New trends in optical fiber communication

Kurosh Bozorgebrahimi (UNINETT)
Josef Vojtěch (CESNET)
Pavel Skoda (CESNET)

GN3-JRA1-T2

NORDUnet2011, Reykjavik, 07-06-2011

"The research leading to these results has received part of its funding from the European Community's Seventh Framework Programme(FP7/2007-2013) under grant agreement nº 238875 (GÉANT)"

connect • communicate • collaborate

Topics

- Evolution of optical fiber
  - Standards type and proprietary type
- Shannon limit and fiber capacity
- Optical Transmission evolution
  - OFDM
  - OTDM
  - Spatial division multiplexing

https://tnc2011.terena.org/web/media/archive/6D

ITU-T standars

- G.650.1: Definitions and test methods for linear, deterministic attributes of single-mode fibre and cable
- G.650.2: Definitions and test methods for statistical and non-linear related attributes of single-mode fibre and cable
- G.650.3: Test methods for installed single-mode optical fibre cable links
- Withdrawn: G.651 - Characteristics of a 50/125 µm multimode graded index optical fibre cable
- G.651.1: Characteristics of a 50/125 µm multimode graded index optical fibre cable for the optical access network
- G.652: Characteristics of a single-mode optical fibre and cable
- G.653: Characteristics of a dispersion-shifted, single-mode optical fibre and cable
- G.654: Characteristics of a cut-off shifted, single-mode optical fibre and cable
- G.655: Characteristics of a non-zero dispersion-shifted single-mode optical fibre and cable
- G.656: Characteristics of a fibre and cable with non-zero dispersion for wideband optical transport
- G.657: Characteristics of a bending-loss insensitive single-mode optical fibre and cable for the access network

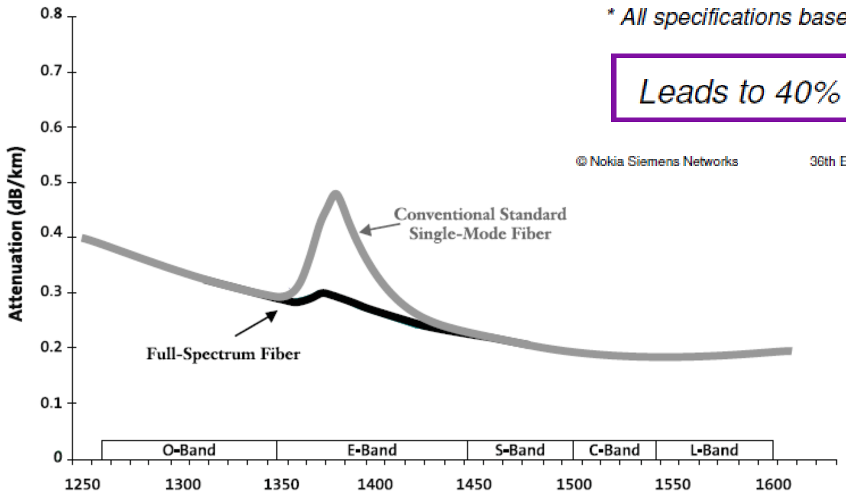
G.652 and it's variations

- G.652 A, B, C and D

Fiber type (Manufacturer)*	Fiber loss @ 1550 nm	CD @ 1550 nm	Effective area
Legacy SSMF	***0.2 dB/km***	***16.5 ps/nm/km***	***83 µm²***
ULAF (OFS)	0.185 dB/km	20 ps/nm/km	120 µm²
Z-PLUS (Sumitomo)	0.168 dB/km	20.5 ps/nm/km	110 µm²
Vascade EX2000 (Corning)	0.161 dB/km	20.5 ps/nm/km	112 µm²
LongLine (Draka)	0.185 dB/km	22 ps/nm/km	120 µm²

