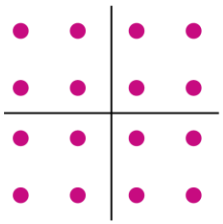
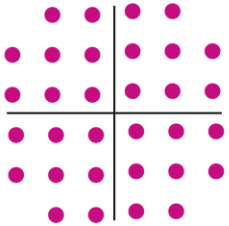
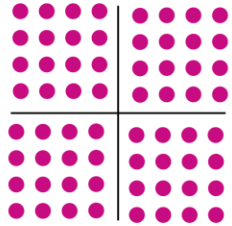
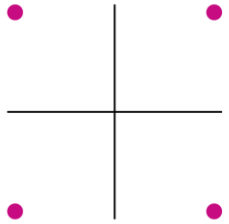
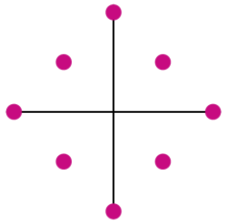
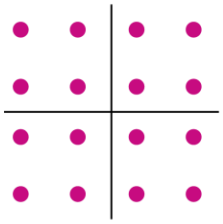
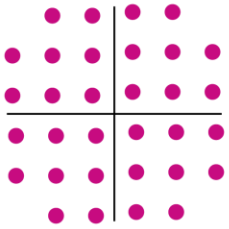
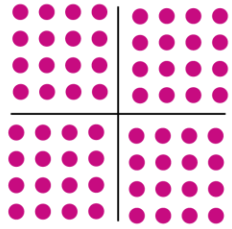




Polarization Modulation

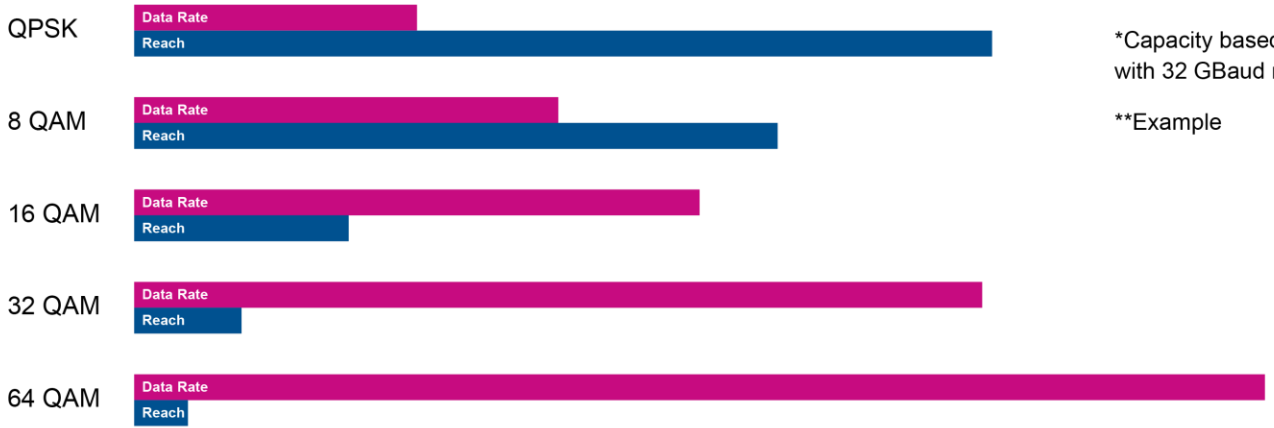


Higher order modulation

	PM-QPSK	PM-8QAM	PM-16QAM	PM-32QAM	PM-64QAM
X-Polorazation	2 bits 	3 bits 	4 bits 	5 bits 	6 bits 
Y-Polorazation	2 bits 	3 bits 	4 bits 	5 bits 	6 bits 
	4 bits/symbol	6 bits/symbol	8 bits/symbol	10 bits/symbol	12 bits/symbol

