
cisco
Cisco Expo 2011
Collaboration and Virtualization without Borders.
Changing the way we work, live, play and learn.

100G and beyond

Bogdan Zapca

Consulting Systems Engineer, bzapca@cisco.com

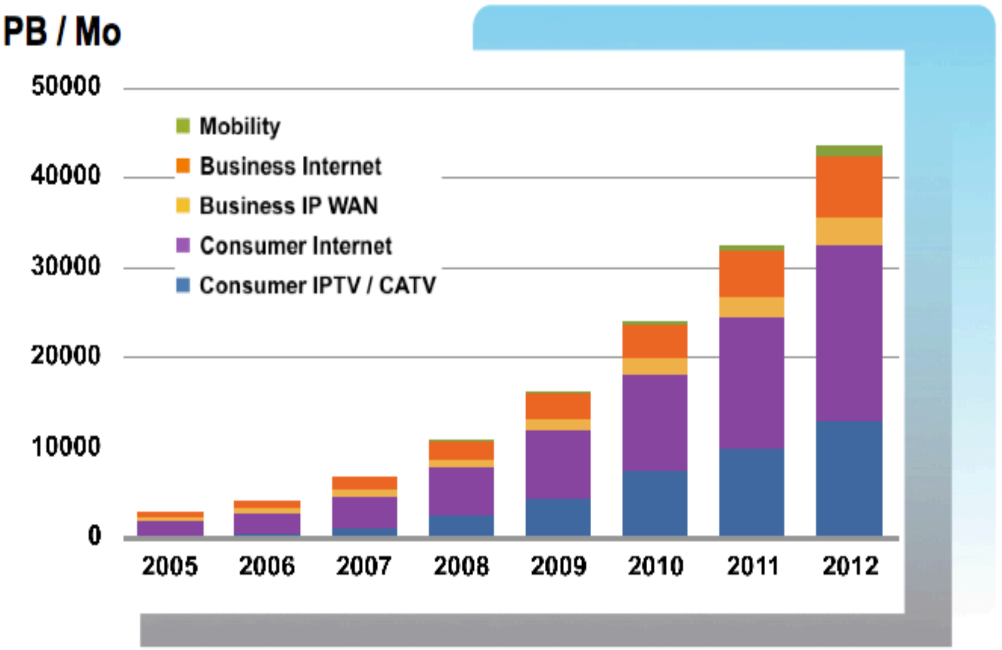
- Some opinions presented here are personal
- During the presentation things like blunt approach, rude and/or offensive language may appear

- Where we are
- 40G and 100G today and tomorrow
- Quo Vadis?
- Beyond 100G

Where are we?

- In 2012, Half a Zettabyte (10^{21}) Will Cross the Global Network
- Services converging on IP
  - Peer to peer
  - Voice
  - Video broadcast and VoD
  - Over the top providers
  - Video conferencing

"According to the annual survey of the global digital output by International Data Corporation, the total amount of global data was expected to pass 1.2 zettabytes sometime during 2010. This is equivalent to the amount of data that would be generated by everyone in the world posting messages on the microblogging site Twitter continuously for a century." – Wikipedia



- Anybody measuring traffic? (i.e. Do you really know what is passing over your network?)
- Does your traffic grow 300% / year?
- What do you need /plan to use 40G or 100G?

40G and 100G today and tomorrow

Slides from Alessandro Cavaciuti

Manager, Engineering – Transceiver Module Group

High Speed Ethernet Drivers

Copper and Fiber 40/100G Options

IEEE 802.3ba Standards

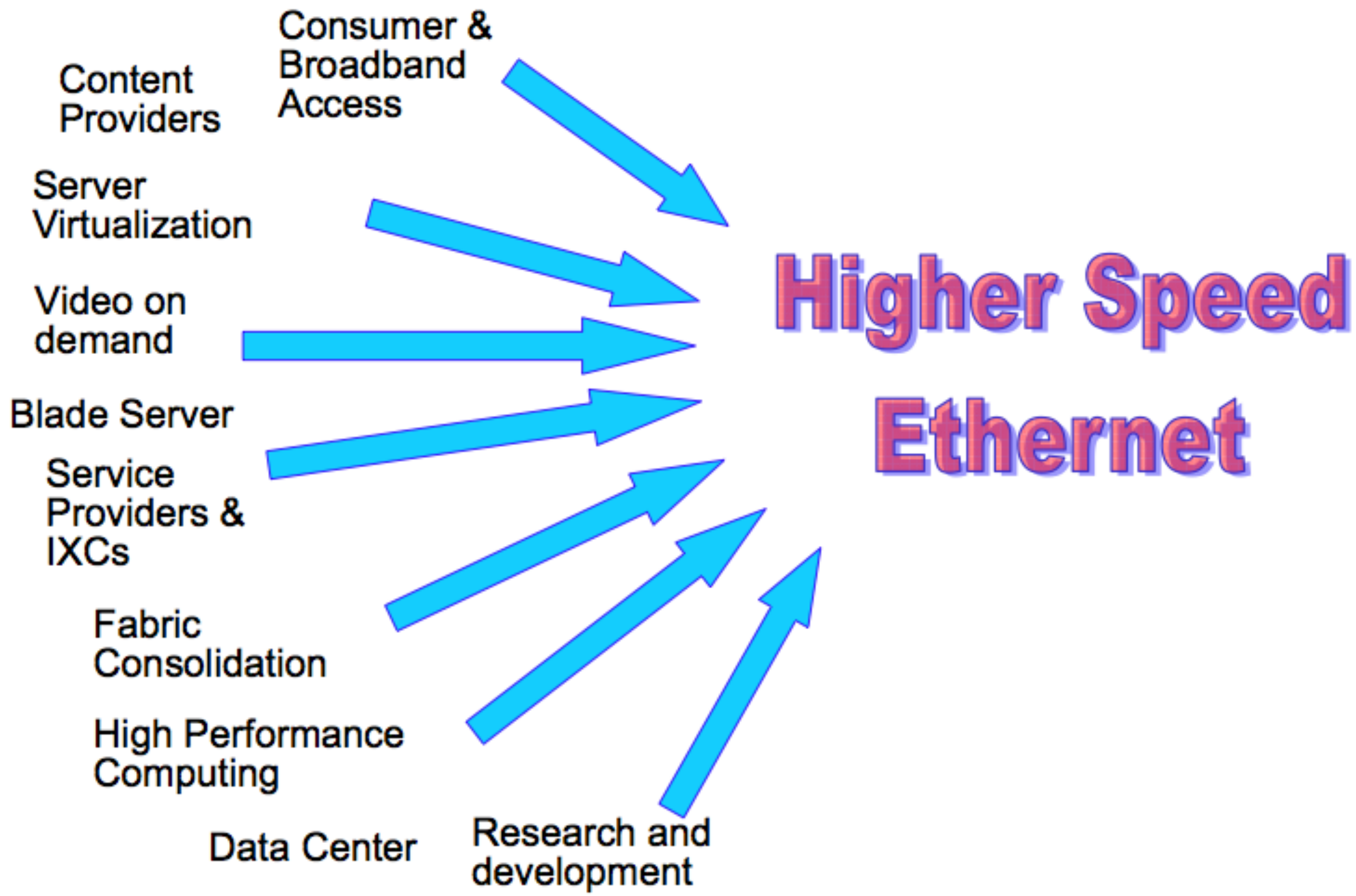
Parallel Optics and Fiber Array Cables

High-Speed Transceivers Form Factors

- 40G
- 100G

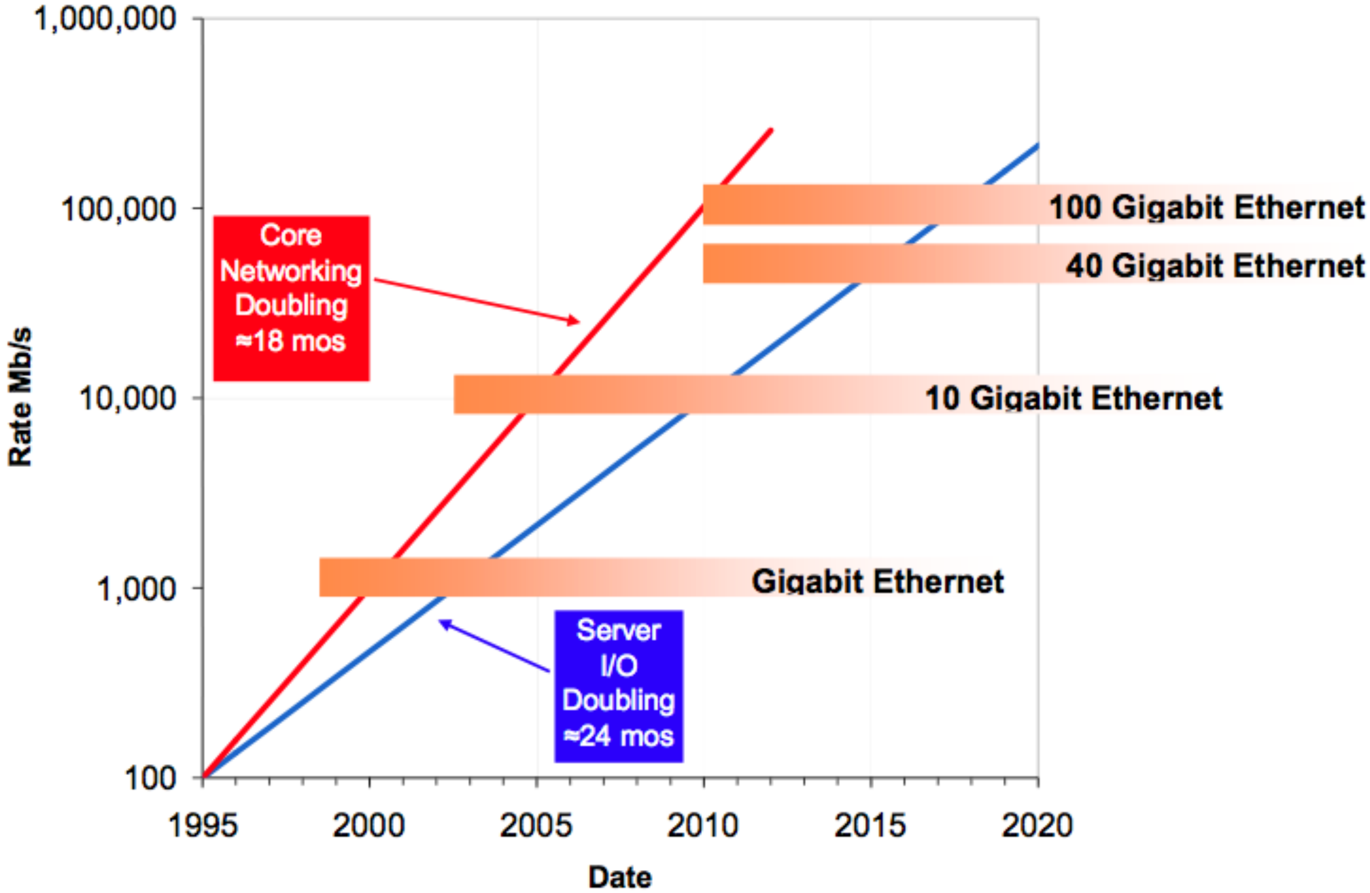
Form Factors Evolution

Market Drivers for More Bandwidth



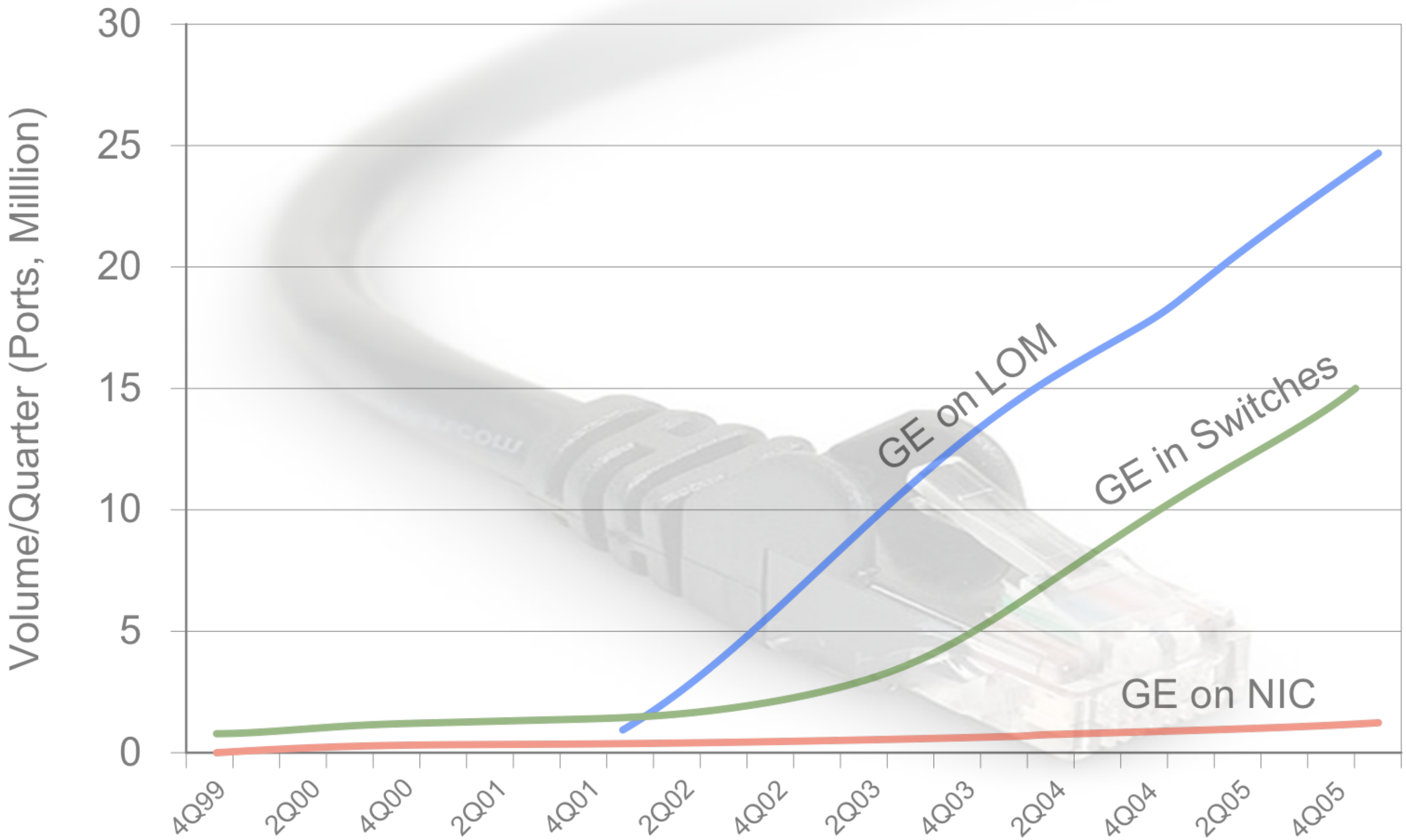
IEEE 802.3 Higher Speed Study Group - TUTORIAL