** All specifications based on information extracted from scientific publications*

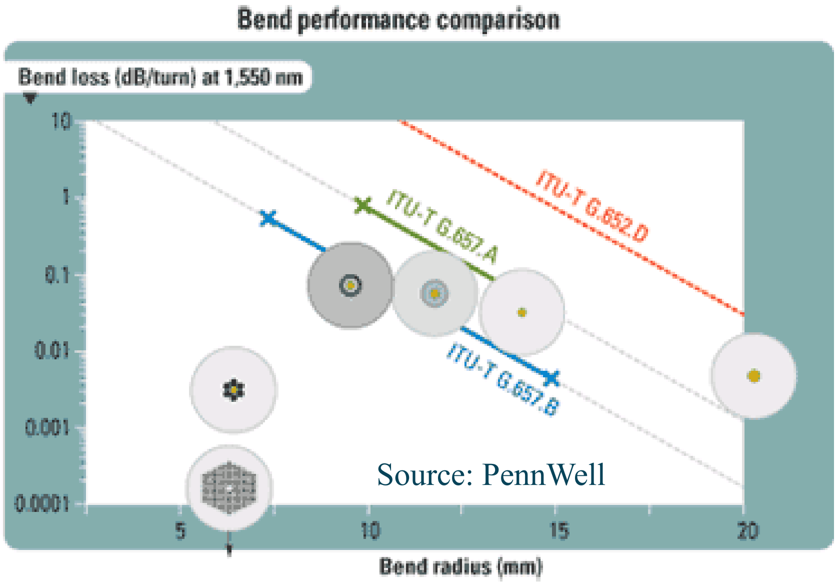
Leads to 40% - 70% enhancement of maximum reach !



Corning

G.657
bending-loss insensitive fiber

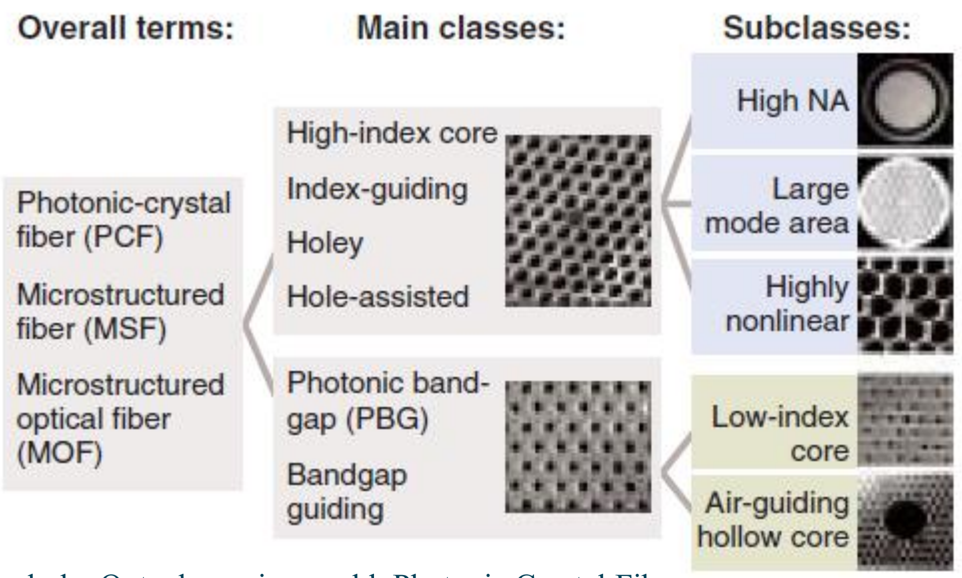
G.657 Low-bending-loss optical fiber for access networks	Minimum bending radius		
	10 mm	7.5 mm	5 mm
Category A Fully compatible with G.652	A1 Specified	A2 Specified	A3 Under discussion
Category B Partially compatible with G.652	B1 No standard product	B2 Specified	B3 Specified