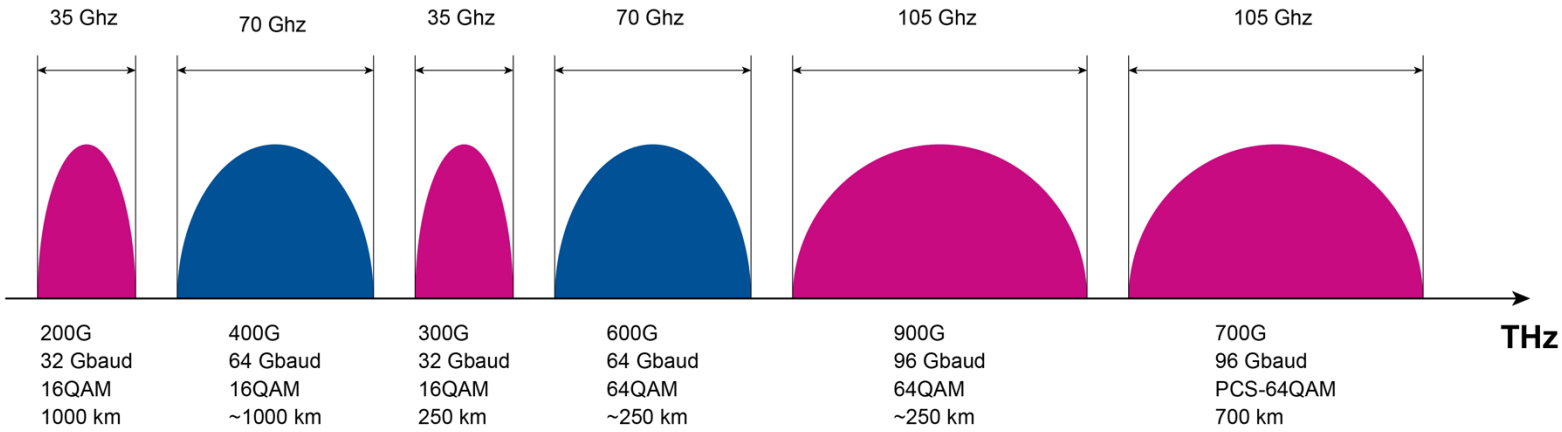
Reach issue: modulation and baud rate

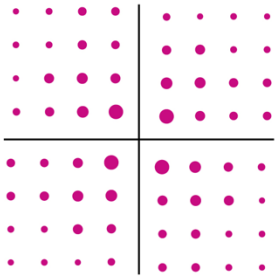
Modulation	Constellation points	Number of bits per polarisation	Bits increase compering to QPSK	Reach reduction compering to QPSK	Capacity*, Gbps	Reach**, km
QPSK	4	2	0.00%	0.00%	100	4000
8 QAM	8	3	50.00%	50.00%	150	2000
16 QAM	16	4	100.00%	75.00%	200	1000
32 QAM	32	5	150.00%	87.50%	250	500
64 QAM	64	6	200.00%	93.75%	300	250