40GbE and 100GbE: Computing and Networking

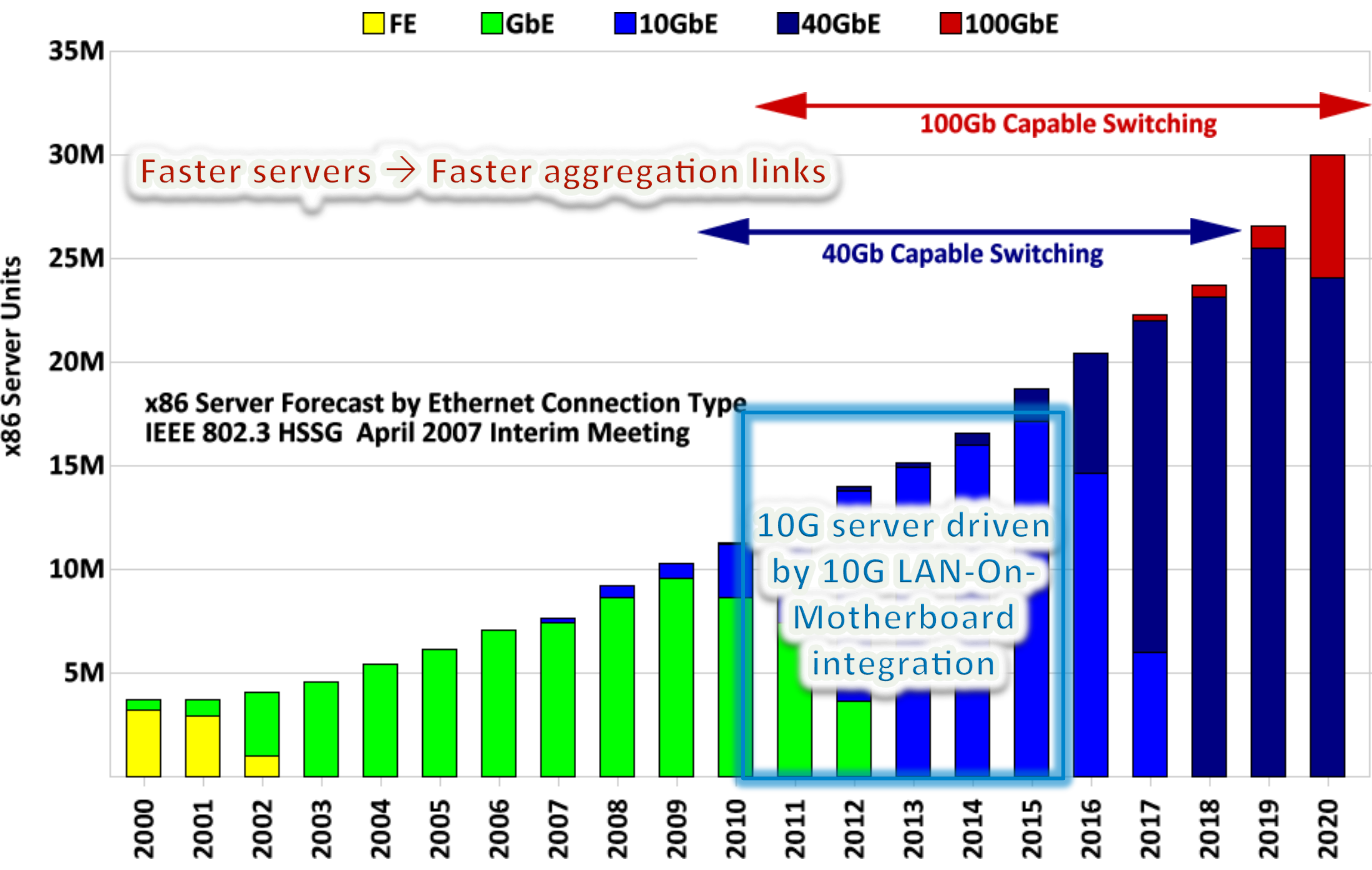


IEEE 802.3 Higher Speed Study Group - TUTORIAL

A look at the Gigabit Ethernet Transition



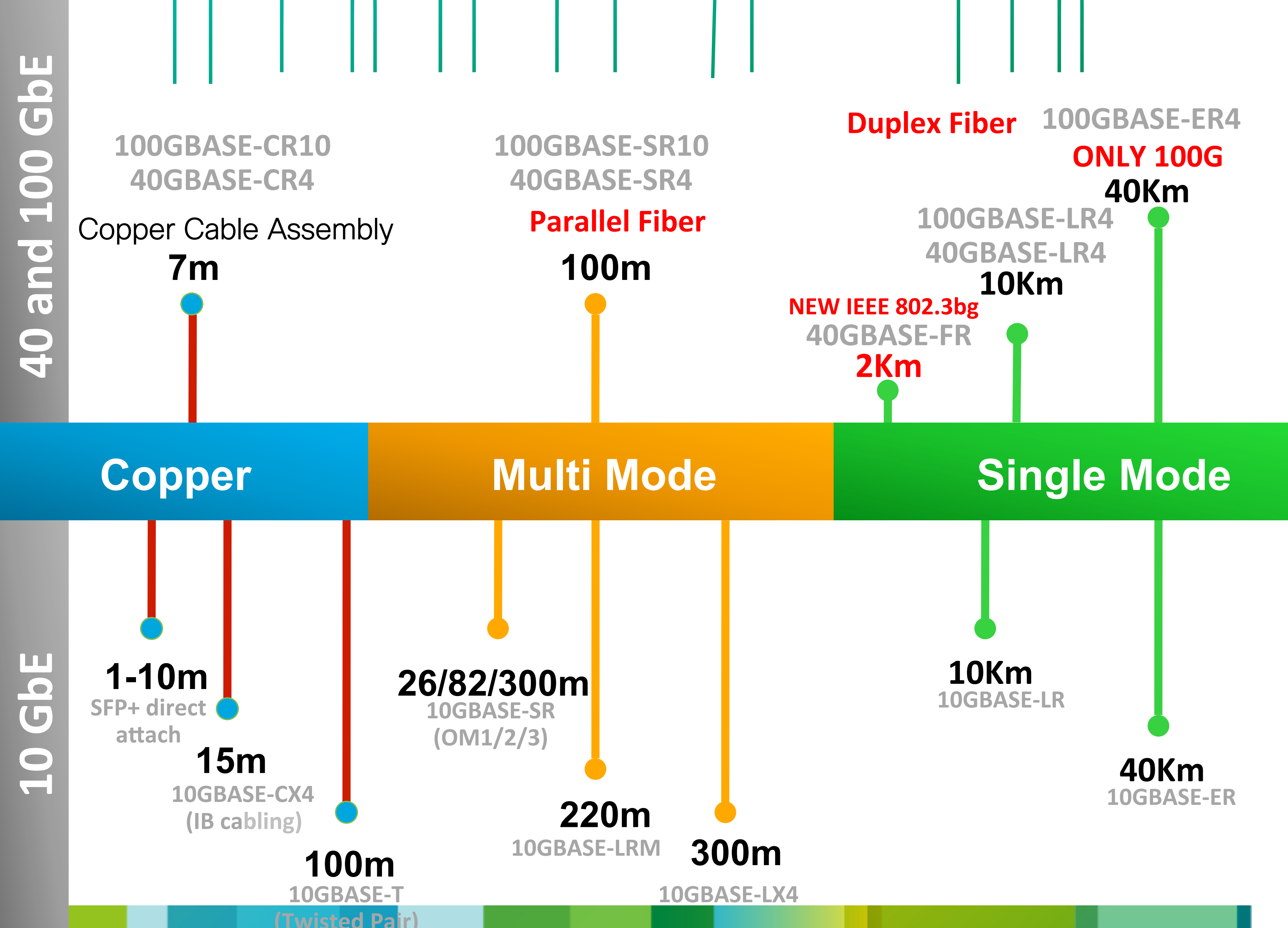
Source: Dell'Oro Q1'06 GbE MSS report, Dell'Oro 7/07 Switch report



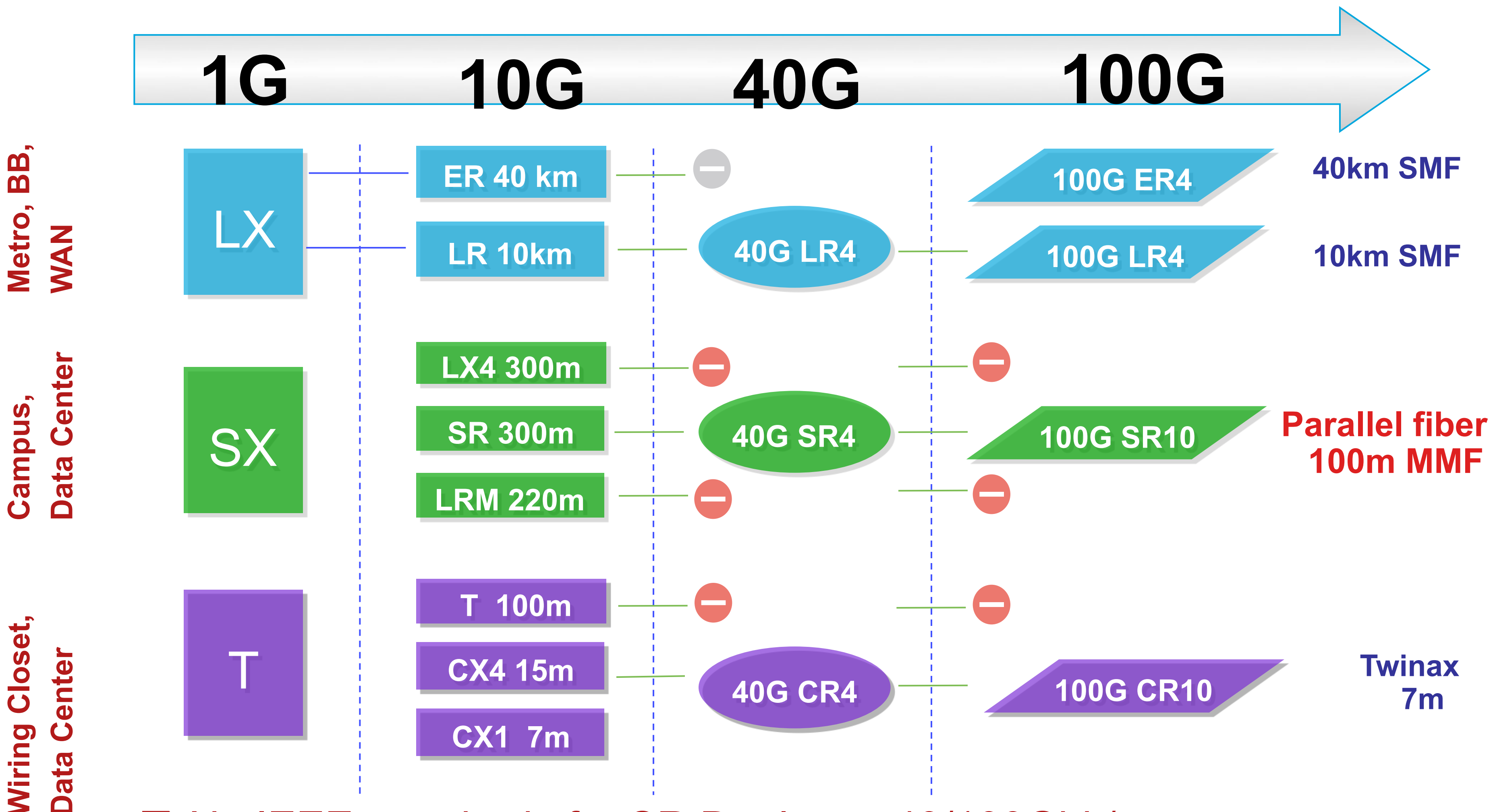
FE
GbE
10GbE
40GbE
100GbE
35M
30M
25M
20M
15M
10M
5M
x86 Server Units
100Gb Capable Switching
Faster servers → Faster aggregation links
40Gb Capable Switching
x86 Server Forecast by Ethernet Connection Type
IEEE 802.3 HSSG April 2007 Interim Meeting
10G server driven by 10G LAN-On-Motherboard integration
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020

June 2010
IEEE 802.3ba
STANDARD COMPLETED

JUNE 2010						
SUN	MON	TUES	WED	THURS	FRI	SAT
		1	2	3	4	5
6	7	8	9	10	11	12
13	14	15	16	17	18	19
20	21	22	23	24	25	26
27	28	29	30	Note:		


40 and 100 GbE
10 GbE
100GBASE-CR10
40GBASE-CR4
Copper Cable Assembly
7m
100GBASE-SR10
40GBASE-SR4
Parallel Fiber
100m
Duplex Fiber
100GBASE-ER4
ONLY 100G
40Km
100GBASE-LR4
40GBASE-LR4
10Km
NEW IEEE 802.3bg
40GBASE-FR
2Km
Copper
Multi Mode
Single Mode
1-10m
SFP+ direct attach
15m
10GBASE-CX4
(IB cabling)
100m
10GBASE-T
(Twisted Pair)
26/82/300m
10GBASE-SR
(OM1/2/3)
220m
10GBASE-LRM
300m
10GBASE-LX4
10Km
10GBASE-LR
40Km
10GBASE-ER

Spec	Distance	Media	Characteristic	Package – 1st gen
40G-CR4	7m	Copper coax	4 x twinax	QSFP & CFP
40G-SR4	100/150 m	OM3/OM4	4 x 10G ribbon	QSFP & CFP
40G-LR4	10km	SM	4x 10G λ 1300nm CWDM	CFP (maybe QSFP)
100G-CR10	7m	Copper coax	10 x CX1	CFP
100G-SR10	100/150 m	OM3/OM4	10 x 10G ribbon	CFP
100G-LR4	10km	SM	4x 25G λ 1300nm LAN WDM	CFP
100G-ER4	40km	SM	4x 25G λ 1300nm LAN WDM	CFP



- ❑ No IEEE standards for SR Duplex at 40/100Gbit/s
- ❑ VCSEL Technology limitations

- No Duplex over Multimode fiber
  - No “40G-SR” equivalent to 10G-SR
  - No support for OM1 or OM2 with 40G-SR4
- No Cat6A or equivalent twisted pair solutions
- 40G beyond 10km reaches even on SM
- 100G beyond 40km – nothing agreed for >40km

These are all areas where vendors can develop MSA options:

Market forces frequently drive more options (eg LRM, LX4)

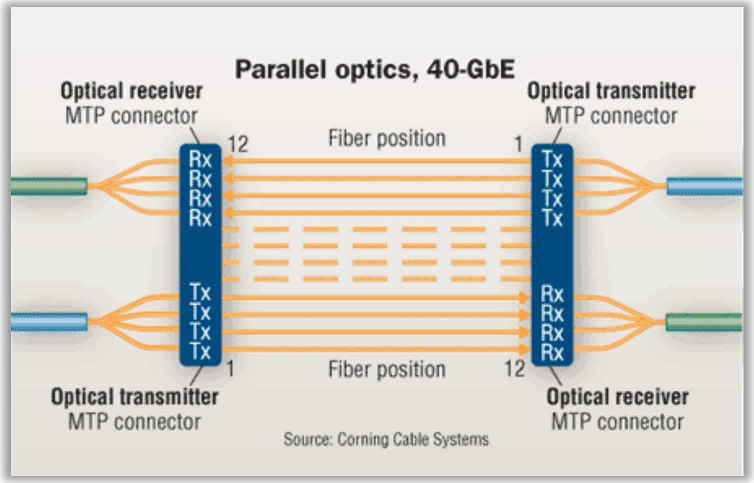
Likely a 40km reach for 40GE on SM will be one of those

- 100G-SR10 is 10x 10G SR – based on 10G optics
- 100G-LR4 is 4x 25G lambda – based on 25G wavelength optics (10km reaches)
- 100G-ER4 is 4x 25G with long haul 25G wavelength optics
- 100G-CR10 is limited to 7m and is not intended for use outside of systems (compute or network)
- No standards for 2x50G or 10x10 DWDM packages