New and non-standrad fibers

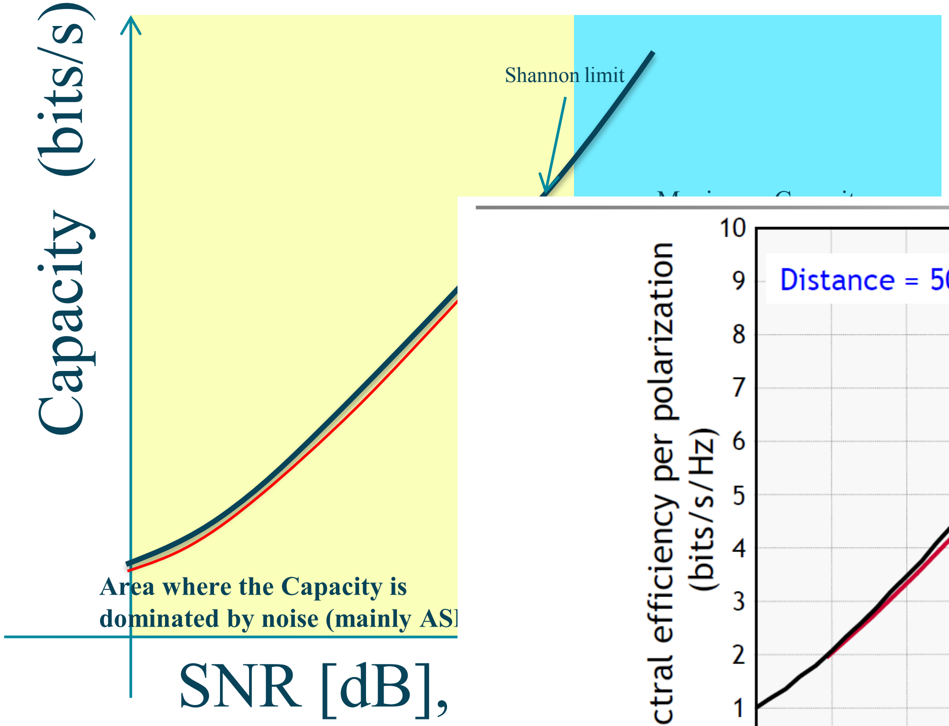
- Multi Core Fiber (MCF)
- Few Mode Fiber (FMF)

- Photonic Crystal Fiber (PCF)

