TRIDENT SUBSEA CABLE

Submarine Transmission

Where Physics beats Standards

Trident Cable System

Subsea Optical fibre cable

Four fibre-pairs, 3570km

~ 45 amplifiers in path

10 Tbps Perth-Singapore

~~16-24~~ 20-30 Tbps Perth-Jakarta

Relies on non-standard optical technology

Outline

- Standards
- Optical Transmission Standards (with no applications)
- Recent Long-Haul Optical Transmission Reality (Non Standards!)

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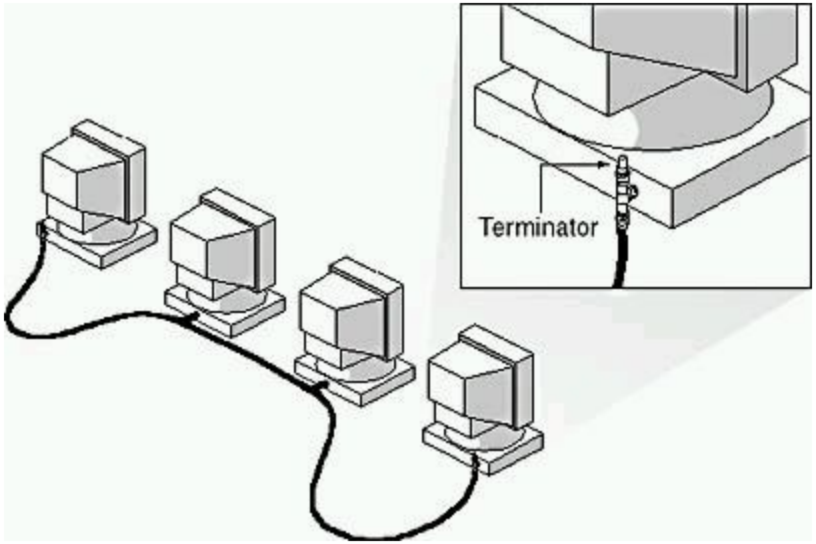
A standard - IEEE 802.3 (Ethernet)



- Originally 10Base5
- 10Base2 – IEEE802.3a (1985)

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Optical Fibre Ethernet

MMF SMF

1993 - 10BaseF – 10Mbps

1995 – 100BaseFX “Fast Ethernet”

1998 – 1000Base-X “Gigabit Ethernet”

2002 – 10GBASE-(SR/LR/ER) “10GigE”

- “-ZR” (80km) ? Non-standard vendor
- “-BX” single-fibre? Non-standard vendor
- LAN PHY – 10.313 Gbps “traditional” framing
- WAN PHY – 9.953 Gbps, SDH STM-64 framing

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Optical Fibre Ethernet

1993 - 10BaseF – 10Mbps

1995 – 100BaseFX “Fast Ethernet”

1998 – 1000Base-X “Gigabit Ethernet”

2002 – 10GBASE-(SR/LR/ER) “10GigE”

1000x speed in 9 years

8 years later….

2010 – 40G/100GBase.XXX Ethernet

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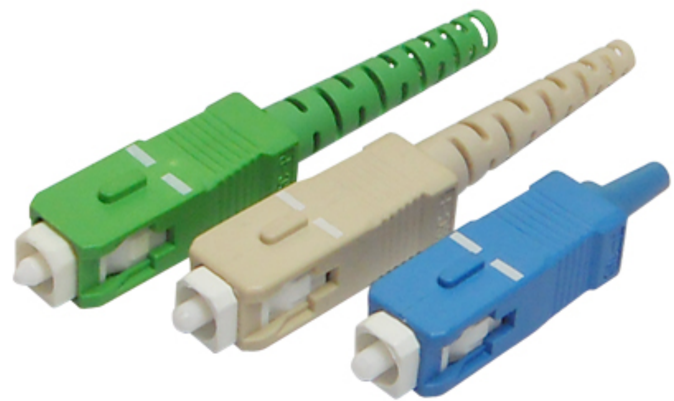
(So Many Standards to choose from…)



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40GbE / 100 GbE

Distance	Medium	40G Ethernet	100G Ethernet
1 m	Backplane	40GBASE-KR4 4 x 10.3125 Gbit/s	
10 m	Coax cable	40GBASE-CR4 4 x 10.3125 Gbit/s parallel coax cable	100GBASE-CR10 10 x 10.3125 Gbit/s parallel coax cable
100 m	MMF	40GBASE-SR4 4 x 10.3125 Gbit/s, 0.8 µm parallel ribbon fiber	100GBASE-SR10 10 x 10.3125 Gbit/s, 0.8 µm parallel ribbon fiber
10 km	SMF	40GBASE-LR4 4 x 10.3125 Gbit/s, 1.3 µm CWDM (20-nm spacing)	100GBASE-LR4 4 x 25.78125 Gbit/s, 1.3 µm LAN-WDM (5-nm spacing)
40 km	SMF		100GBASE-ER4 4 x 25.78125 Gbit/s, 1.3 µm LAN-WDM (5-nm spacing)

MMF: multi-mode fiber
SMF: single-mode fiber
CWDM: coarse WDM
LAN: local area network