40-GbE

4 Fiber Pairs

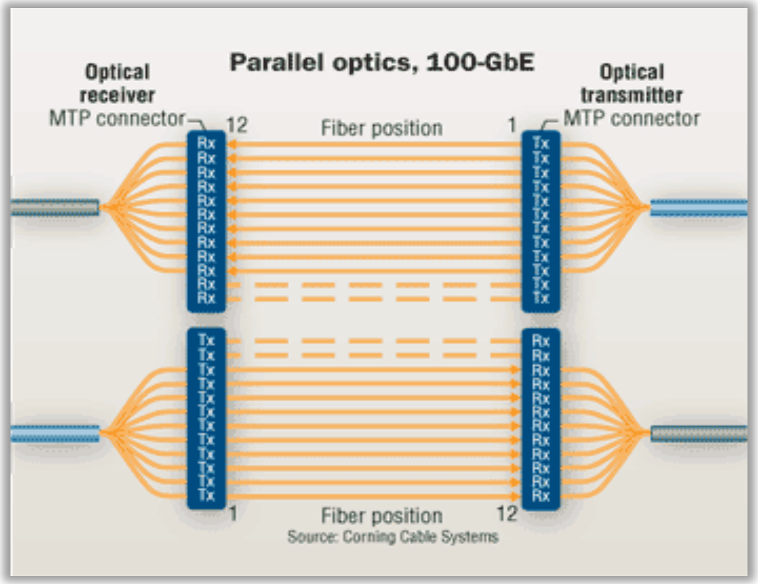
- MTP Connector with 12 fibers
- 4 TX, 4 RX allows for 40G



100-GbE

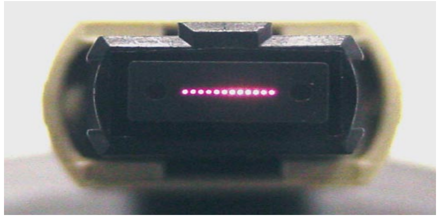
10 Fiber Pairs

- MTP Connector with 2x12 fibers
- 10 TX, 10 RX allows for 100G



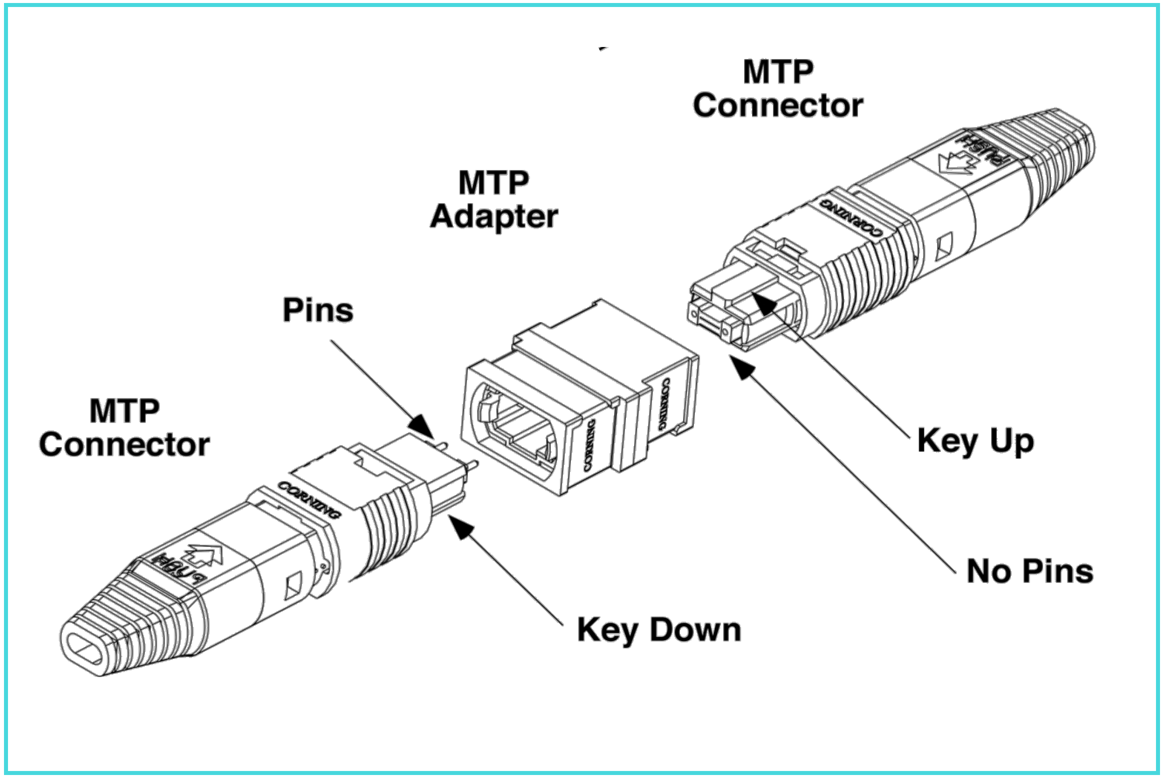
- MPO cables used for optical cabling trunks today
- Custom-length cabling delivered with factory-installed connectors on both ends
- MPO Structured Cabling trunks and LC patch leads
- MPO Cables are plugged into the back of patch panels
- At 40GbE/100GbE "MPO" will plug directly into QSFP/CFP

MPO Plugs for 40G
(12-fiber array connectors)

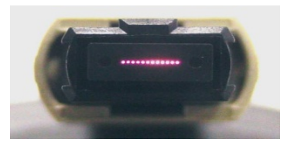


MPO Plugs for 100G
(24-fiber array connectors)

- High-density 12-fiber connector
- Push-pull style latching
- Pinned to pinless mating

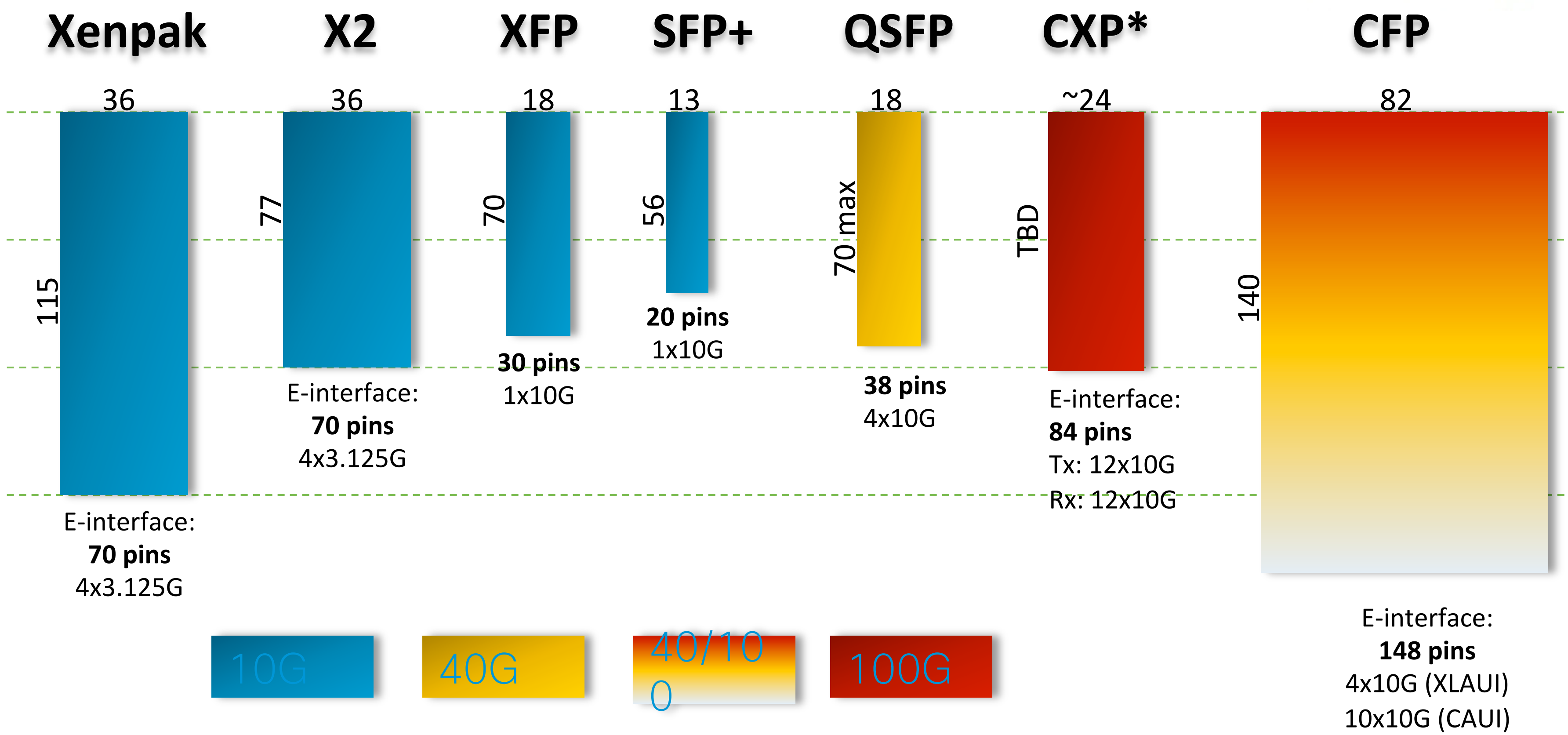


MPO Plugs for 40G
(12-fiber array connectors)



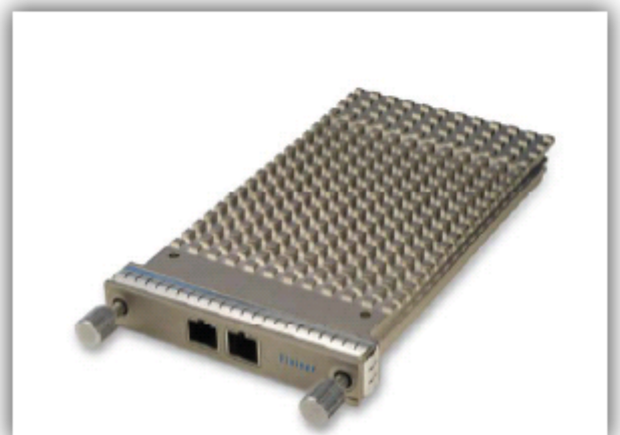
MPO Plugs for 100G
(24-fiber array connectors)

Duplex SC connector
for SMF



All units are in millimeters and round numbers

CFP



Applications:

- Single Mode Fiber 10Km
- Multi Mode OM-3 100m
- MultiMode OM-4 150 m
- “FourX” converter for 4x10GbE (SFP+)

Power Consumption:

- Up to 8W @ 40GbE

QSFP

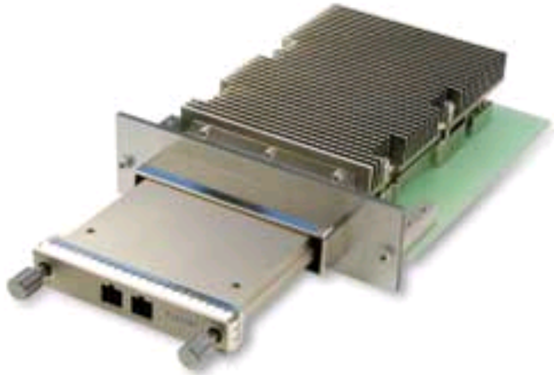
Applications:

- Multi Mode OM-3 100m
- MultiMode OM-4 150 m
- Twinax Copper
- Single Mode Fiber 10Km (Future)

Power Consumption:

- Up to 3.5W

100GbE CFP requires “Riding HeatSink” SMF optimized



CFP features a new concept known as the riding heat sink, in which the heat sink is attached to rails on the host card and “rides” on top of the CFP, which is flat topped.

Applications:

- Single Mode Fiber 10Km and 40Km
- Multi Mode OM-3 100m
- Multi Mode OM-4 100m

Power Consumption:

- Up to 24W

CXP MMF/Twinax optimized

CXP was created to satisfy the high-density requirements of the data center, targeting parallel interconnections for 12x QDR InfiniBand (120 Gbps), 100 GbETwinax co-located in the same facility. The InfiniBand Trade Association is currently standardizing the CXP.

Applications:

- Twinax Cu assembly up to 7 m
- Multi Mode OM-3 100m
- Multi Mode OM-4 100m

Power Consumption:

- Up to 3.5W

- 1st gen optics will be in multiple packages:
  - Single Mode requires more power which increases size / restricts density
  - Multi Mode optics use less power and so allow higher port density
- 2nd gen may rationalize to fewer choices or increase overlap
- Do expect additional non-standard interconnect options as well in 2012+

Planned for 1st Generation   Not Planned for 1st Generation

Media	Reach	Speed	CFP	QSFP	CXP
Single Mode	10Km	100G			
		40G		Future	
	40Km	100G			
		40G	No Std	No Std	No Std
Multi Mode	100m	100G			
		40G			
Copper	7m	100G			
		40G			

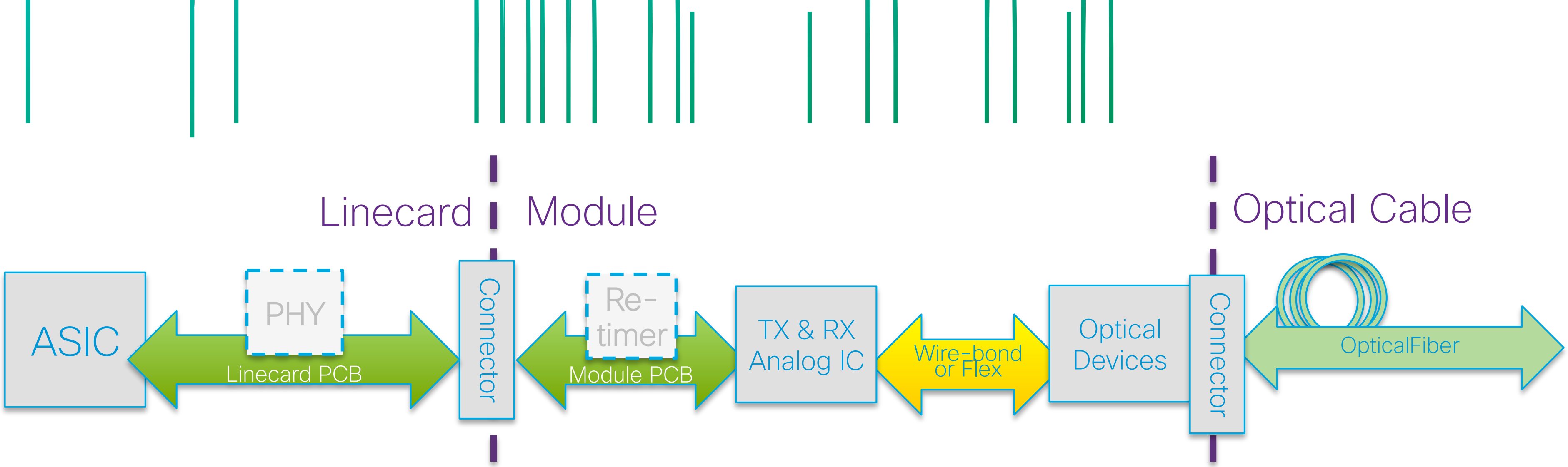
- Form factor evolution #1 priority is to preserve optical backward compatibility
- 10GE is a clear example:

  300pin ➪ Xenpak ➪ X2 ➪ XFP ➪ SFP+

  Yet we all hope in fewer transitions!!!
- Squeezing the same optical interfaces in a smaller box is a multi-faceted challenge:
  - Power density/heat dissipation
  - Electrical connector density/electrical lane baud rate
  - EMI/SI
  - Module PCB real estate (for both electronics/optics)
  - VCSEL Bandwidth

- 10G baud electrical signaling is now understood and managed
- Yet 10G lanes for 100G+ total throughput is not real estate optimized
- Size of pins cannot effectively be further reduced
- Need to move to 25G electrical lanes
- Optical components need to be integrated (i.e. demux+RXs)

CFP	QSFP
148 pins	38 pins
24 10G diff pairs	8 10G diff pairs
82 mm	18 mm



- Communication chain performance depends upon signal integrity of each element
- Moving from today's 10G baud rate to 25G poses several challenges:
  - Connector performance in terms of IL, Reflection, XT
  - EMI /Shielding
  - PCB performance
  - Power Efficiency/cost of active components (Phys/CDRs/Laser drivers…)
  - Integrated optics VCSEL arrays performance/power consumption

40G and 100G ready solutions are available now

Cisco is investing heavily in both areas and will continue to be your trusted partner through this technology/market transition

- 40G deployments:
  - Multimode requires 4 fiber pairs – MPO-12 is the connector type
  - Distance is limited to 100m with OM3 – not 300m (10G-SR)
  - 4x 10G = 1x 40G from a cabling infrastructure perspective
  - Single mode 40G optics uses duplex fibers up to 10 Km
- 100G deployments
  - Multimode uses 20 fibers on MPO-24 connectors up to 100m OM-3
  - Single mode 100G optics uses duplex fibers up to 10 Km
- Optics will reduce in size and power over time

Quo Vadis?