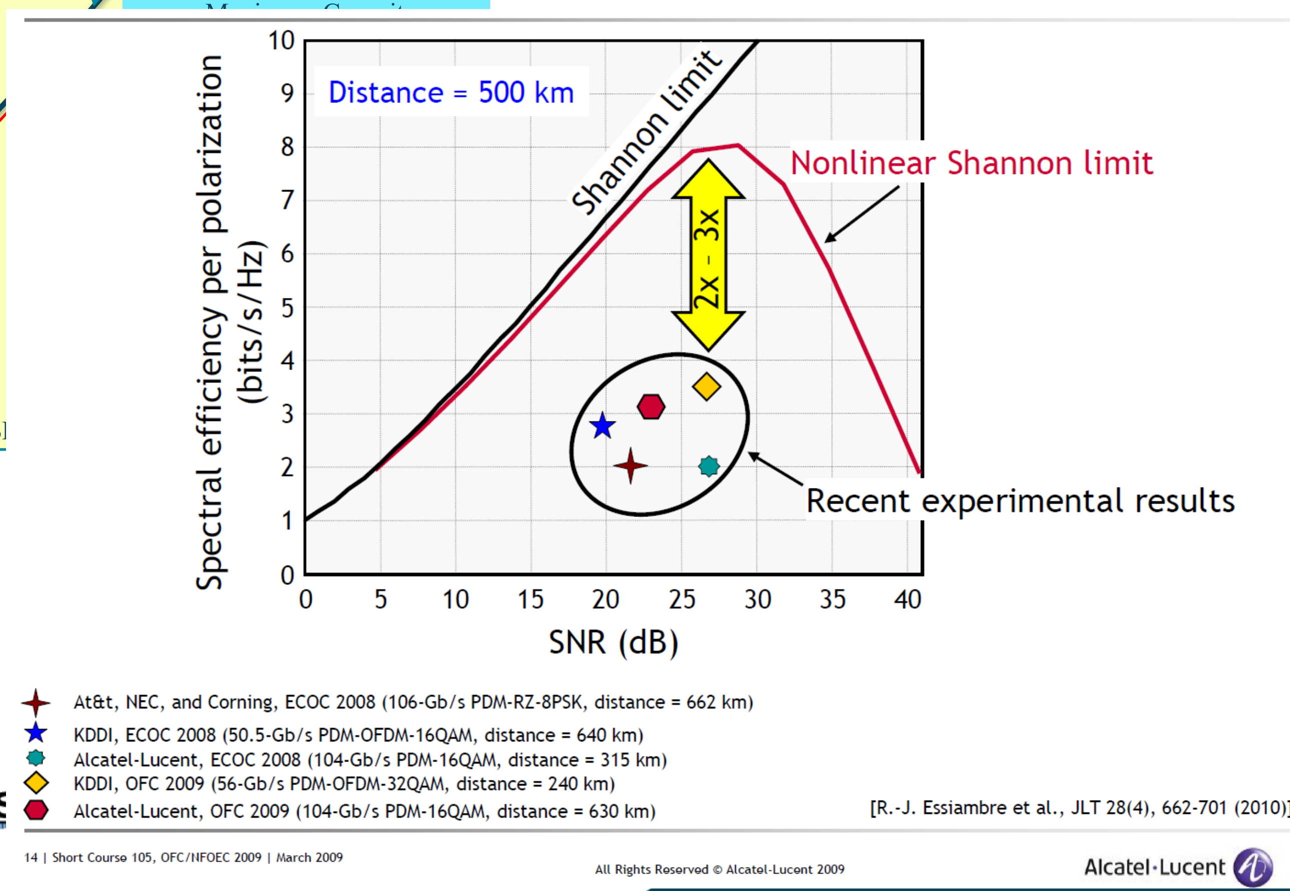


Source: Dr. Jason Eichenholz, Optoelecronics world, Photonic Crystal Fiber

Shannon limit and fiber capacity



- Shannon capacity
  - C =B log2 (1 + SNR)