*Capacity based on using x and y polarisations with 32 GBaud rate with 20% FEC

**Example





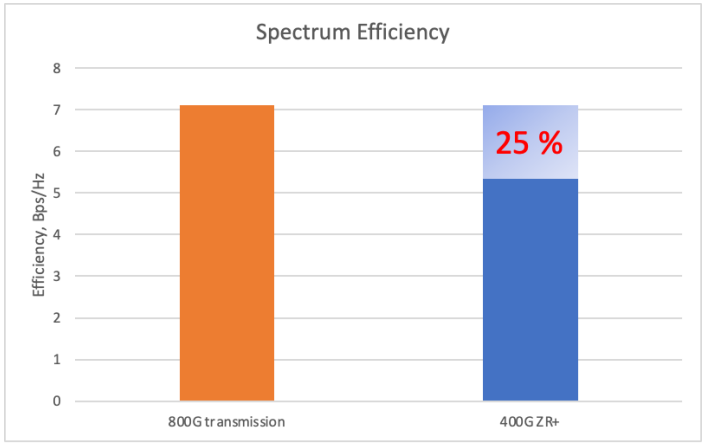
Probabilistic Constellation Shaping

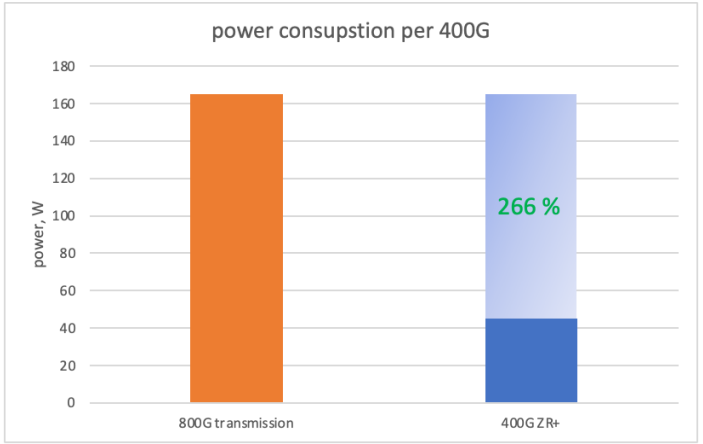
Granularity

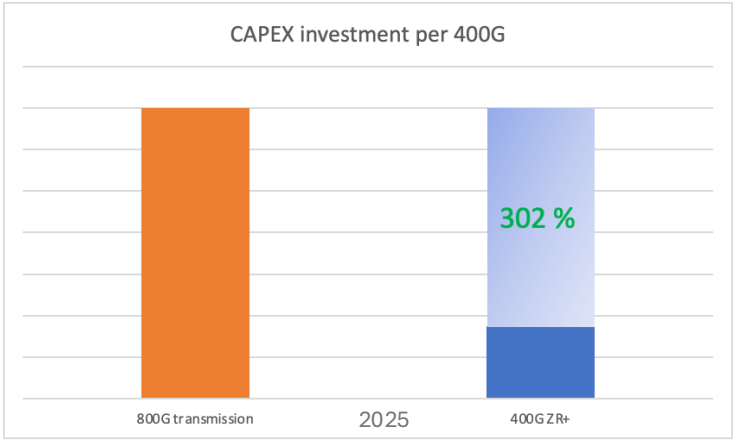