- Users: 2.0B (28%)
  - 5B left to go
  - Up from 360M in 2000
  - 445% growth => 16% annual growth
  - 2020: Everyone who can be economically connected
- Broadband: 283M (14%)
  - Growing at 1.47% /yr
  - 2020: 327M

- Ample growth potential, especially upgrades
- Sources: www.internetworldstats.com, www.oecd.org

- Video, video, video
- HD
- Gaming (GT5)
- Person-to-person video (umi, Skype, FaceTime)
- Multiparty teleconferencing (Skype, Telepresence)
- 3D video
- 3D teleconferencing
- Tactile-presence: Remote surgery
- Remote virtual reality

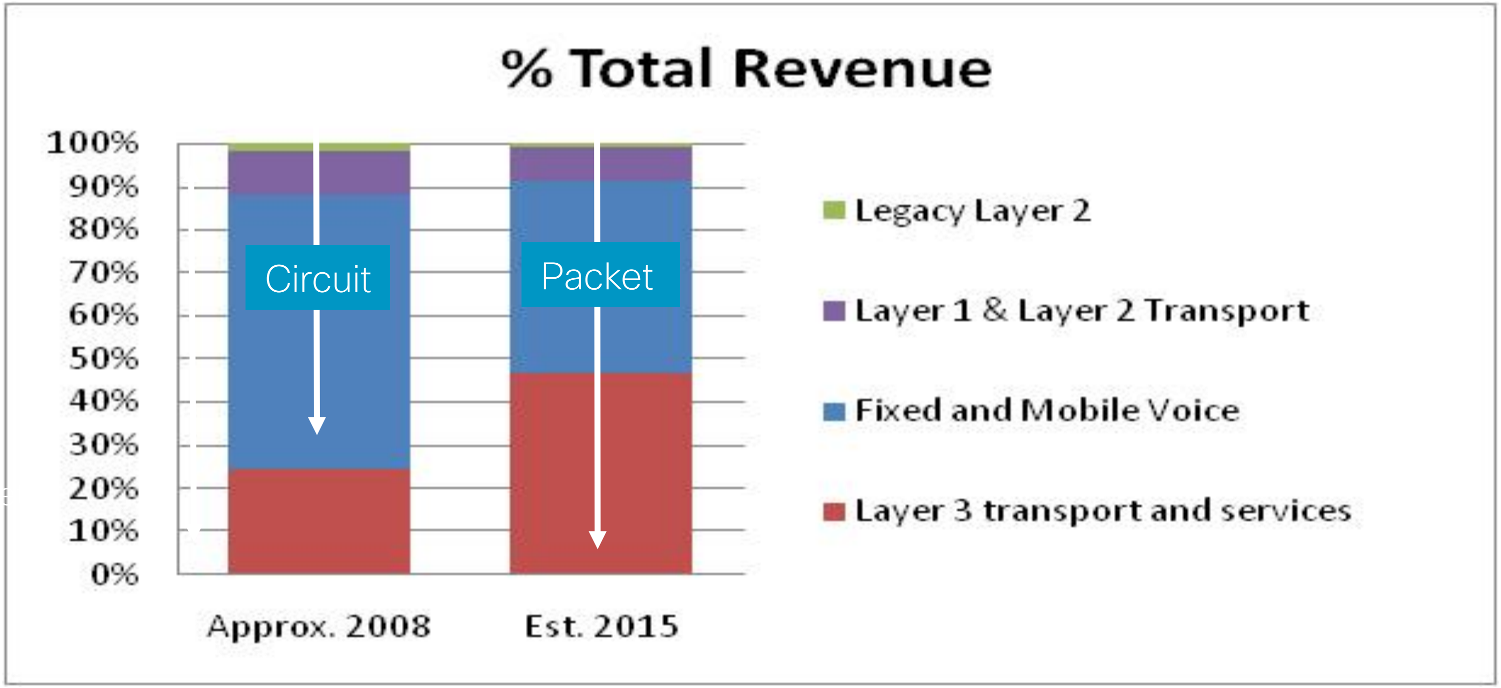
- More cable, DSL, faster
- FTTH
- 802.11n
- WiGig?
- 4G, LTE, …
- Coherent optics
- IPoDWDM, ROADM, OTN switching
- GMPLS based path computation
- 100G, 40G as ISP building blocks now
- 1T, 10T, 100T Ethernet
- Exabit-scale routers (Gigabit, Terabit, Petabit, Exabit)

- Terabyte (TB) = 10^{12}
- Petabyte (PB) = 10^{15}
- Exabyte (EB) = 10^{18}
- 2000: 1EB/yr
- 2009: 175EB/yr

  CAGR since 2000: 77%
- 2014: 768EB/yr
- Linear: 34% annual growth (CAGR)
- 2020: 4,450EB/yr (linear), 71,840EB/yr (exponential)

- Sources: Cisco Visual Networking Index

- ~3M Internet subscribers in Romania
- ~7.3M Households
- CAGR?

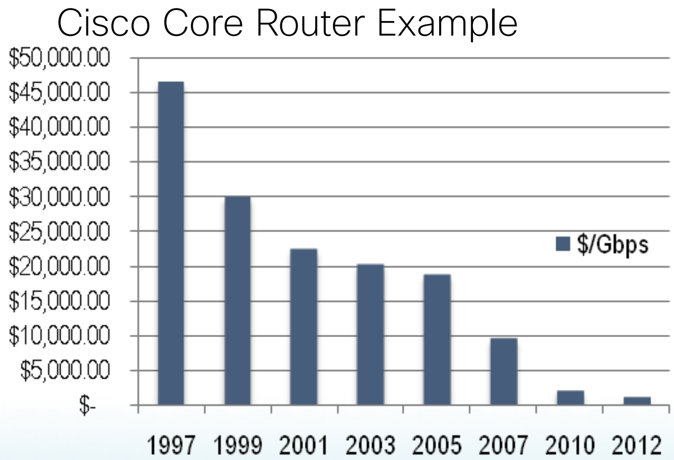


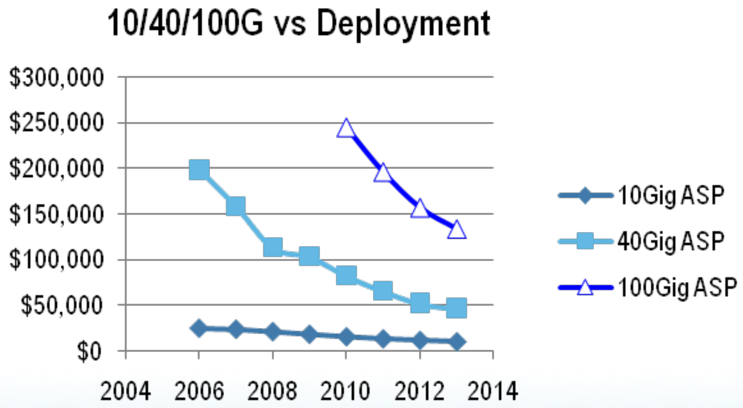
- Future SP revenue will be dominated by services using packet technology
- Packet Traffic levels already dominates and growing rapidly
    - 34% CAGR in packet traffic predicted until 2014*
- Consumer traffic dominates / video is a large constituent
- Existing circuit switched services transitioning to packet – Voice

Sources : * Cisco VNI 2010, Total Revenue : Cisco based on SP accounts analysis and estimates

Routers: 23% Cumulative Average $/Gbps Drop per year / fewer ASICs

Optics: $/G stays flat (best case) or increases from one technology to the next





- Silicon has fundamentally followed Moore’s law
- Optics has fundamentally an Analog Problem

Beyond 100G

Slides from various sources

- Minimize Transport Cost per Bit by Maximizing Unregenerated Reach and Capacity per Fiber
- Optimize Nodes Architecture to allow Switching at different Layers
- From Point-to-Point to Mesh Architecture

- Glenn Wellbrock, Director of Backbone Network Architecture - Verizon Business

- Cost Optimization is a multi-dimensional problem as you could:
  - Increase overall Capacity per Fiber
  - Increase overall Unregenerated Reach per Wavelength
- How can Capacity per Fiber be increased?
  - More Wavelengths
  - Higher per-Wavelength Bit Rate
- How can Unregenerated Reach be increased?
  - Better Optical Amplification solutions
  - Lower OSNR required per Wavelength Bit Rate

- All Transmission Effects scale with Channel's bit-rate:

  CD Tolerance scales as the Square of Bit Rate
  (800ps/nm @ 10G → 50ps/nm @ 40G)

  PMD Tolerance, OSNR Requirement, Bandwidth and Unregenerated Reach scale Linearly with Bit Rate
  (10ps @ 10G → 2.5ps @ 40G)

- Transition between 2.5Gbps and 10Gbps has introduced the use of FEC coding

- Transition to 40Gbps, 100Gbps, 1,000Gbps cannot be supported only by more powerful coding

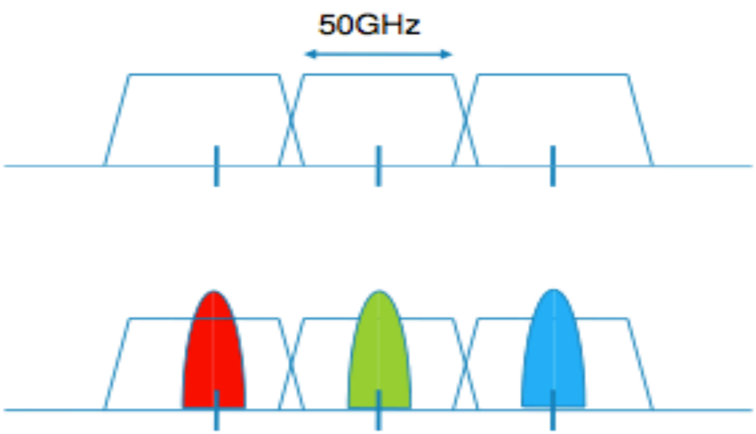
  Increase Complexity of Modulation Schema and Optical Receiver to provide an effective answer: CP-DQPSK

50 GHz channel grid

concept

50GHz channel grid
Center frequency +/- 25GHz

10Gb/s ASK, NRZ
+/- 10GHz



Spectral efficiency

vs. modulation format

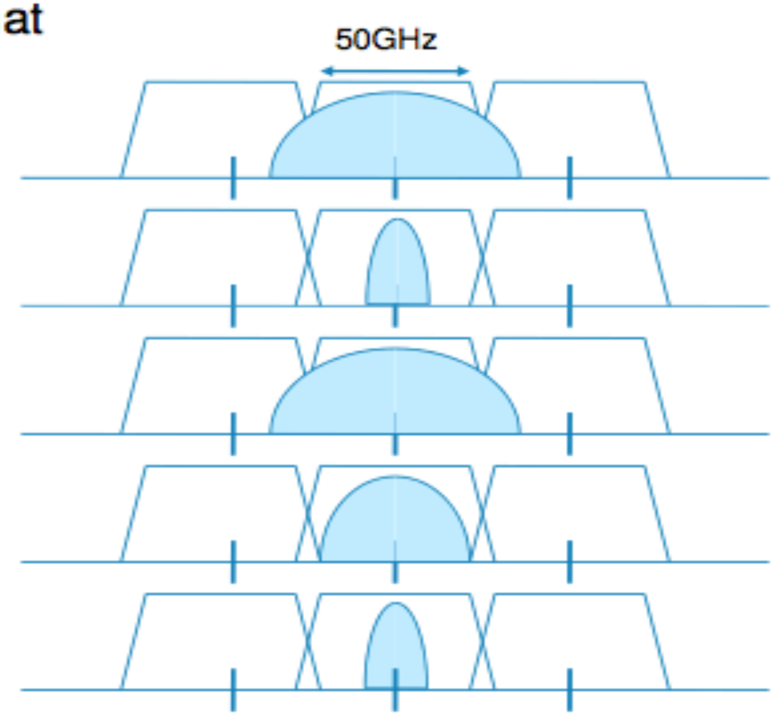
40Gb/s ASK, NRZ
+/- 40GHz

40Gb/s ODB
+/- 10GHz

40Gb/s DPSK
1x40Gbaud: +/- 40GHz

40Gb/s RZ DQPSK
2x20Gbaud+RZ

40Gb/s CP QPSK
2x10Gbaud+PolMux



10G – 40G – 100G

choosing the best option

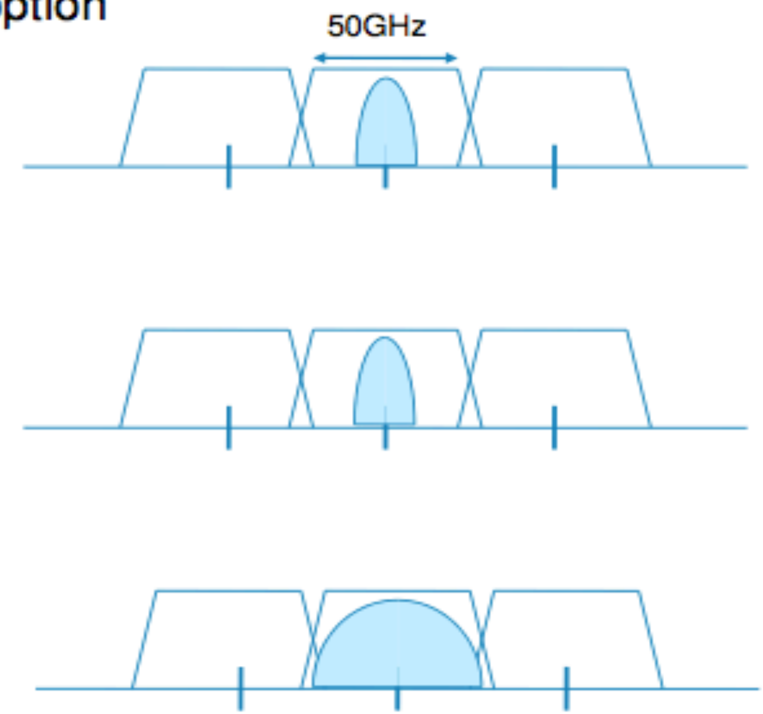
10Gb/s ASK, NRZ
+/- 10GHz

↓

40Gb/s CP QPSK
2x10Gbaud+PolMux

↓

100Gb/s CP QPSK
2x25Gbaud+PolMux



Choosing the best modulation format

From 2.5Gb/s to 100Gb/s

2.5G

2.5G NRZ
ASK

10G

10G NRZ
ASK
Variant:
Chirp
Electronic equalizer
MLSE

40G

40G ODB
40Gbs, ASK + PSK

40G DPSK
40Gb PSK

40G A-DPSK
40Gb PSK
A=Adaptive

40G RZ-QPSK
20Gbaud, Q-PSK, RZ

40G CP-QPSK
10Gbaud, pol mux,
Coherent Rx

100G

100G CP-QPSK
25Gbaud, pol mux,
Coherent Rx

> 100G

--- ? ---

Most likely
Multilevel Tx
Polarization mux
Coherent Rx

e.g.
25 Gbaud 16QAM

--- ? ---

- Future interfaces will continue to use polarization multiplexing, phase modulation and coherent receiver technology