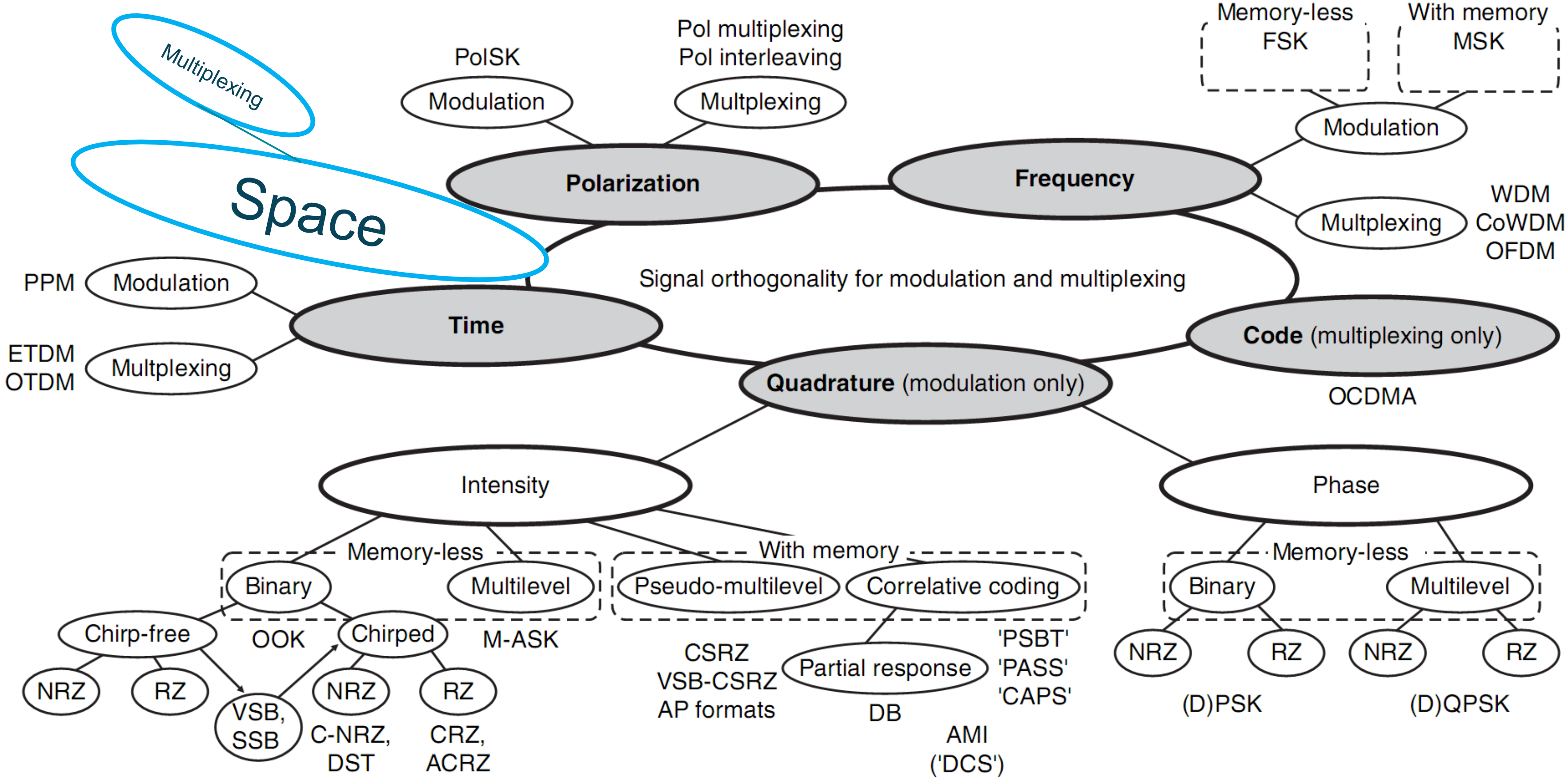


Three Breakthrough Technologies ”3M”

- Ultramulti-level coherent transmission (Multilevel modulation)
- New optical fibre technologies (Multi-core fibres)
- Mode division multiplexing (Multi-mode control with MIMO)

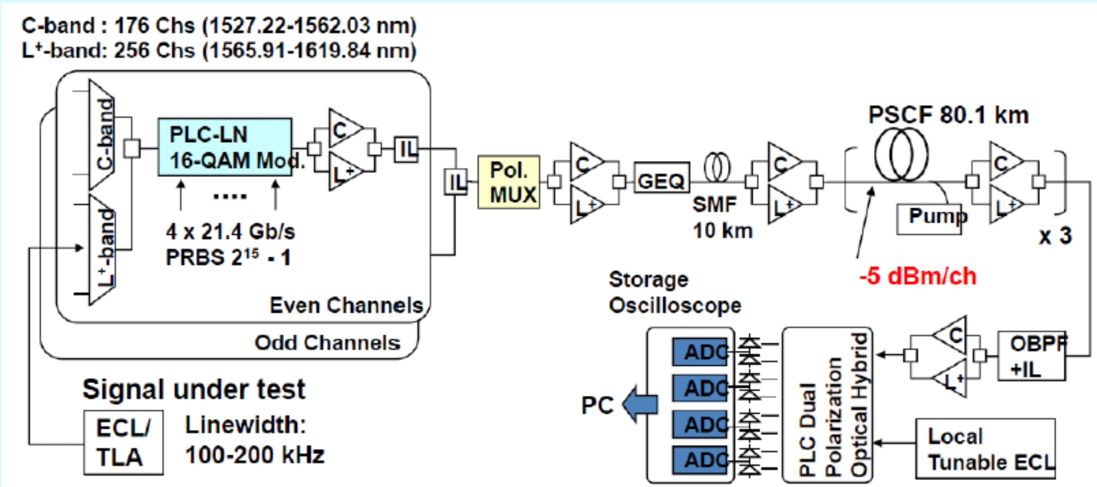
Possibilities
Modulation and multiplexing

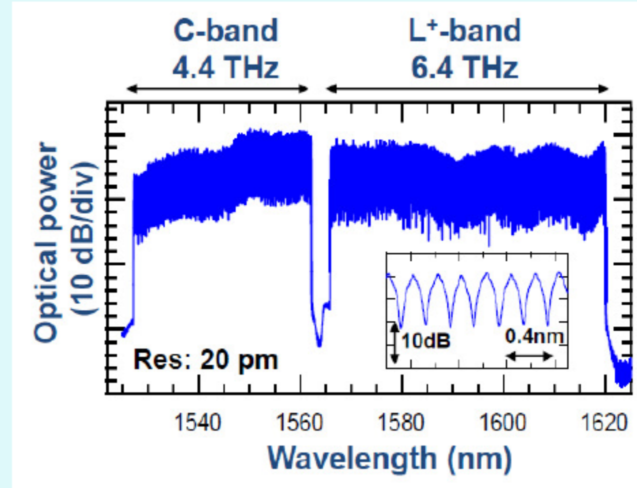
Modes
Multi Core fibers



Source: Ivan P. Kaminow, Tingye Li and Alan E. Willner, Optical Fiber Telecommunication, Academic Press, 2008