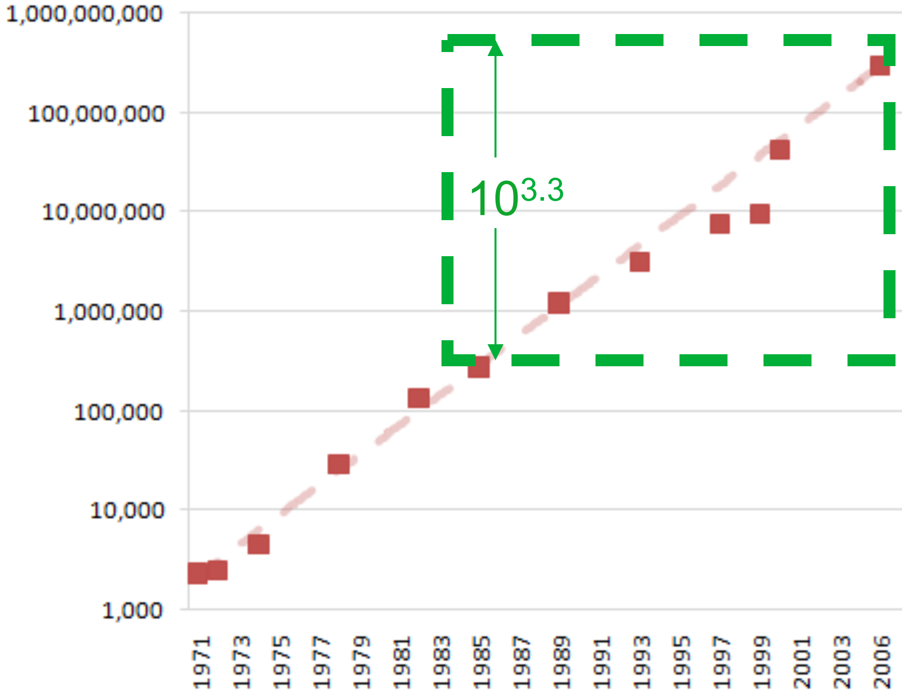
Multiple Parallel 10Gb channels

MMOF requires multiple fibres

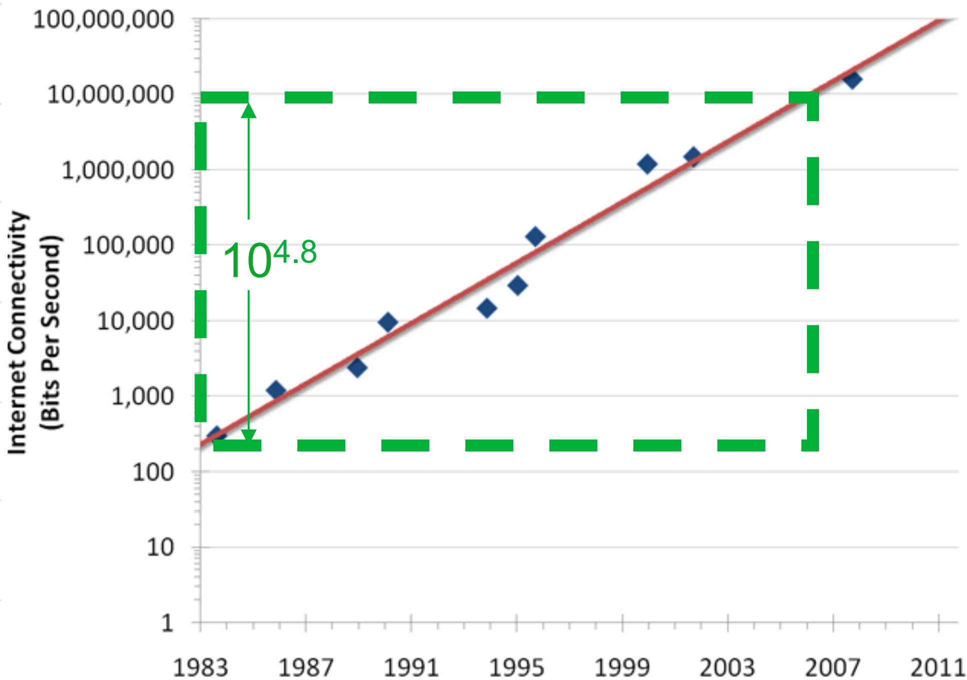
No long-range 40G - datacentres and server connect only

100GbE not compatible with DWDM

Why multiple lanes?



Moore's Law
Transistor count doubles every 24 months



Nielson's Law
Link Capacity doubles every 18 months

Bandwidth Requirement outstrips
Moore's Law by over 30 times!
Electronics scaling slowly

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Why multiple lanes?

10Gbps is FAST!

Speed of Light (in glass)?