+

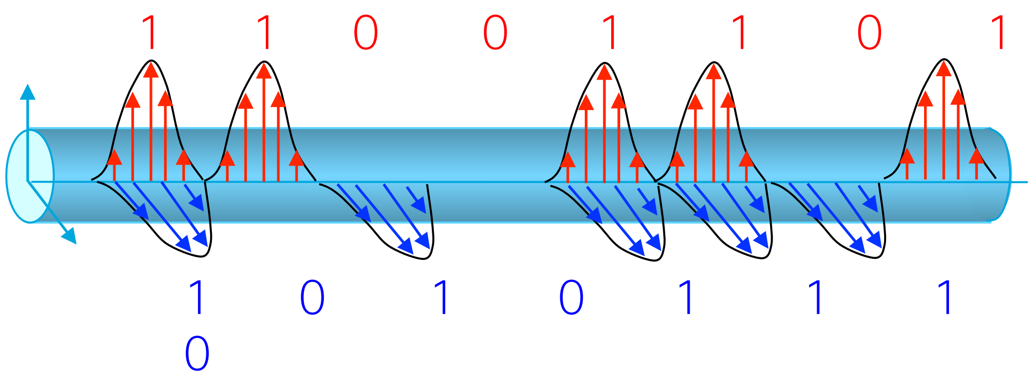
- High bandwidth efficiency (2 bit / (s Hz) with 100 Gb/s and 50 GHz grid)
- Good OSNR performance
- Large CD tolerance
- Large PMD tolerance
- Coherent channel selection capability (no optical filtering at Rx side)

–

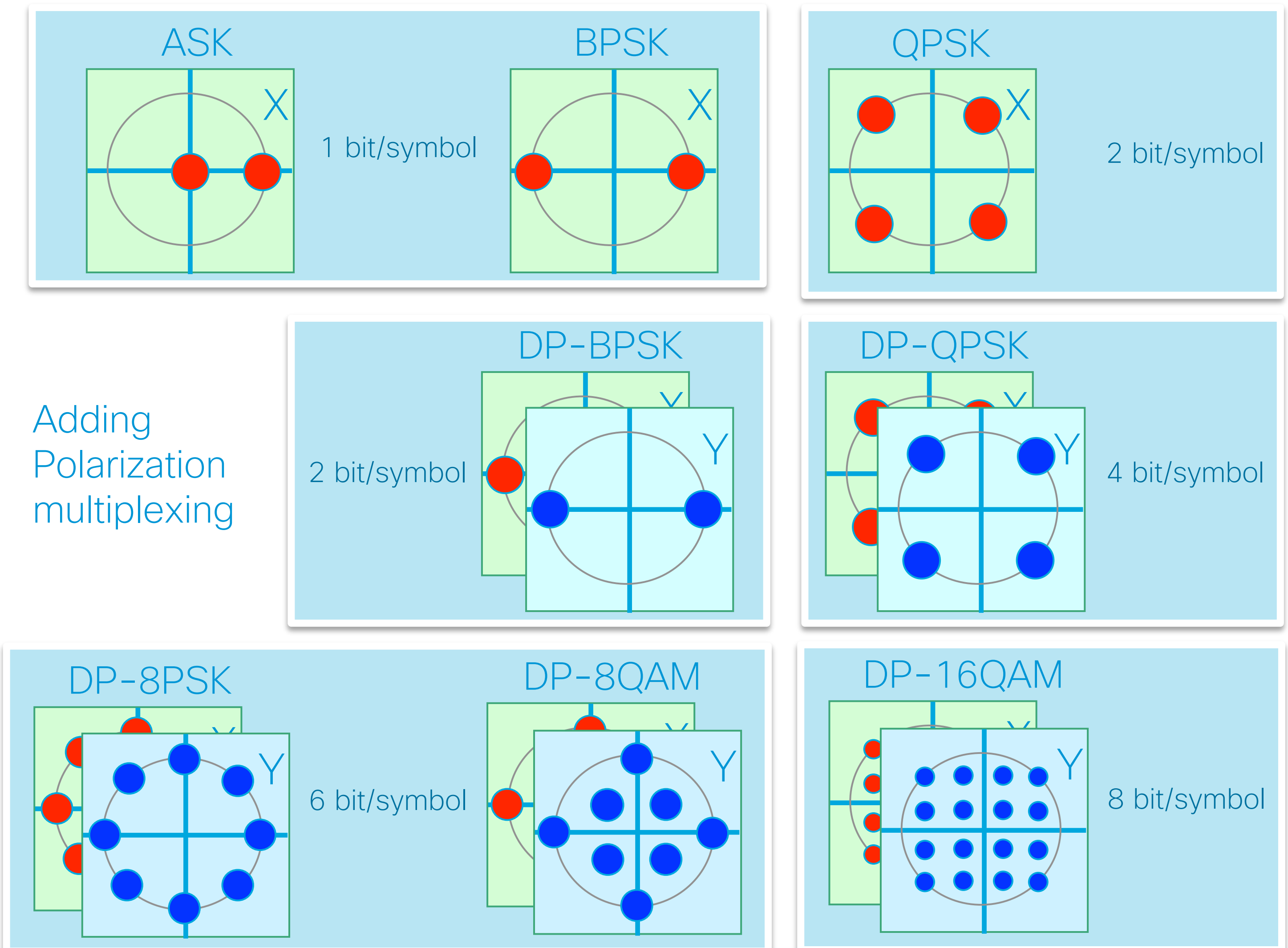
- High power consumption for DSP
- Complex optical components (modulator, coherent receiver)

- Polarization multiplexing PM(or dual polarization DP)
  Transmission of independent signals modulated on two orthogonal polarizations on the fiber

  → **Duplication of spectral efficiency**



Example: ASK


ASK
X
1 bit/symbol
BPSK
X
QPSK
X
2 bit/symbol
Adding Polarization multiplexing
DP-BPSK
Y
2 bit/symbol
DP-QPSK
Y
4 bit/symbol
DP-8PSK
Y
6 bit/symbol
DP-8QAM
Y
DP-16QAM
Y
8 bit/symbol

- CP: Coherent Polarized

  Leverages on Polarization Multiplexing to transmit with Lower Baud Rate (e.g. 40Gbps as 10GBaud)

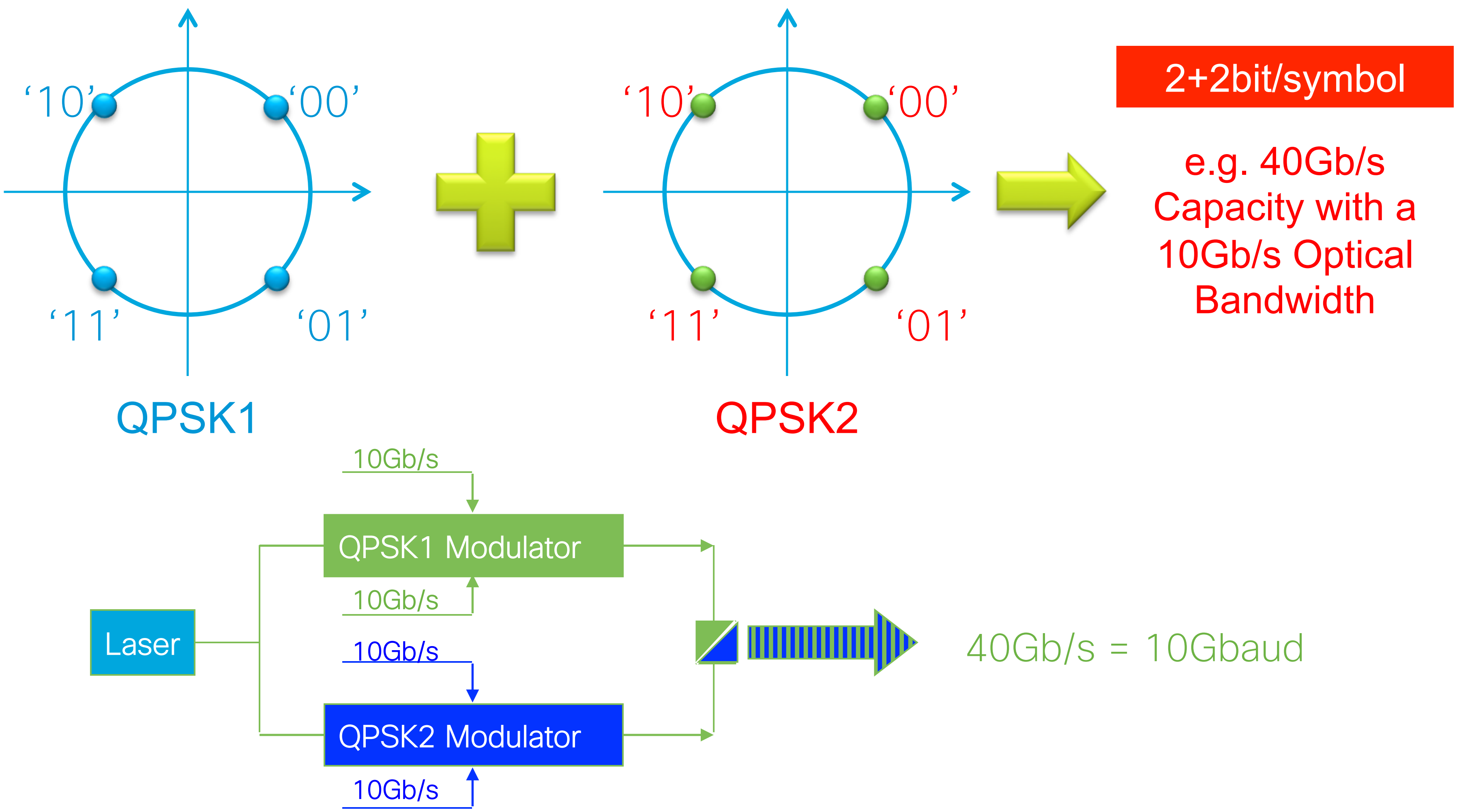
  Leverages on Coherent Detection and Electronic Post-Processing to provide high tolerance to PMD and CD

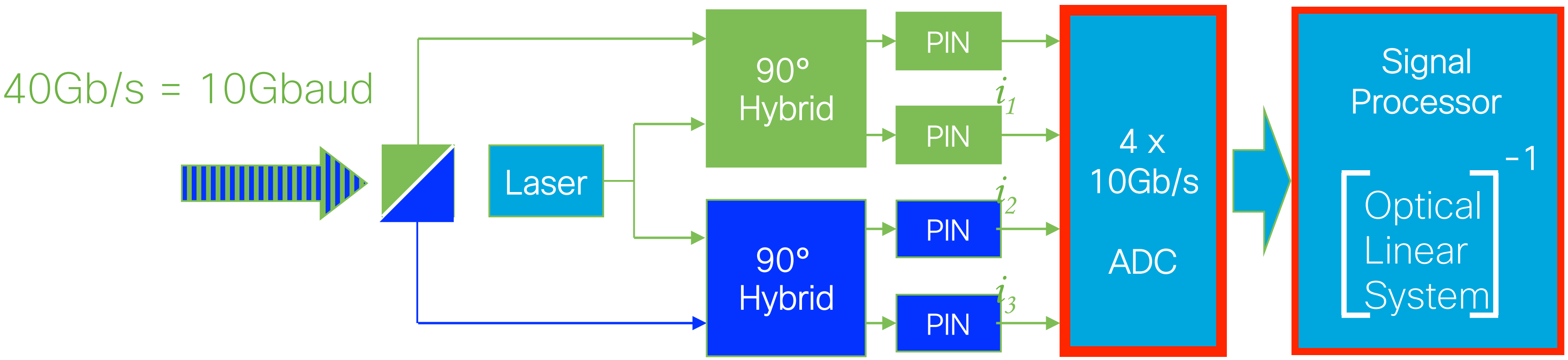
- DQPSK: Differential QPSK

  Differential operating mode provides required system robustness against Laser Cycle Slips

  Laser Cycle Slips can be caused by ASE, Laser Phase Noise and XPM (induced by 10G IM/DD channels)

  Even w/o 10G channels ASE and Laser Phase Noise can cause Laser Cycle Slips


'10'
'00'
'11'
'01'
QPSK1
'10'
'00'
'11'
'01'
QPSK2
2+2bit/symbol
e.g. 40Gb/s Capacity with a 10Gb/s Optical Bandwidth
10Gb/s
QPSK1 Modulator
10Gb/s
Laser
10Gb/s
QPSK2 Modulator
10Gb/s
40Gb/s = 10Gbaud



- RX Laser behaves as Local Oscillator to provide a Polarization reference
- 90° Hybrid:

  Converts Phase modulation in Amplitude modulation

  Provides In-Phase and Quadrature information Φ (i0 , i1)
- Signal Processor:

  Calculates the Inverse Optical System Matrix

  Recovers Polarization

  Compensates CD and PMD electronically

High Chromatic Dispersion (CD) Robustness

- Can avoid Dispersion Compensation Units (DCUs)
- No need to have precise Fiber Characterization
- Simpler Network Design

High Polarization Mode Dispersion (PMD) Robustness

- High Bit Rate Wavelengths deployable on all Fiber types
- No need for “fancy” PMD Compensator devices
- No need to have precise Fiber Characterization

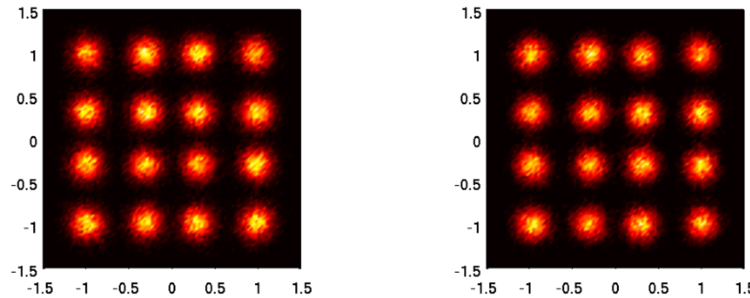
Low Optical Signal-to-Noise Ratio (OSNR) Needed

- More capacity at greater distances w/o OEO Regeneration
- Possibility to launch lower per-channel Power
- Higher tolerance to Channels Interfences

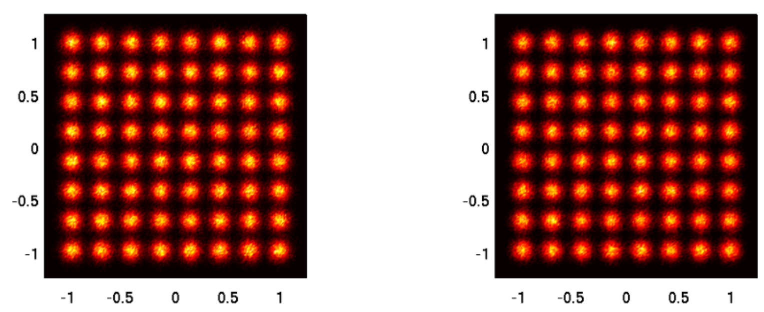
- 40Gbps Wavelengths
  20Gb/s ADC Required @ Receiver
  Optical Bandwidth of ~10GHz
- 100Gbps Wavelengths
  50Gb/s ADC Required @ Receiver
  Optical Bandwidth of ~25GHz
- 1,000Gbps Wavelengths
  500Gb/s ADC Required @ Receiver
  Optical Bandwidth of ~250GHz