69.1Tbit/s QAM transmission





69.1 Tbit/s (432x171 Gbit/s), PDM-16QAM transmission over 240 km

A. Sano et al., OFC2010, PDPB7

101.7-Tb/s (370×294-Gb/s) PDM-128QAM-OFDM

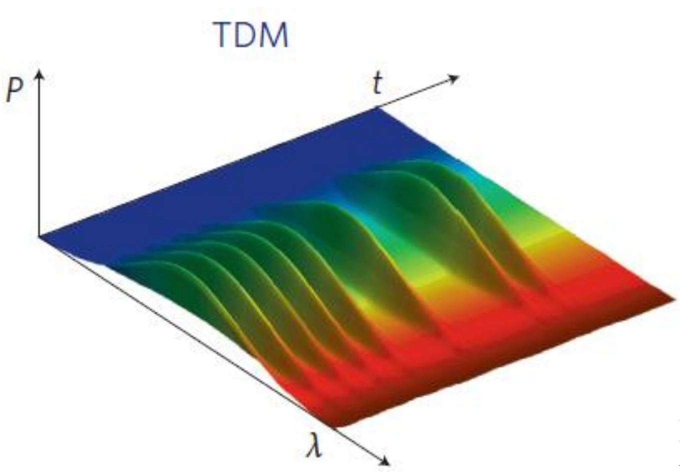
GÉANT

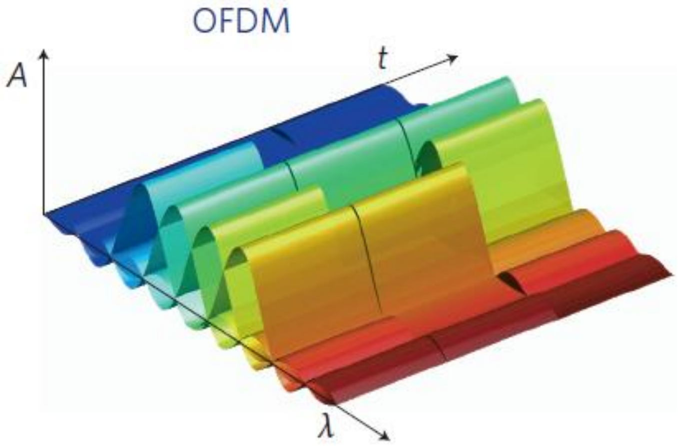
- 370x294-Gb/s WDM transmission
- each 25-GHz channel with 4x73.5 Gb/s OFDM subbands where PDM-128QAM was used at each modulated subcarrier
- We further partition the 25 GHz usable bandwidth per channel into four equal subbands, each of which carries an OFDM signal with 6 GHz bandwidth.

Dayou Qian et al., OFC2011, PDPB5

Beyond 100G bitrates per wavelength (single laser source): OTDM vs OFDM

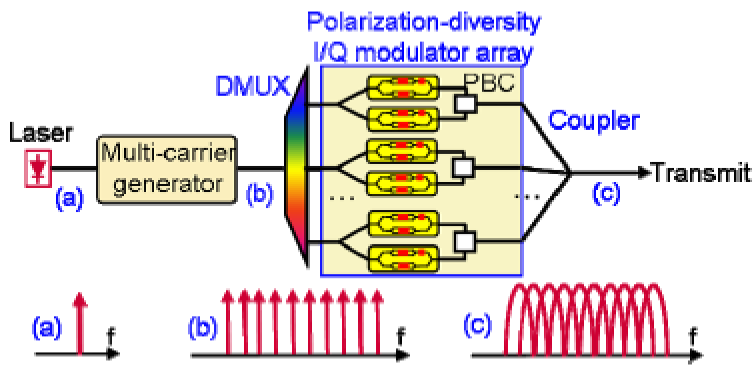
- To different method which are used to achieve higher bitrates per single channel
  - Orthogonal frequency division multiplexing
  - Optical time division multiplexing