Reduced Nonlinearities

Baud Rate Flexibility

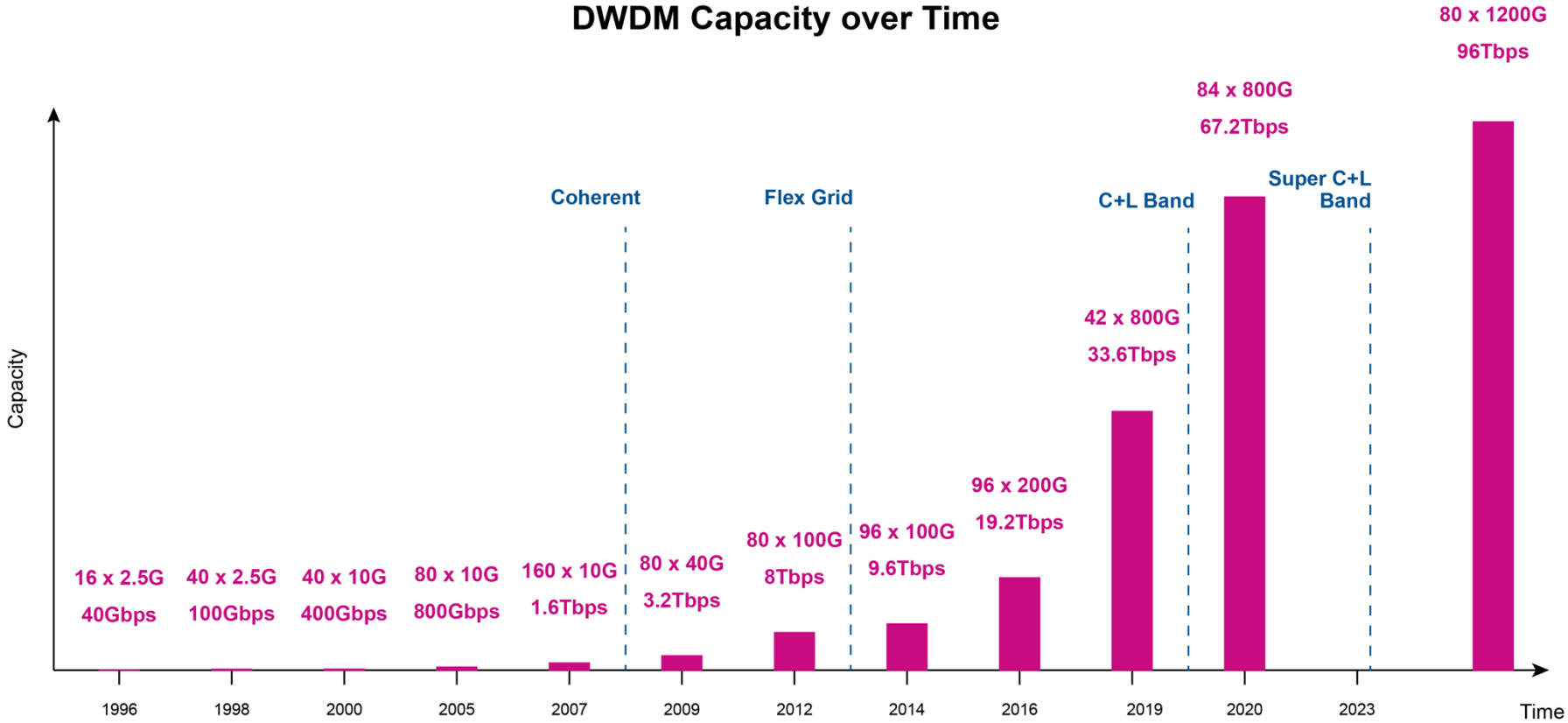
Spectral efficiency vs common sense



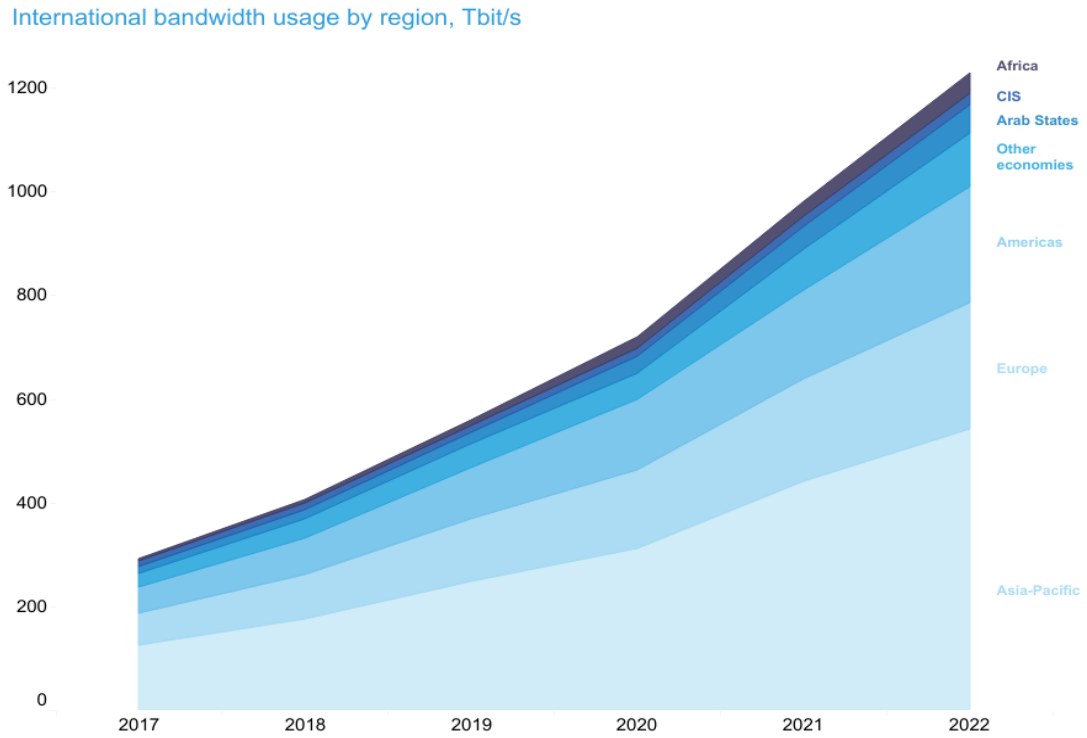




DWDM Capacity over Time



International bandwidth



Note: 1 Terabit = 1'000'000 Megabit.