Only 20 cm per nanosecond
0.2 mm per picosecond

Bitrate	Bits/metre	Bit time
10Gbps	54.8	91 ps/18.2 mm
40Gbps	220	22.7 ps/4.5mm

Desktop CPUs: ~2-3GHz limit per core then 2/4/8 cores
On/Off Lasers: ~10GHz-25GHz per lane then multi lanes

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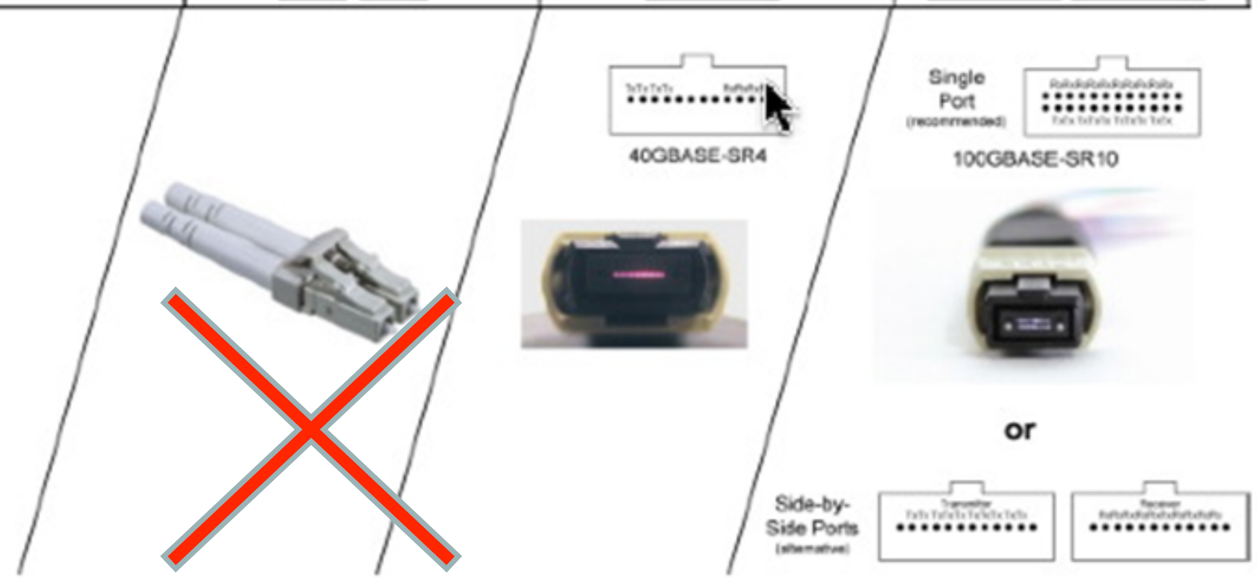
New Multimode Cabling &

IEEE 802.3 Ethernet Channel Layout

Data Rate	10Gb/s	40Gb/s	100Gb/s
Laser Type	VCSEL	VCSEL Array	VCSEL Array
Fiber Type	OM3	OM3/OM4	OM3/OM4
Connector	LC x 2	12-fiber MPO	2x12f MPO or 1x24f MPO
# of Fibers	2	12	24
Schematic			



Etherealmind.com

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400G Ethernet

8 years later…~2017/8 – IEEE802.3bs 200GE & 400GE

100m MMF	25G NRZ x16 fibers		
500m SMF			1λ x 100G PAM4 x4 fibers
2km SMF		8λ x 50G PAM4 x1 fiber	
10km SMF		8λ x 50G PAM4 x1 fiber	

Selected

"x1 fibers" uses 2 fibers total (1 in each direction)
"x4 fibers" uses 8 fibers total (4 in each direction)
"x16 fibers" uses 32 fibers total (16 in each direction)

MMF – 32 fibres (16 in each direction) – another new MPO connector/cable

SMF within datacentre – 8 fibres, new PAM4 signal format

SMF "longhaul" – only 10km max. Formats incompatible – no interconnect with attenuators

NO 40km option - Incompatible with DWDM long-haul

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Standards Bumping into Physics

- 25-50 Gbaud pushes boundary of physics and opto-electronic interfaces – any more increase is from parallelization and multiple lanes
- Pace of Ethernet standards has slowed – from 1000x/9yr to 10x/8yr to 2-4x/8yr
  - But Nielsen's Law is not slowing down!
- No capacity benefit to Structured Cabling – still only 10G/fibre MM, 100G/fibre SM. MPO connectors difficult to break out.
- Adding latency – every 100G+ link requires FEC (Forward Error Correction) & re-alignment of parallel signals before combining - ~20-30 microseconds per link

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Ethernet Irony!

Every Ethernet segment is now…

Point-to-Point Full Duplex

One transmitter, One receiver per "wire"

No Collisions!

Ethernet has evolved to make CSMA/CD superfluous!

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Intercontinental Capacity

Long-haul Optical

- Each fibre core is expensive – requires many amplifiers, repeaters, and power
- Very low fibre-count – 2,4,6 pairs.
- Big $$$ on terminal equipment to maximise throughput per pair using DWDM techniques
- 40 – 80 amplifiers means high attenuation, low SNR, close to noise floor

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Submarine Channel Capacity

Capacity per wavelength	Year	Cable
2.5 Gbps	1995-2000	various
10 Gbps	2000-2010	Japan-US, AJC
40 Gbps	2011	APCN2 upgrade
100 Gbps	2012-	SCCS upgrade, FASTER, many
200 Gbps	(trial 2014)	(Japan-US 630km segment)