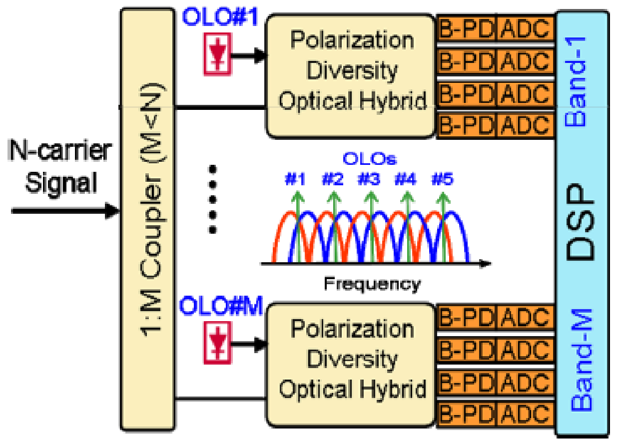




Figures: D.Hillerkuss et al. 26 Tbit s21 line-rate super-channel transmission utilizing all-optical fast Fourier transform processing, nature photonics, DOI:10.1038

Superchannel



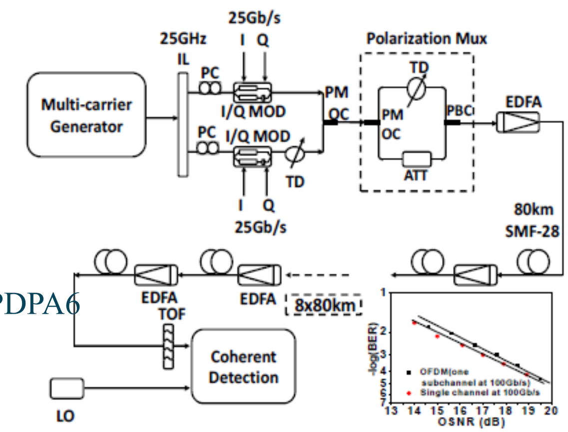


Ref.	Format	Superchannel data rate (Gb/s)	Composition	Intrachannel SE (b/s/Hz)	Reach (km)	ISEDP (km×b/s/Hz)
7	NRZ-OOK (DD)	288	7 x 41.3-Gb/s	0.93	1200	1116
4	DQPSK (DD)	100	2 x 25-Gb/s	1.87	1300	2431
8	Duobinary (DD)	100	4 x 25-Gb/s	0.93	100	93
9	NGI-CO-OFDM PDM-QPSK	112	2 x 56-Gb/s	3.74	10093	37748
6	NGI-CO-OFDM PDM-QPSK	1200	24 x 50-Gb/s	3.74	7200	26928
12	GI-CO-OFDM PDM-QPSK	1080	36 x 30-Gb/s	3.15	600	1890
13	GI-CO-OFDM PDM-QPSK	1210	50 x 24.2-Gb/s	3.33	400	1332
14	RGI-CO-OFDM PDM-16QAM	448	10 x 45-Gb/s	7.00	2000	14000

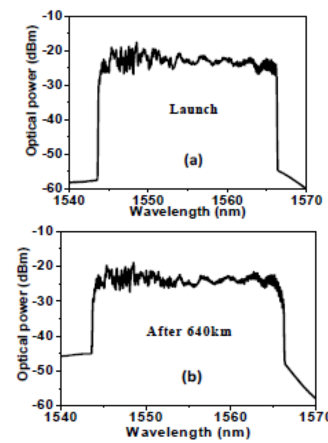
Recent experimental demonstrations of superchannels, source: ECOC2010, Tu.3.C.5

Single source Optical OFDM (superchannel) vs OTDM

- 11.2 Tbit/s High capacity per channel by using 112 optical sub-carriers with subcarrier spacing of 25GHz