Need Extra “Complexity” to address 1,000Gbps Wavelengths

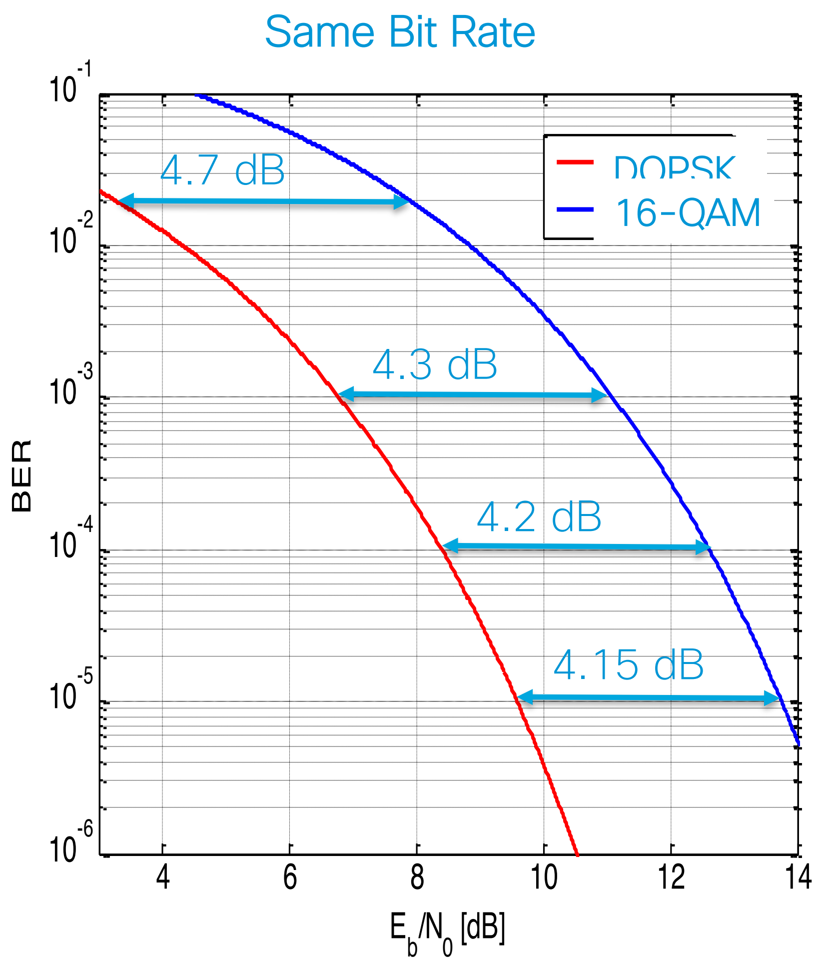
Scattering diagram for CP-16QAM (4+4bit/symbol)



Scattering diagram for CP-64QAM (8+8bit/symbol)



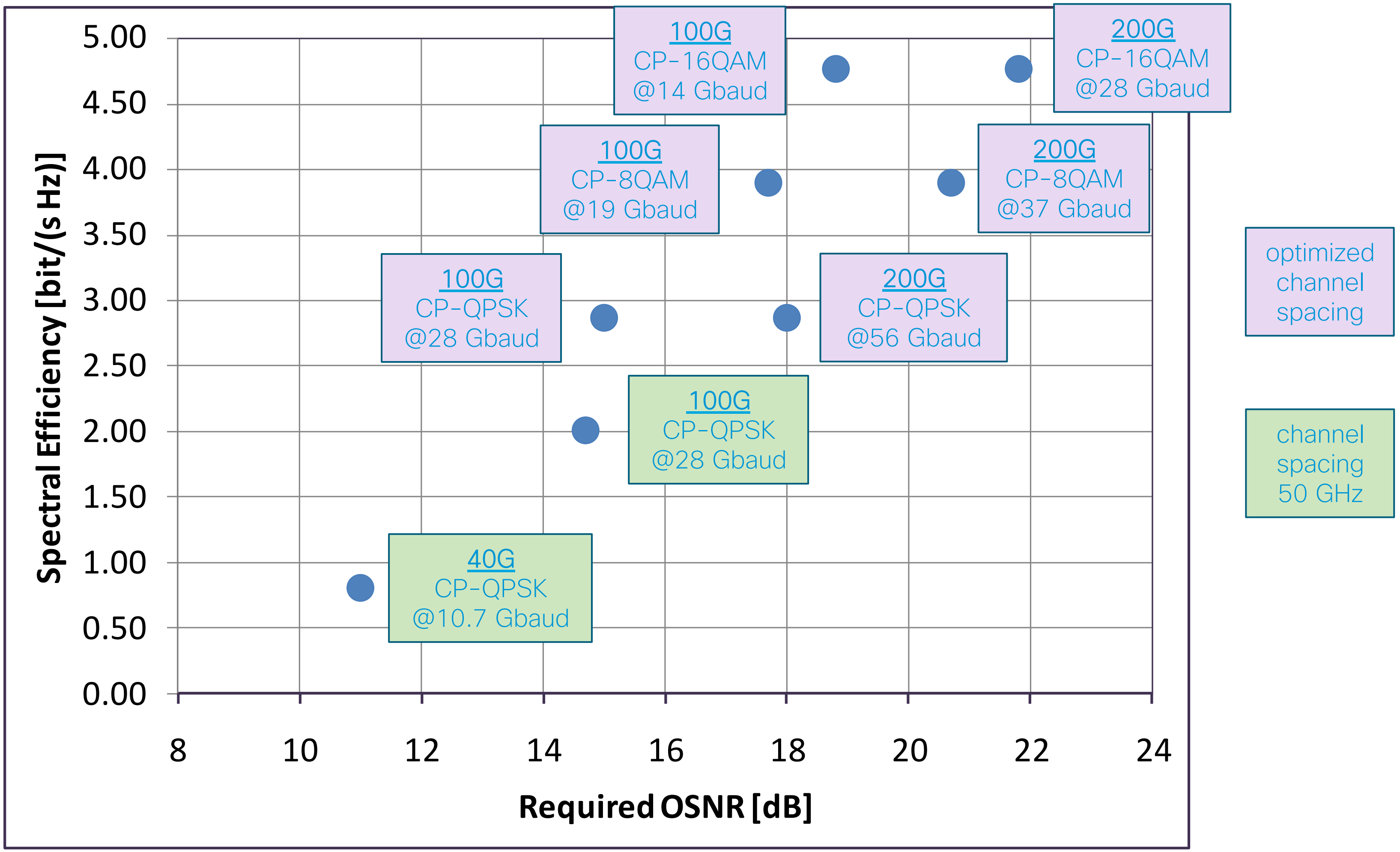
X-pol Y-pol



OSNR Gain of CP-DQPSK vs. CP-16QAM is:

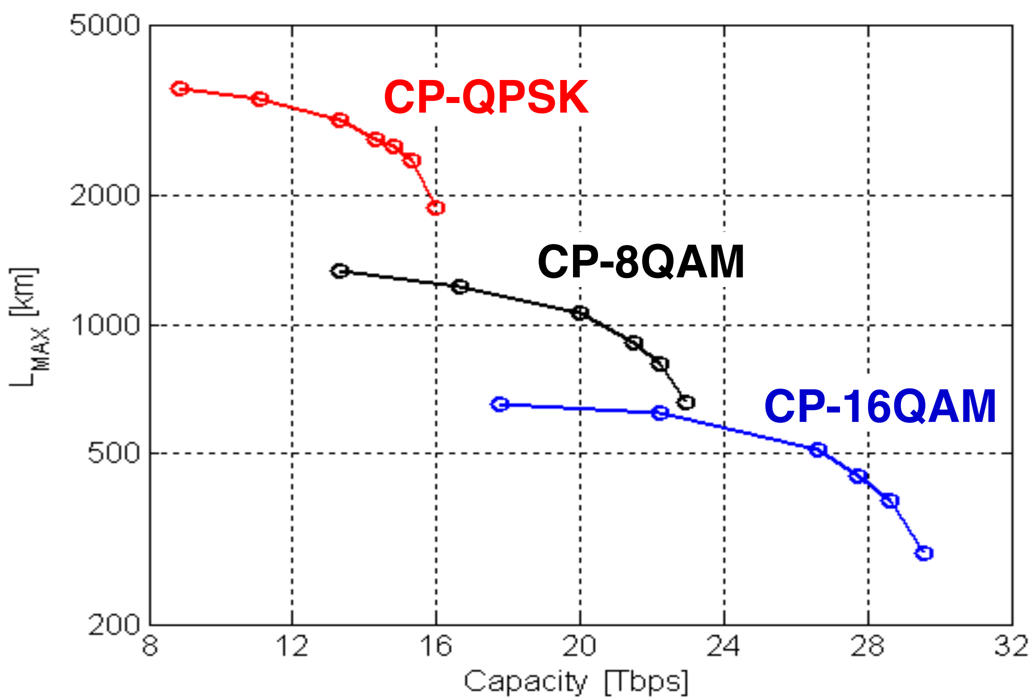
- 4 dB comparing at Constant Bit-Rate
- 7 dB comparing at Constant Baud-Rate

Need a Solution which would NOT sacrifice Reach:
Super-Channel



Assumptions: BER = 1e-3, 7 % FEC OH, differential encoding

SMF – 90 km span length – span loss 25 dB – n x 100Gb/s



- capacity is varied by varying the subcarrier spacing
- curves are limited to the right at (subcarrier spacing) ≈ (Baud Rate)

- Higher modulation format
  - + Higher spectral efficiency
  - + Less optical components per Gbit/s
  - + Higher system density per Gbit/s
  - - Higher ADC resolution necessary
  - - Shorter reach
- Higher symbol rate
  - + Less optical components per Gbit/s
  - + Higher system density per Gbit/s
  - - Higher bandwidth demand on optical components
  - - Higher sampling rate demands
- Higher number of channels
  - + Higher spectral efficiency by closer channel packing
  - - Same amount of optical components per Gbit/s

The solution is optimal combination between

- Modulation format
  - optimized for compromise between reach and spectral efficiency
- Symbol rate
  - optimized to capabilities of optical components and electronic DSP capabilities
- Number of channels required for link capacity

- PROBLEM:

  sending 1 Tb/s over a single carrier is not reasonable

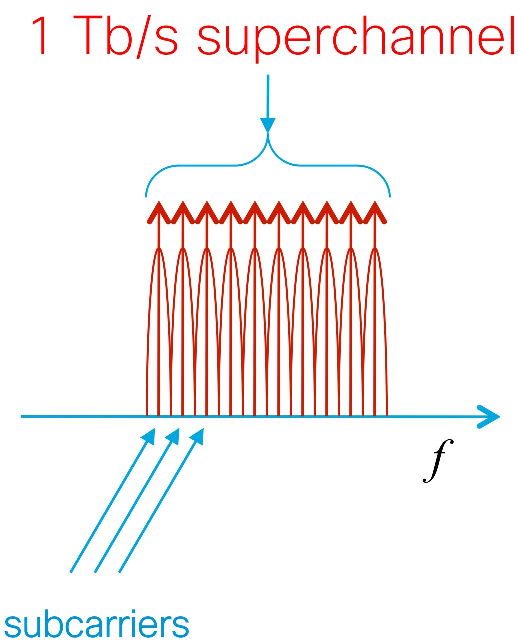
  even with future 100 GS/s ADC technology it would require PM-1024QAM

  → poor sensitivity, phase noise issues, non-linearity impact, hardware problems, very short reach

- SOLUTION:

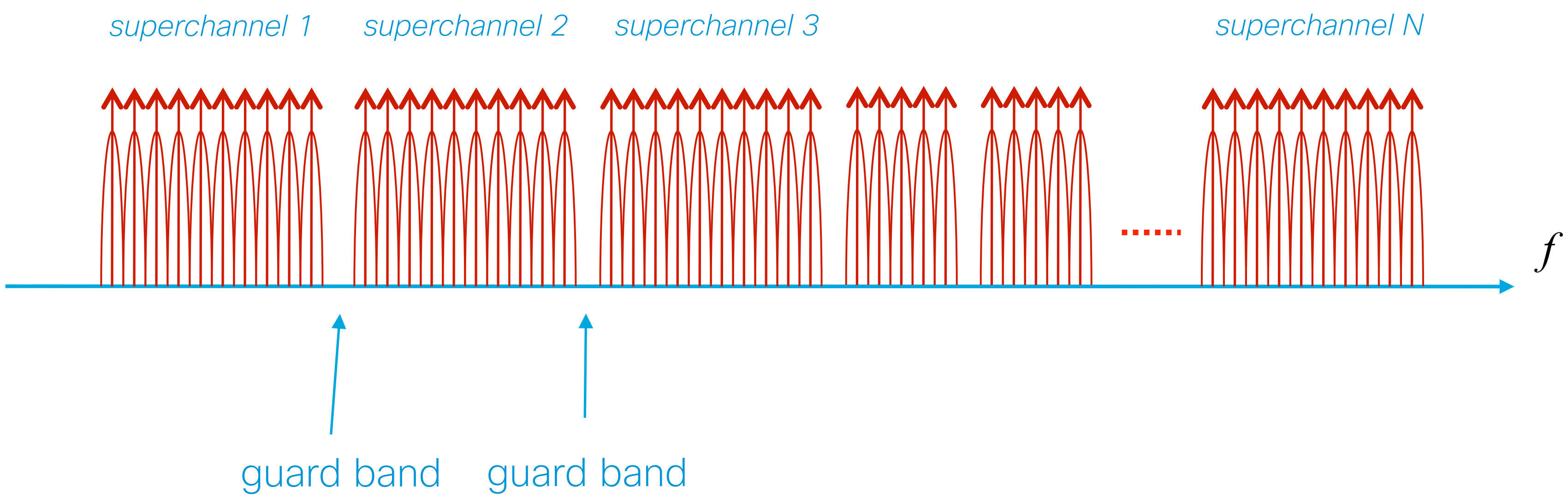
  information distributed over a few subcarriers spaced as closely as possible forming a 1 Tb/s superchannel