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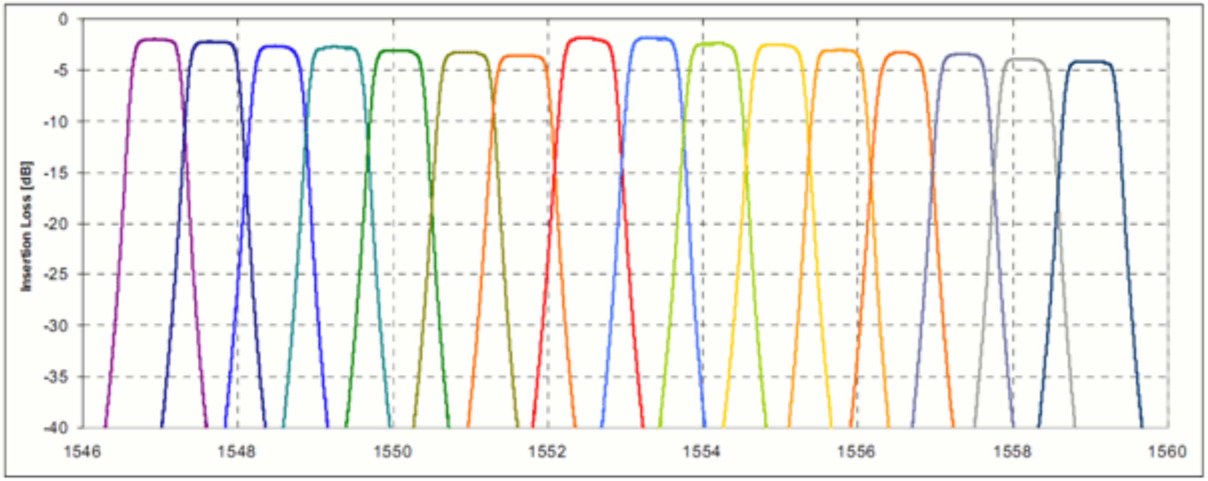
Multiple Channels

- **ITU-T G.694.1 Spectral Grids for DWDM**



- Defined ~80 channels, 50 GHz spacing

80 x 10 Gbps = 800 Gbps per fibre-pair

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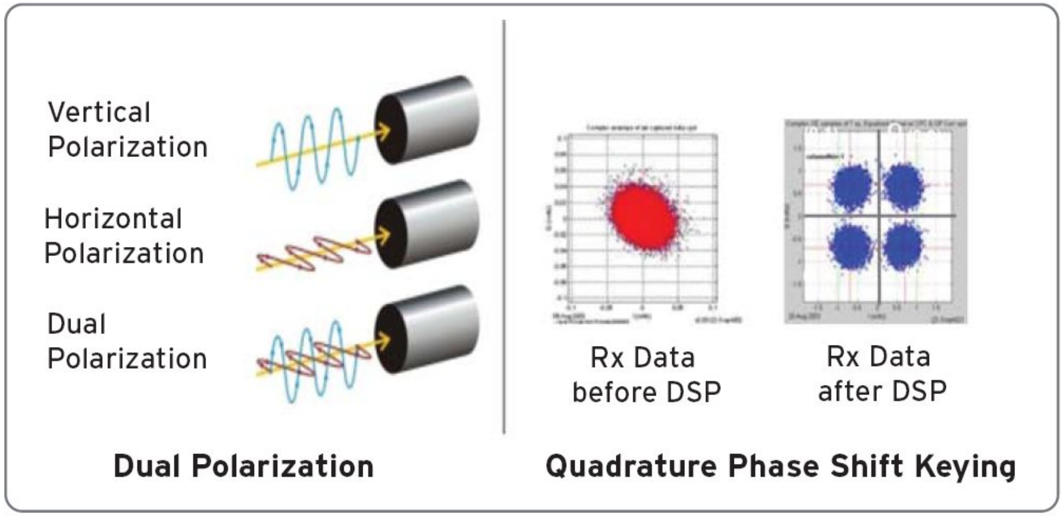
Long Haul 100G

- Line coding developed by Nortel – **DP-QPSK** – adopted by OIF (Optical Interworking Forum)
- Combine 2 separate parallel signals
- ~112 Gbps from 2x 25 - 28 Gbaud per sec carriers



No interoperable standard

- Works through existing 50 GHz DWDM equipment
- More robust than 40Gbps NRZ (On-Off-Keying)
- shipping equipment from 2010
- Completely different from 100G Ethernet signalling

80 x 100 Gbps = 8 Tbps per fibre-pair

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100Gbps – Non-Standard!

- ITU-T G.959.1 OTN Physical Layer Interfaces (2012)

Class	Speed
OTU-1	2.5 Gbps
OTU-2	10 Gbps
OTU-3	40 Gbps

- No 100Gbps physical interface defined!

No standard (use 100GbE)

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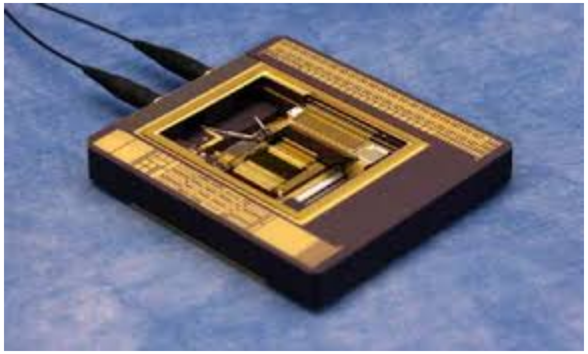
Coherent Detection