Source: ITU


Oslo
Stockholm
Helsinki
Saint Petersburg
Tallinn
Riga
Vilnius
Minsk
Moscow
Copenhagen
Dublin
London
Paris
Madrid
Lisbon
Hamburg
Berlin
Poznan
Warsaw
Prague
Bratislava
Vienna
Budapest
Zagreb
Ljubljana
Belgrade
Sarajevo
Sofia
Skopje
Tirana
Rome
Milan
Padua
Bologna
Marseille
Zurich
Munich
Stuttgart
Frankfurt
Cologne
Nuremberg
Brno
Katowice
Krakow
Wroclaw
Lublin
Biala Podlaska
Lutsk
Lviv
Uzhhorod
Kyiv
Chernihiv
Kharkiv
Dnipro
Zaporizhia
Odessa
Mykolaiv
Chisinau
Bucharest
Timisoara
Ankara
Tbilisi
Yerevan
Gyumry
Vanadzor
Baku
Voronezh
Saratov
Uralsk
Aktobe
Saksaulskiy
Chelyabinsk
Petropavl
Kostanay
Kaliningrad
Gdansk
Klaipeda
Kaunas
Daugavpils
Rezekne
Ventspils
Cesis
Bialystok
Monastyryshche
Leeds
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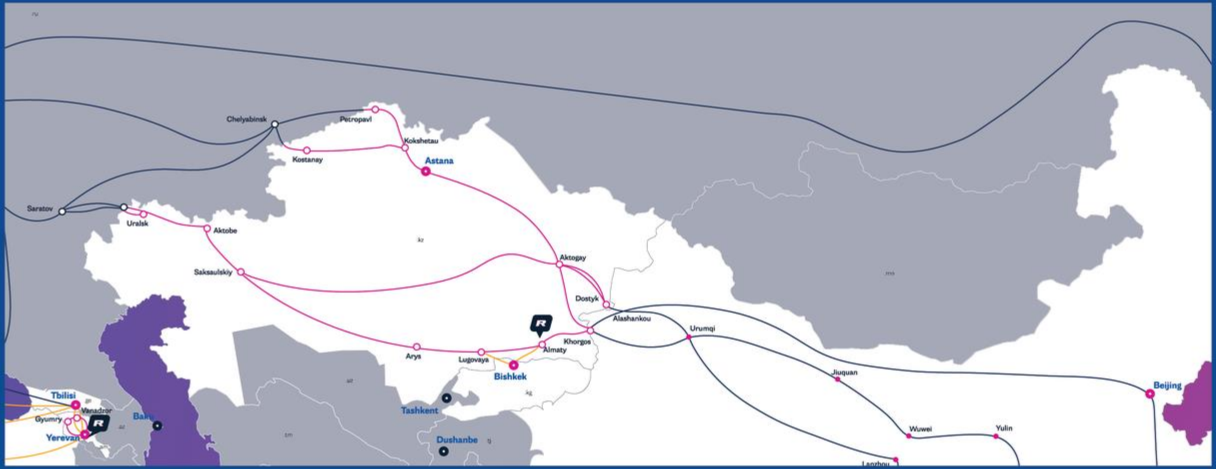
Groningen
Meppel
Dusseldorf
Rotterdam
Brussels
AEC-2
AEC-1
EXA Express
To USA
Dunant
Marea

Chelyabinsk
Petropavl
Kokshetau
Astana
Kostanay
Saratov
Uralsk
Aktobe
Saksaulskiy
Aktogay
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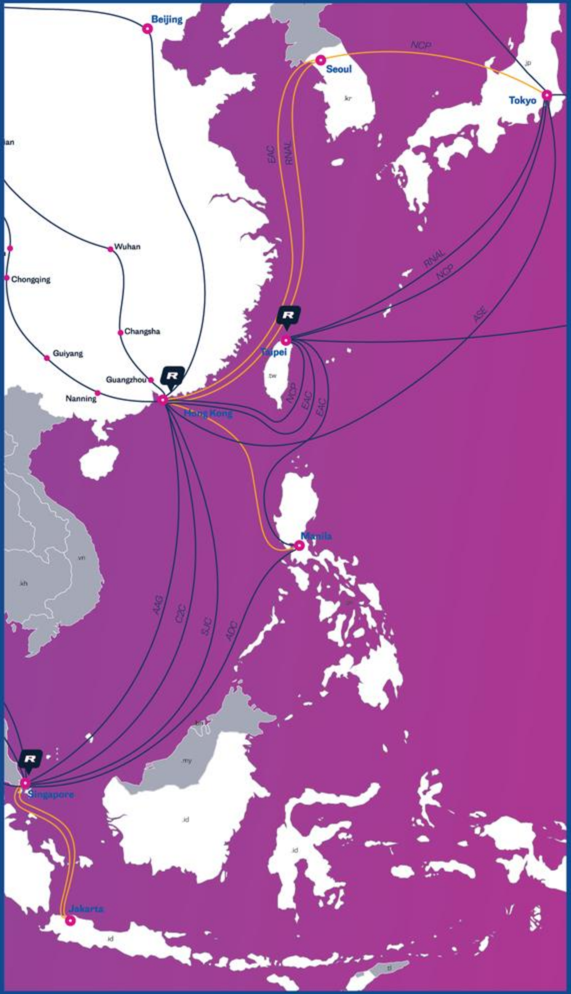
Lugovaya
Arys
Tashkent
Dushanbe
Jiuquan
Wuwei
Yulin
Lanzhou
Beijing
Tbilisi
Vanadzor
Gyumry
Yerevan
Baku

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