  each subcarrier working at a lower rate, compatible with current ADCs and DSPs



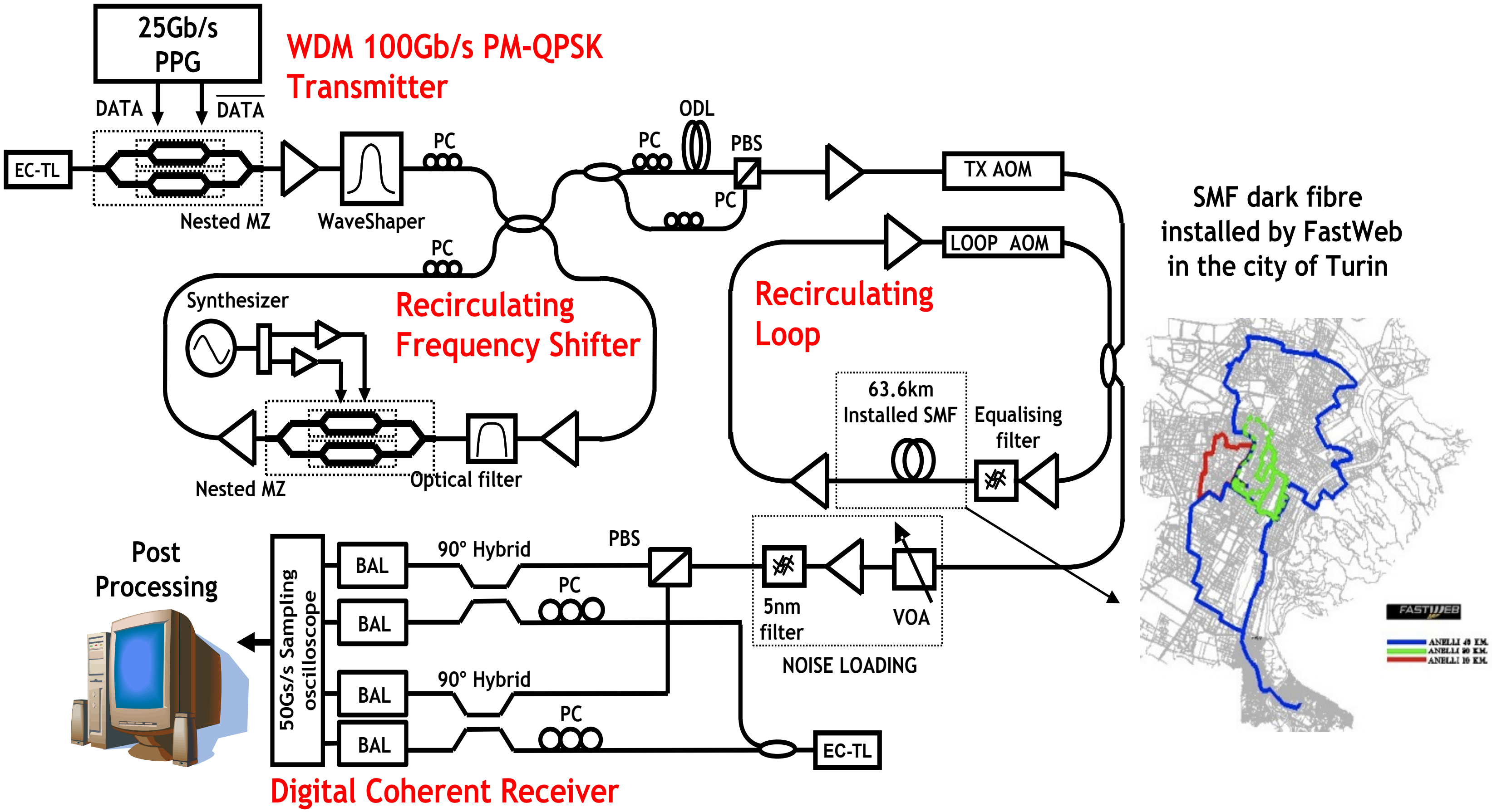
- Each superchannel would form a separate and distinct group, traveling as a single entity across optical cross connects

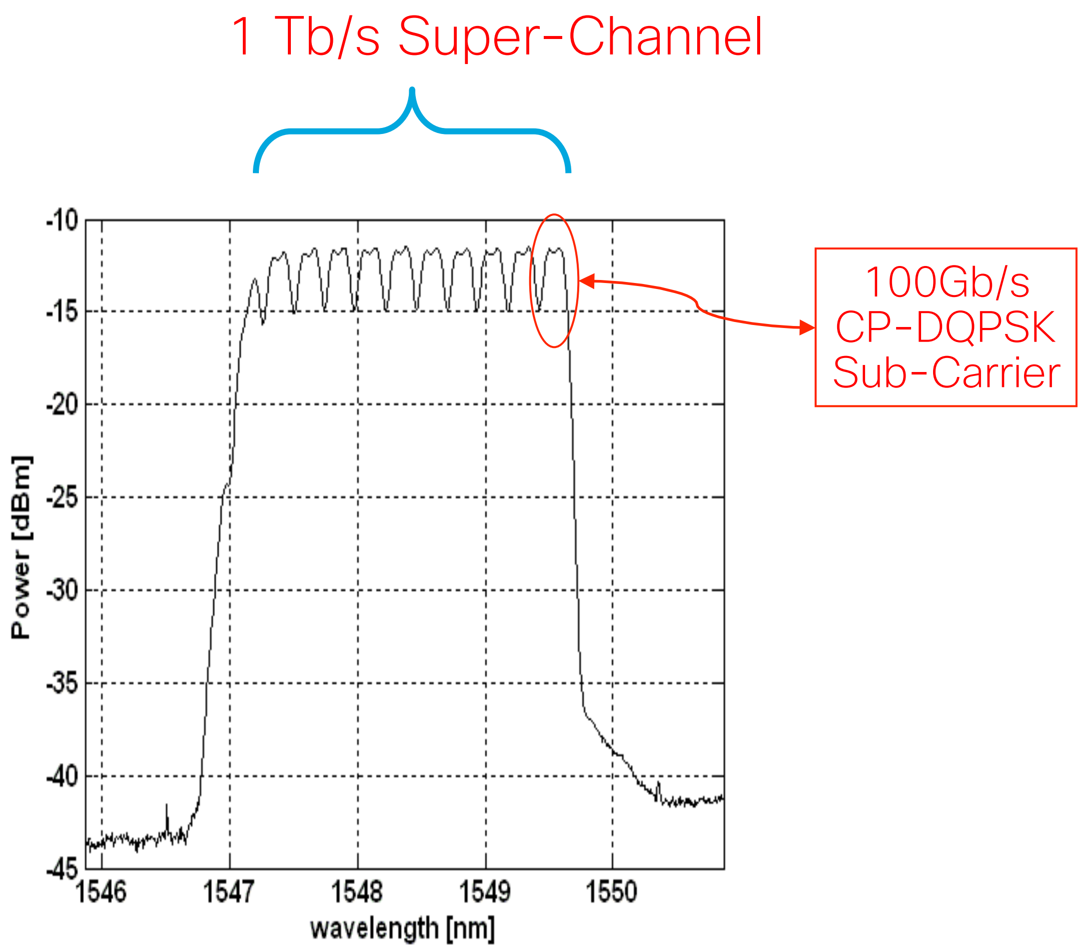
1 Tbit/s superchannels with guard bands



▶ *Design Goals: good transmission performance and bandwidth efficiency*

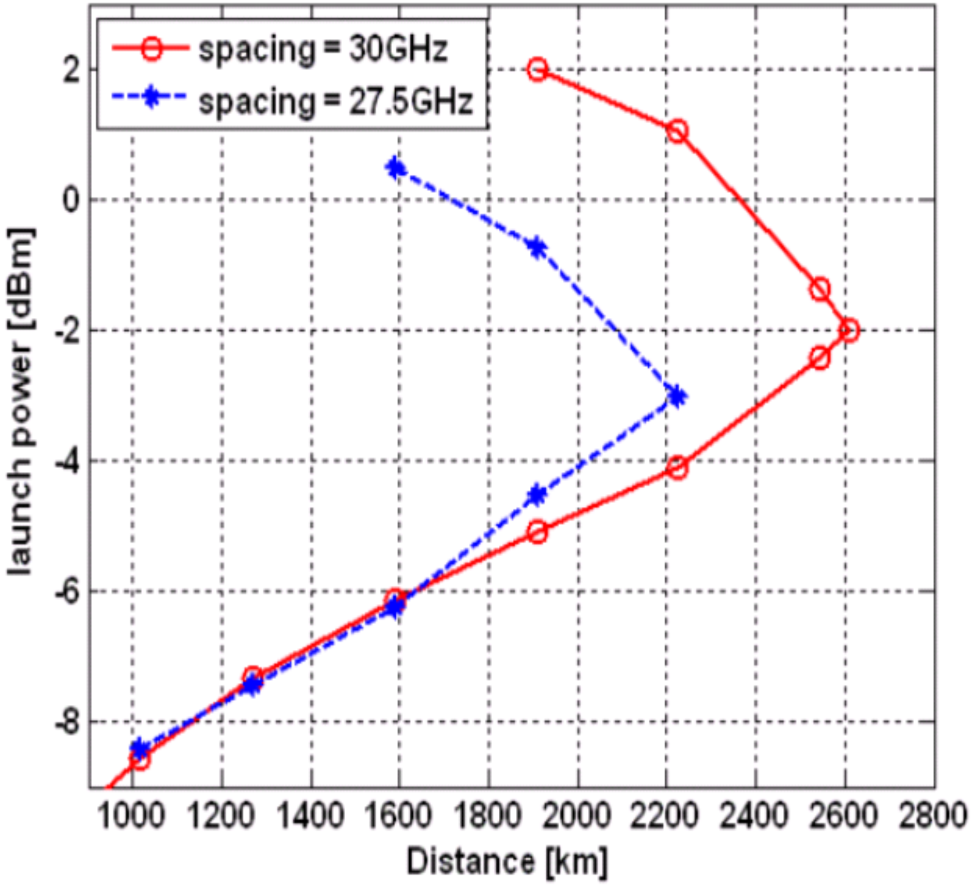
OFC 2010: *"Investigation of the Impact of Ultra-Narrow Carrier Spacing on the Transmission of a 10-Carrier 1Tb/s Superchannel"*



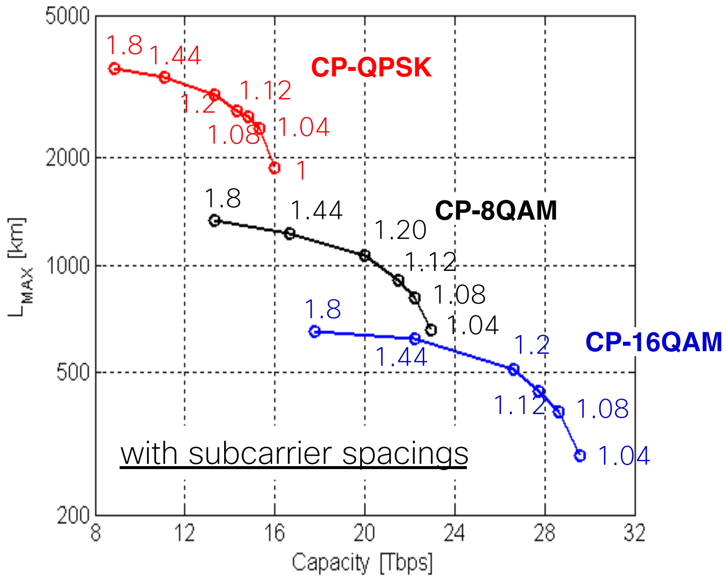


1 Tb/s Super-Channel
100Gb/s
CP-DQPSK
Sub-Carrier
Power [dBm]
wavelength [nm]
-10
-15
-20
-25
-30
-35
-40
-45
1546
1547
1548
1549
1550

→ 41 spans at BER=3e-3 with spacing 1.2
→ 35 spans at BER=3e-3 with spacing 1.1



- Sub-Carrier spacing: 1.2 times the Baud Rate
- Different approaches for 1,000Gb/s:
  - CP-QPSK: 10 Sub-Carriers at 111 Gbit/s each
    - back-to-back sensitivity 12 dB
  - CP-8QAM: 8 Sub-Carriers at 138.75 Gbit/s each
    - back-to-back sensitivity 16.1 dB
  - CP-16QAQM: 5 Sub-Carriers at 222 Gbit/s each
    - back-to-back sensitivity 19.1 dB
- System Configuration:
  - Span of 90km each (ITU-T G.652)
  - Span Insertion Loss: 25dB



- Leverage of existing optical components
  - Modulators and integrated receiver offer efficiently bandwidth capabilities of 28 to 32 Gsymbols/s
- Current ASIC technology makes 55 to 60 GSamples/s implementable

100G
1λ x CP-QPSK
@32 Gbaud

400G
2λ x
CP-16QAM
or
4λ x CP-QPSK
@32 Gbaud

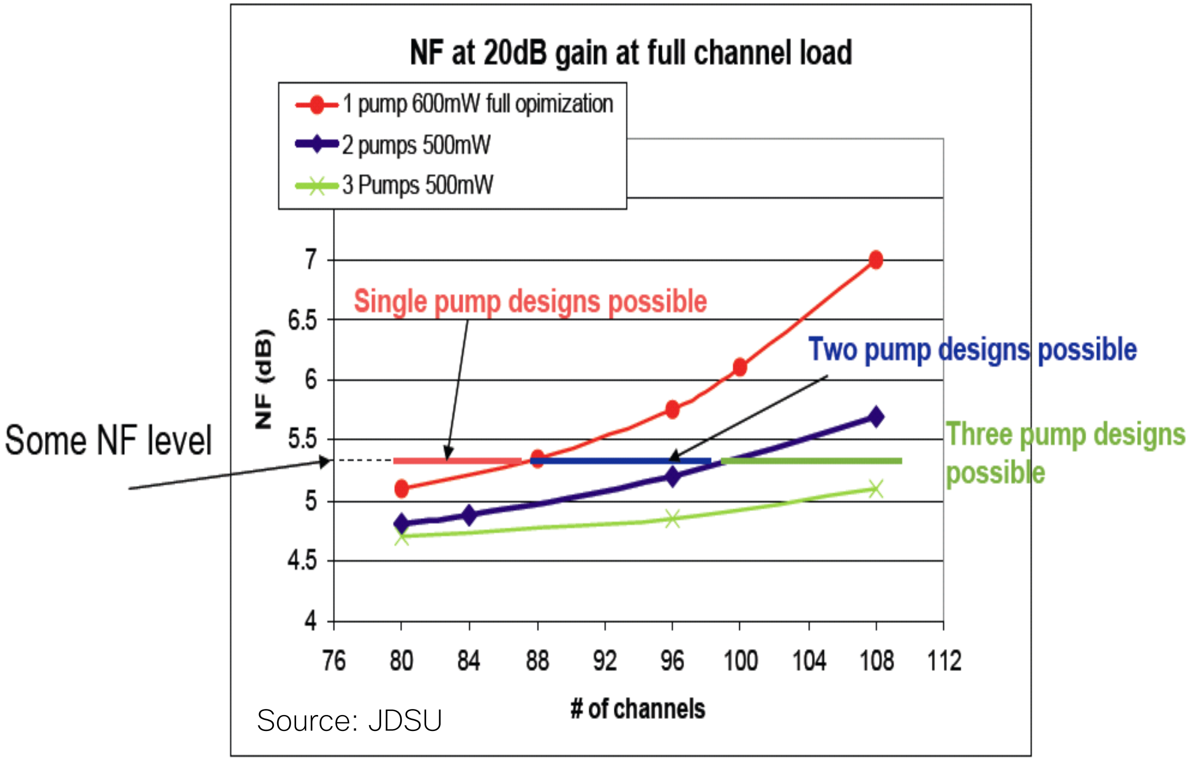
1T
5λ x
CP-16QAM
or
10λ x CP-QPSK
@32 Gbaud

- Reach optimized
- 4 x optical components

- cost, capacity optimized
- 2 x optical components
- reduced reach

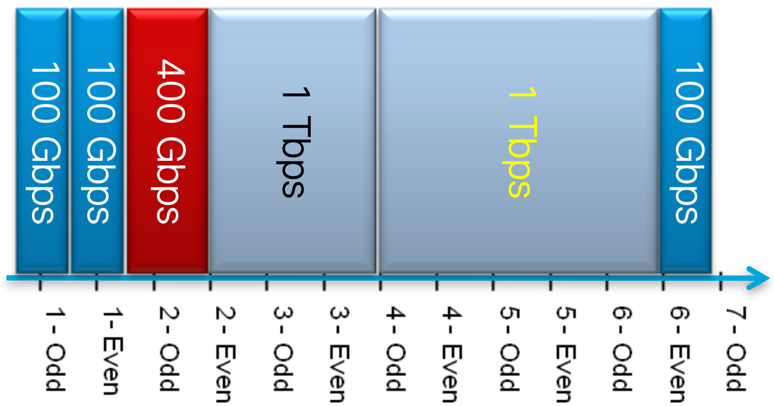
- Virtually all the DWDM Systems deployed in the world leverage on the C-band part of the Optical Spectrum (1530nm – 1560nm)
- L-band Systems are available and have been selectively deployed
- Systems which can combine C-band and L-band on the same fiber pair are available
- Reference number of Wavelength in the C-band is 80 @ 50GHz Channels Spacing