- ~2010 dedicated DSP processors became fast enough to directly process optical signal
- Software correction for Chromatic & Polarisation Dispersion
- Locked-Laser frequency vastly better noise rejection & sensitivity
- Instantly enabled jump from 10Gbps to 100 Gbps



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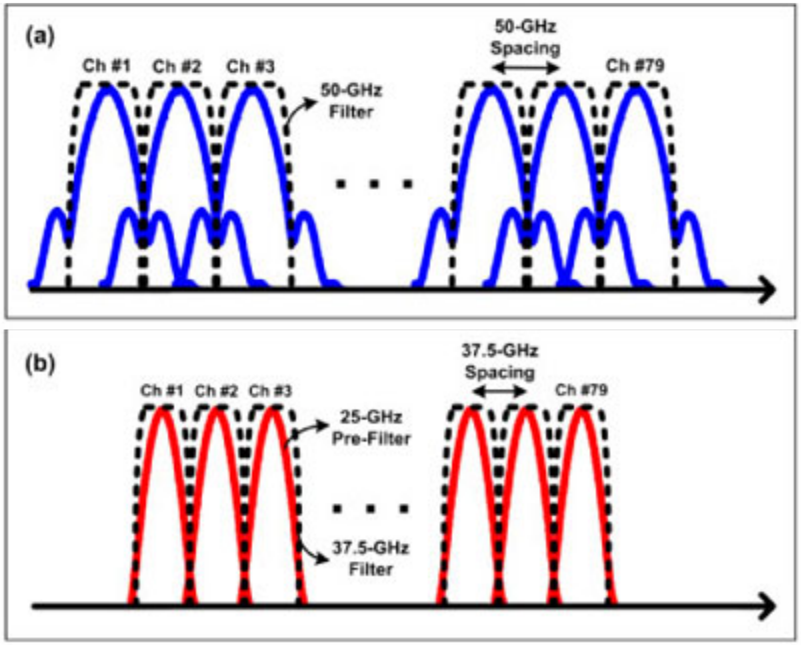
Narrower Channels

Re-paint the lane-lines – squeeze channels into 37.5 GHz spacing

- ~~80~~ (+25%) 100 channels in the same spectrum band

100 x 100 Gbps = 10 Tbps per fibre-pair

Non-standard



...DM system scenarios with 79x224-Gb/s RZ-DP-16QAM channels. (a) 50-GHz ch...
(b) 25-GHz optical pre-filtering and 37.5-GHz channel grid.

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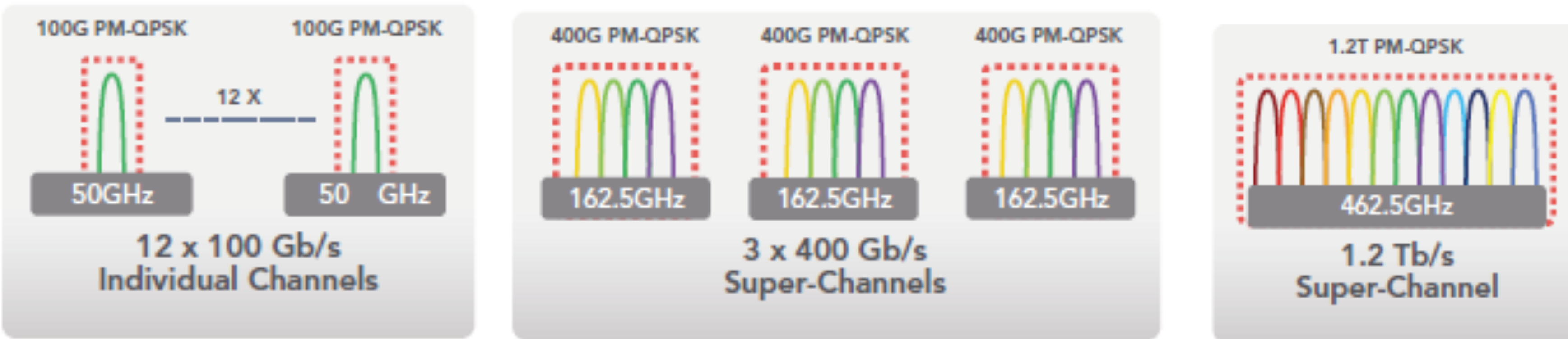
Wider 'Superchannels'

Combine adjacent channels to carry higher bit-rates in less spectrum



600 GHz | 488 GHz | 462.5 GHz

- 400Gbps in (2x50) 100GHz superchannel

40 x 400 Gbps = 16 Tbps per fibre-pair

Non- standard!

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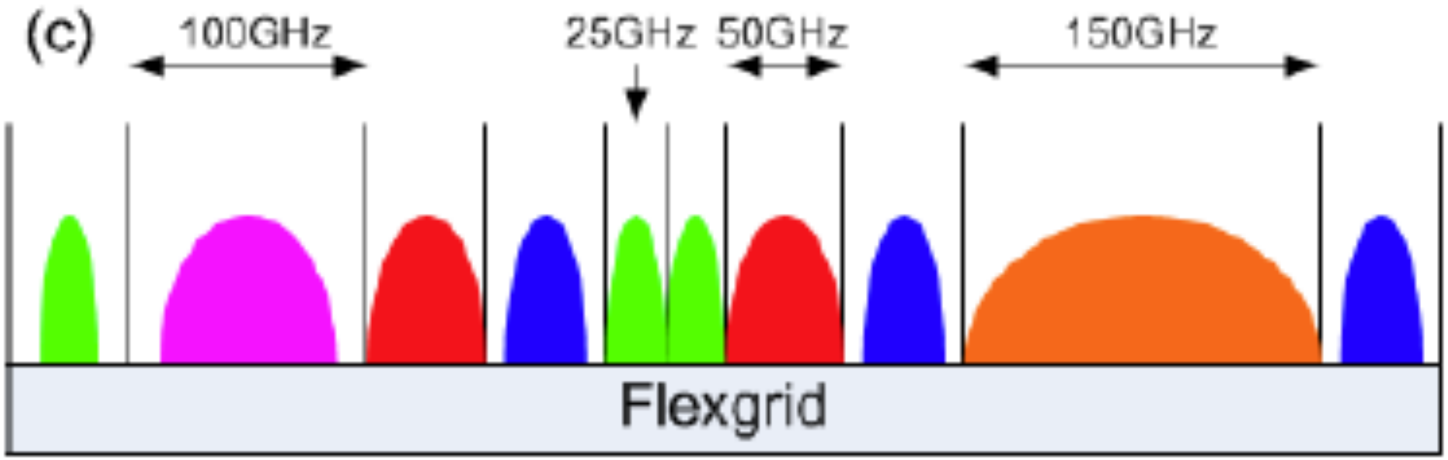
Infinera White Paper - https://www.infinera.com/wp-content/uploads/2015/07/Infinera-WP-Evolution_of_Next-Gen_Optical_Networks.pdf#page=9&zoom=auto,-12,499

More Channels

- **ITU-T G.694.1 Spectral Grids for DWDM**



- 37.5Ghz channels & superchannels completely non-standard….
- …until Feb 2012 Edition 2 defined 'Flexible Grid' on 12.5 GHz granularity.

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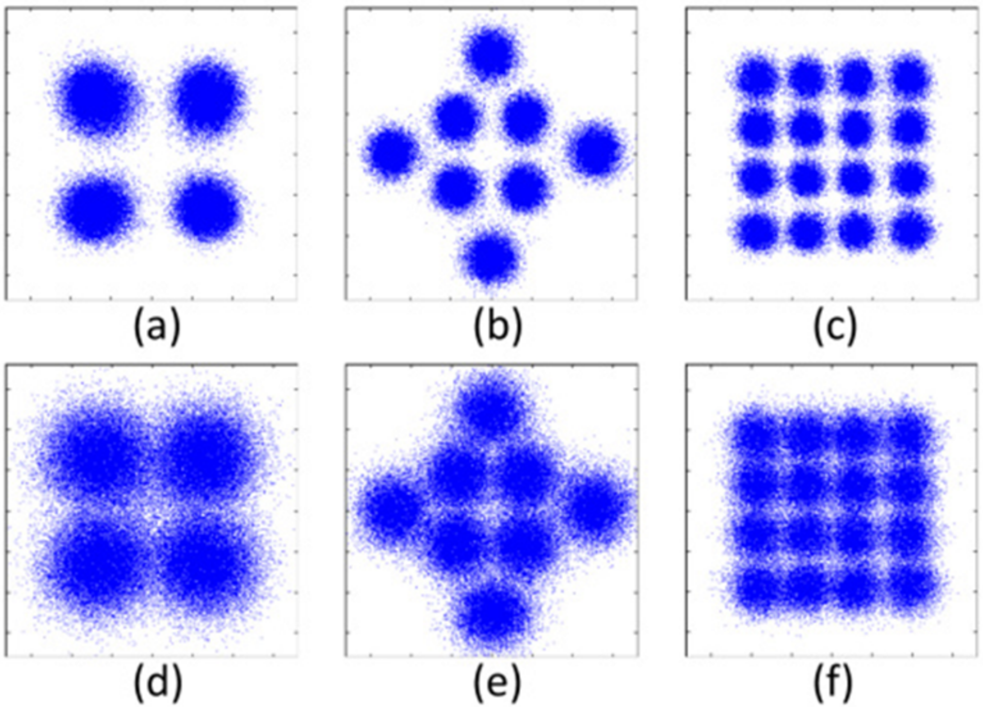
200G, 300G, 400G….

- More complex encoding - 8QAM, 16QAM (following radio tech)



@25Gbaud 100G 150G 200G

@50Gbaud 200G 300G 400G

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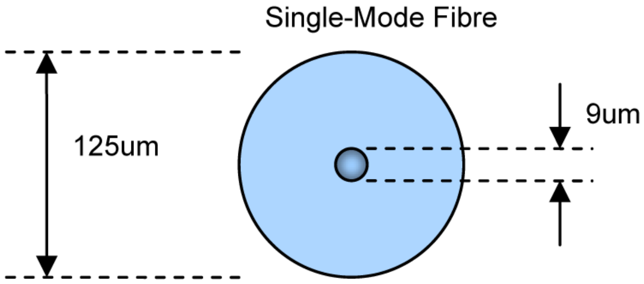
Better Fibre



- "Standard" fibres – 0.22 dB/km, core 65µm^2
- **Low-Loss Fibre** – 0.17dB/km
  - ~25% longer spans, fewer repeaters, lower noise
- **Large Effective Area** fibre – core 130µm^2
  - Supports Higher signal power, bigger amplifiers