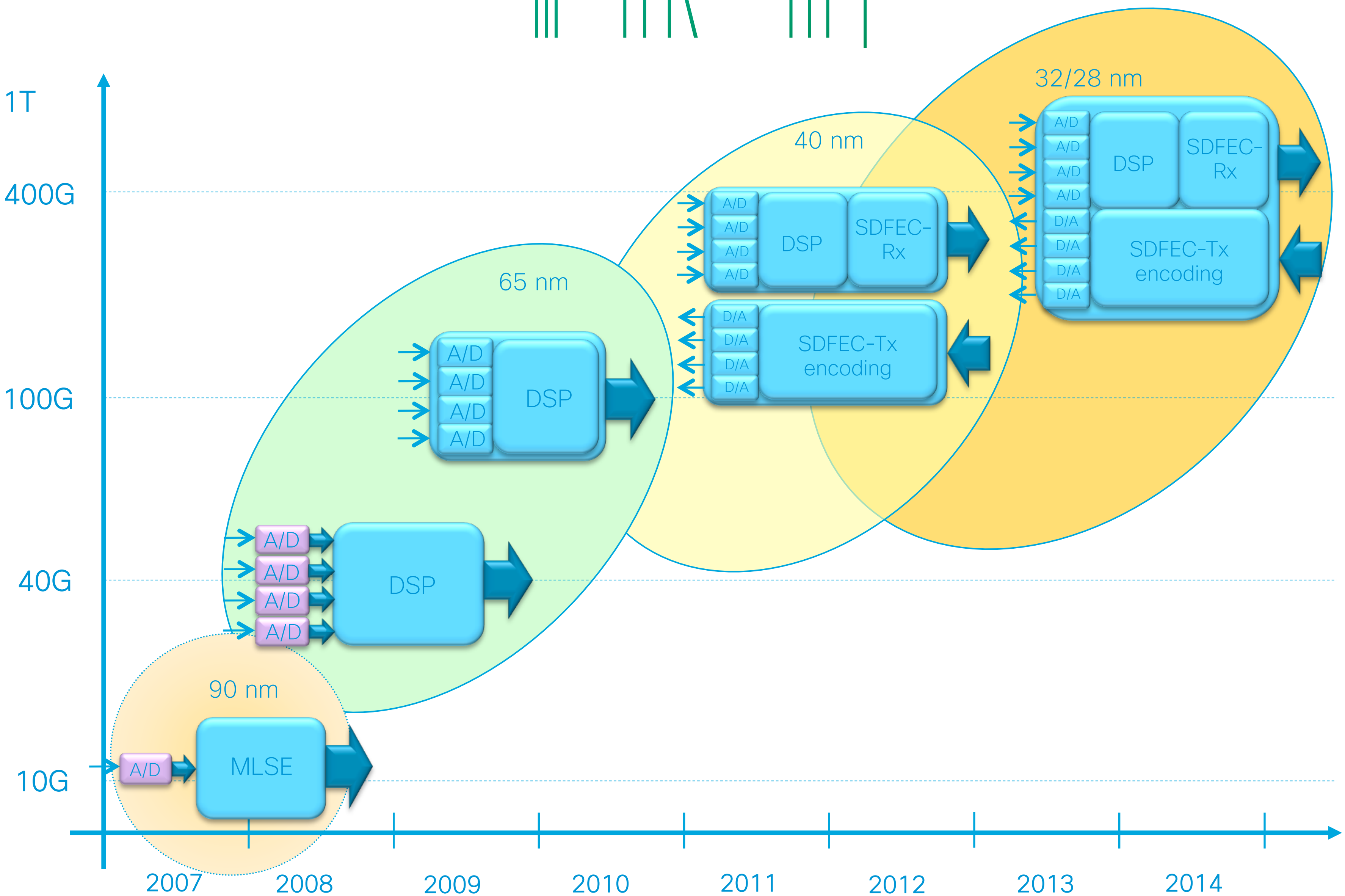
- Would it be Possible / Practical to do more?



- 80Chs @ 50GHz Spacing in the C-Band is NOT a Physical limit
- There is the possibility to grow the Channel Count to 96Chs or more
- Additional Channels add Complexity (Power Consumption, Space, Cost) to the Amplifier

- Not all the Systems are created equal
- Different Modulation Formats allows to trade Capacity for Reach
- A **Flex Spectrum DWDM System** removes ANY restrictions from the Channels Spacing and Modulation Format point of view
  - Possibility to mix very efficiently wavelengths with different Bit Rates on the same system
  - Allows scalability to higher per-channel Bit Rates
  - Allows maximum flexibility in controlling non-linear effects due to wavelengths interactions (XPM, FWM)
  - Allows support of Alien Multiplex Sections through the DWDM System




1T
400G
100G
40G
10G
2007
2008
2009
2010
2011
2012
2013
2014
90 nm
A/D
MLSE
65 nm
A/D
DSP
40 nm
A/D
DSP
SDFEC-Rx
D/A
SDFEC-Tx encoding
32/28 nm
A/D
DSP
SDFEC-Rx
D/A
SDFEC-Tx encoding

- Coherent Optical Transmission allows today to support 40Gbps wavelengths → 3.2Tbps (80chs @ 40G each) over 3,000Km
- Evolution of FEC and DSP Chips will allow transport of 100Gbps wavelengths at about the same Distance → 8.0Tbps over >2,500Km
- 1,000Gbps per wavelength will require yet another “technology migration” to be usable but is expected to allow about 12.0Tbps over >1,500Km

- The next phase of innovation in the optical networking will be driven by sophisticated modulation formats and advanced DSP technologies
- Cisco will continue to invest in the 40G, 100G and beyond DSP technologies with the objective of maintaining innovation across our portfolio
- Optical interfaces are a key part of our customer's network growth in both the optical and routing domains
- Service Providers need cost effective and architecturally efficient solutions to deal with demands created by video and mobility applications

Thank you.

CISCO

Core Evolution

Core Challenges

1. Core Packet Bandwidth Requirements
2. Support for sub-lambda legacy clients
3. Overall Cost structure of IP networks

(Items 1 and 2 bracketed:) 100G DWDM upgrade

Core Bandwidth Requirements and Legacy Services

Today: 10G DWDM Systems

- Packet solutions consuming multiple 10G lambdas
- SONET/SDH Client Systems → 10G with no plans or need for additional capacity

Fibre Exhaust and Client Demand Issues

40G and 100G DWDM to support Packet Services

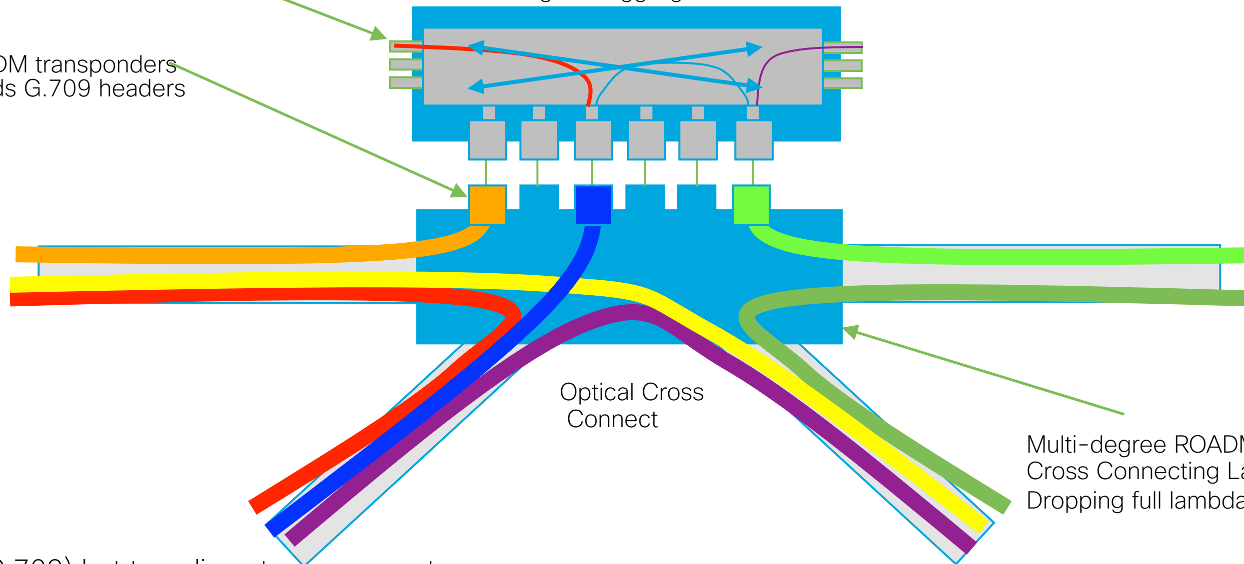
- How to support 10G systems

10G and 100G DWDM coexistence

OR

Full OTN Hierarchy

Optical Transport Network (OTN)



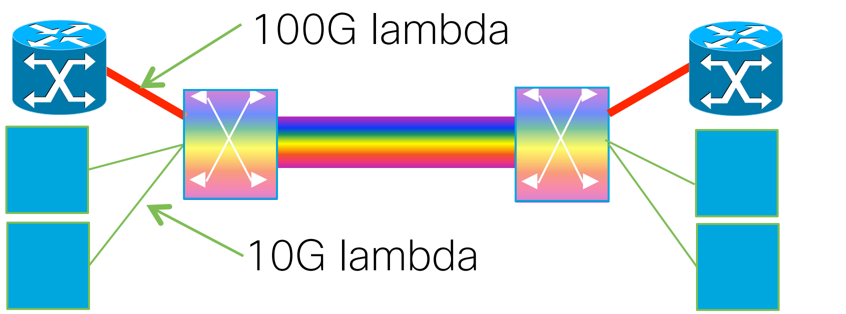
- Single Standard (G.709) but two discrete components
  - Photonics and Electronics
  - Multiple versions (up to v3)

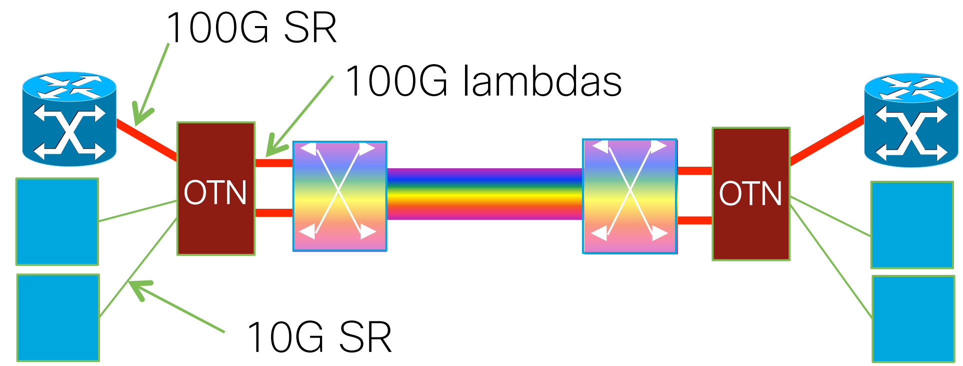
- Digital Wrapper
  - Opti-electrical and optical components : Transponders and ROADM
  - Header information for management of optical layer
  - Forward Error Correction for increasing optical drive distances

- OTN Hierarchy and Cross Connecting

The major debate is on the role of OTN Cross Connecting in a world dominated by packet traffic

Solutions for Implementing 100G DWDM

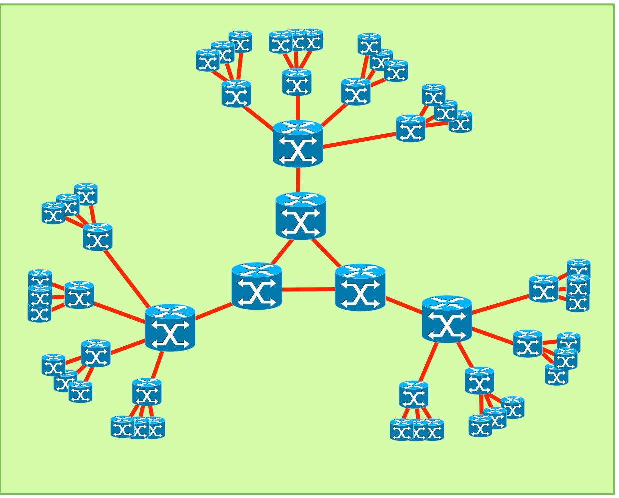




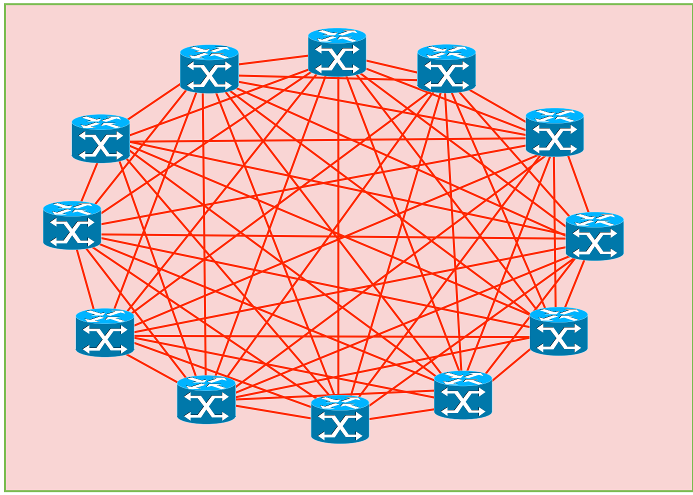
<u>10G and 100G DWDM Coexistence</u>	<u>OTN Multiplexing</u>
▪ 10G and 100G lambdas co-exist on same fibre ▪ Packet uses 100G, everything else 10G	• All lambdas upgraded to 100Gbps • Sub-100G services provided by OTN OEO
<u>Advantages</u> Only high demand clients upgraded to 100G Protects existing 10G DWDM investment Lowest cost per bit (100G TXPs>10 x10G TXPs)	<u>Advantages</u> All lambdas on a fibre are 100G
<u>Disadvantages</u> Need a guard band between 10G and 100G frequencies Not appealing in ULH environments	<u>Disadvantages</u> 100TXP investment upfront Need an additional OTN OEO All 10G TXPs are obsolete

Building Cost Effective IP networks

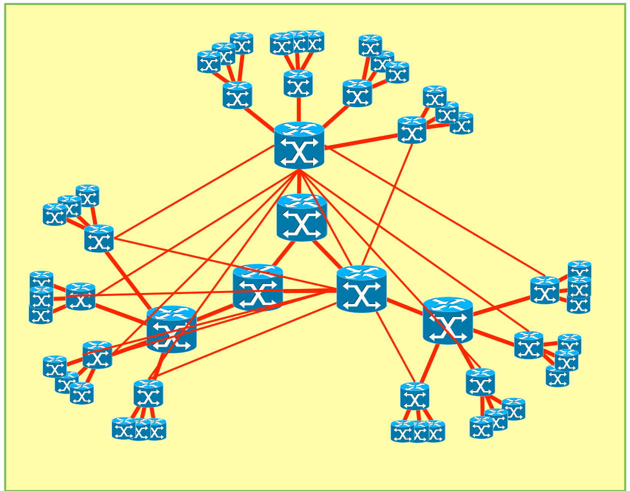
Hierarchical



Hollow (OTN based)



High Bandwidth Photonics Bypass



Simple operational model

Utilise agile photonics layer

Cost optimised

Photonics level switching

Reduces Opti-electrical components

Reduces OEOs

Thank you.