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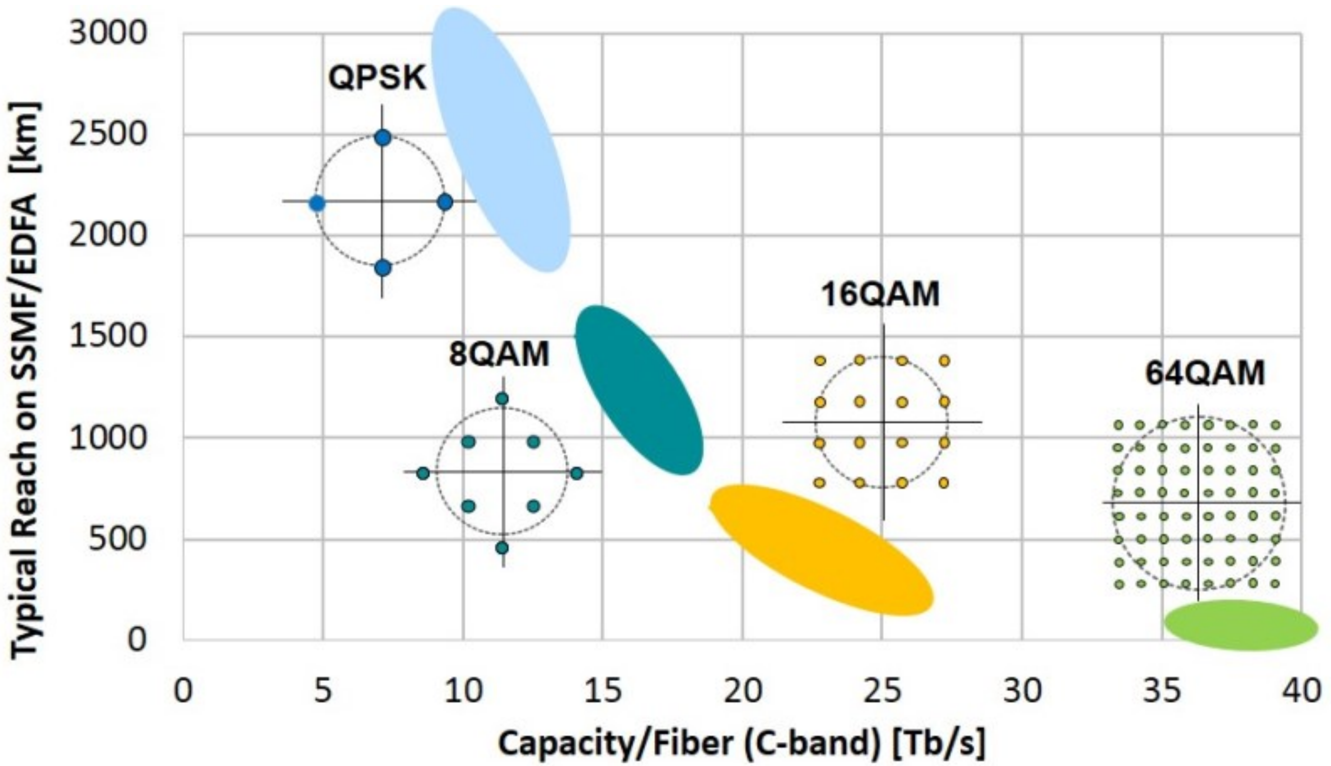
Compromises

- Currently at limit of optical & electrical physics and speeds
- Tradeoff of rate vs reach vs bandwidth vs stability



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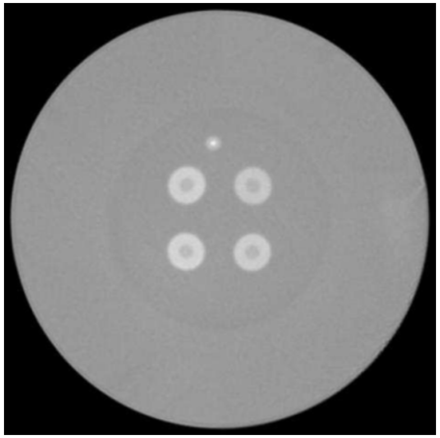
Further into the Future....

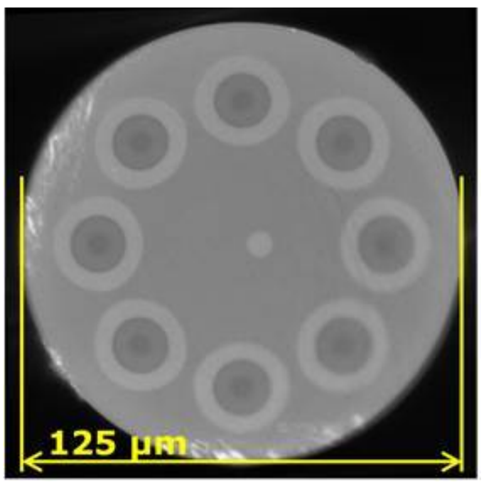
(Spurring a new wave of new cables...)

Multi-core Single-mode



March 25, 2016 06:55 AM Eastern Daylight Time

OSAKA, Japan--(BUSINESS WIRE)--**Sumitomo Electric Industries, Ltd. (TOKYO:5802)(ISIN:JP3407400005) has developed a new-type coupled multi-core optical fiber suitable for ultra-long-haul transmission, which has set new records of the low attenuation and the low spatial mode dispersion in the optical fibers for space division multiplexing.**



Design and fabrication of ultra-low crosstalk and low-loss multi-core fiber

Tetsuya Hayashi,* Toshiki Taru, Osamu Shimakawa, Takashi Sasaki, and Eisuke Sasaoka

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Abstract: We designed and fabricated a multi-core fiber (MCF) in which seven identical trench-assisted pure-silica cores were arranged hexagonally. To design MCF, the relation among the crosstalk, fiber parameters, and fiber bend was derived using a new approximation model based on the coupled-mode theory with the equivalent index model. The mean values of the statistical distributions of the crosstalk were observed to be extremely low and estimated to be less than –30 dB even after 10,000 km propagation because of the trench-assisted cores and utilization of the fiber bend. The attenuation of each core was very low for MCFs (0.175–0.181 dB/km at 1550 nm) because of the pure-silica cores. Both the crosstalk and attenuation values are the lowest achieved in MCFs.

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NTT labs

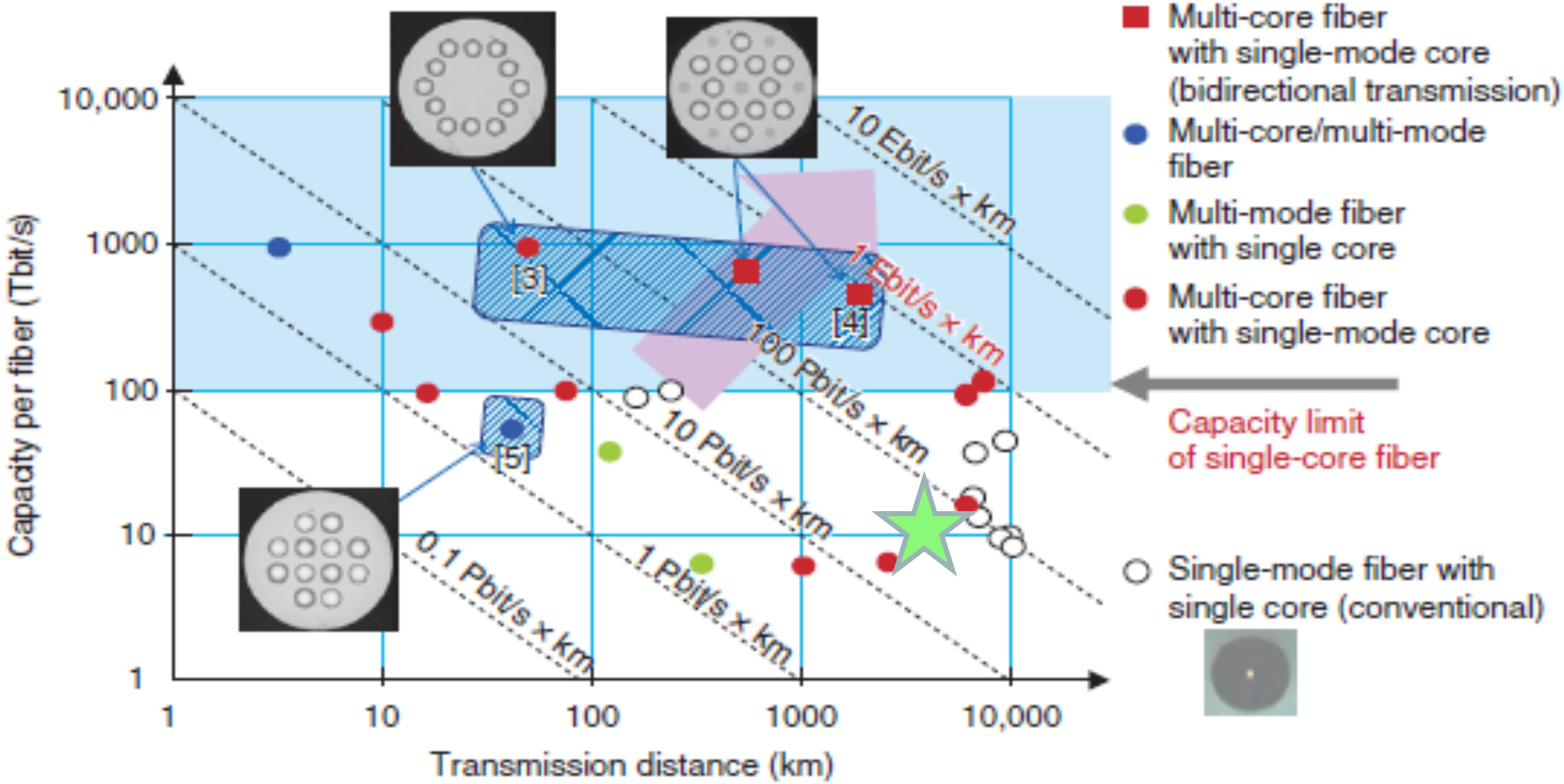

Fig. 3. State of SDM research and development.

https://www.ntt-review.jp/archive/ntttechnical.php?contents=ntr201412ra3.pdf&mode=show_pdf

Questions?

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