OFC2011, PDPA6

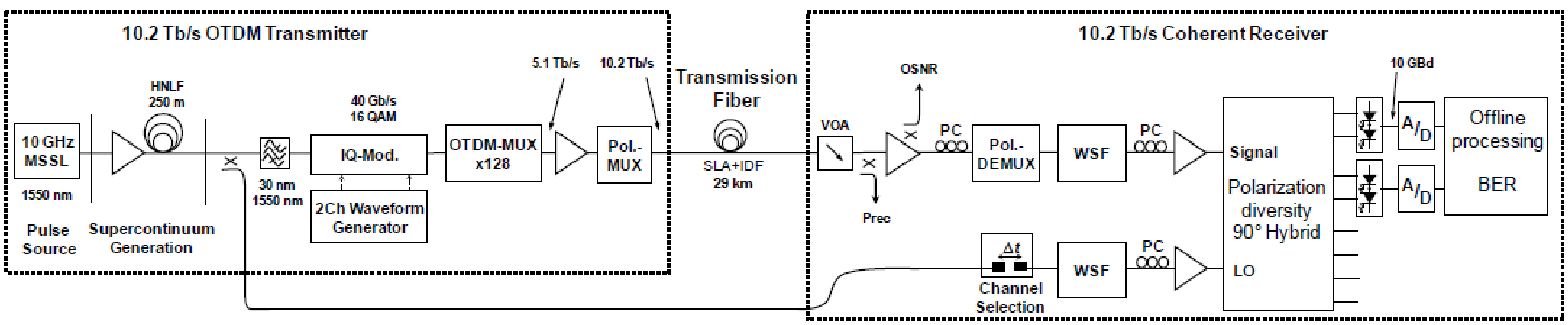


- **D. Hillerkuss et al. , 26Tbit/s line-rate super-channel transmission utilizing all-optical fast Fourier transform processing, Published 22 May 2011, nature photonics**

Single source Optical OFDM (superchannel) vs OTDM

- High capacity per channel by using OTDM: 40 Gbit/s base channel rate and Optical time-division multiplexing by a factor of 128 using passive fiber delay multiplexers. (10.2 Tbit/s). 30nm

OFC2011, PDPA9



Capacity beyond 100G and commercially availability?

- Standard is a MUST
- Mainstream thinking is that the next rate will be 400G or 1T
  - Both line-side and client-side should be considerd
- Consensus between ITU-T and IEEE about the line-side and client-side bitrates are necessary
  - *ITU-T: There have been few preliminary contributions about ODU5*
  - *IEEE 802.3 has created a "bandwidth assessment ad hoc"*
    - *gather data that might eventually lead to the creation of a "next rate" project*
- A development beyond 100Gbit/s will be similar to that happened from 10G to 40G/100G.
  - IEEE used 4 years to develop 40GbE and 100GbE recommendation/standard (2006-2010)
- ***Next rate products as it is for 100G today will not be ready before at least 2016***

Spatial multiplexing

- Multi-Core fiber
  - Crosstalk is one of the main issues
- Multimode fiber
  - Mode Division Multiplexing (MDM)
  - Challenges
    - *Mode coupling*
    - *Intersymbolic interference at receiver side*

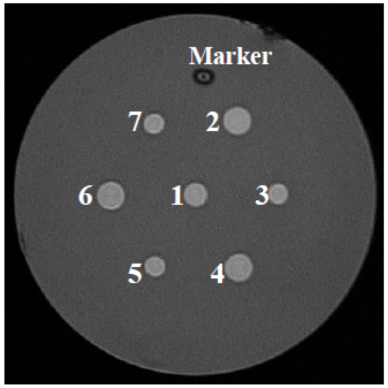
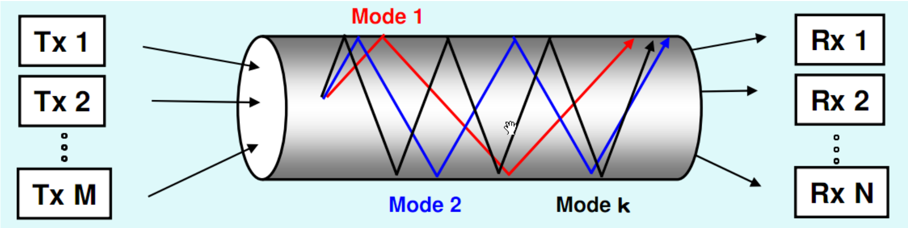


Fig. 1. A cross section of the fabricated fiber.

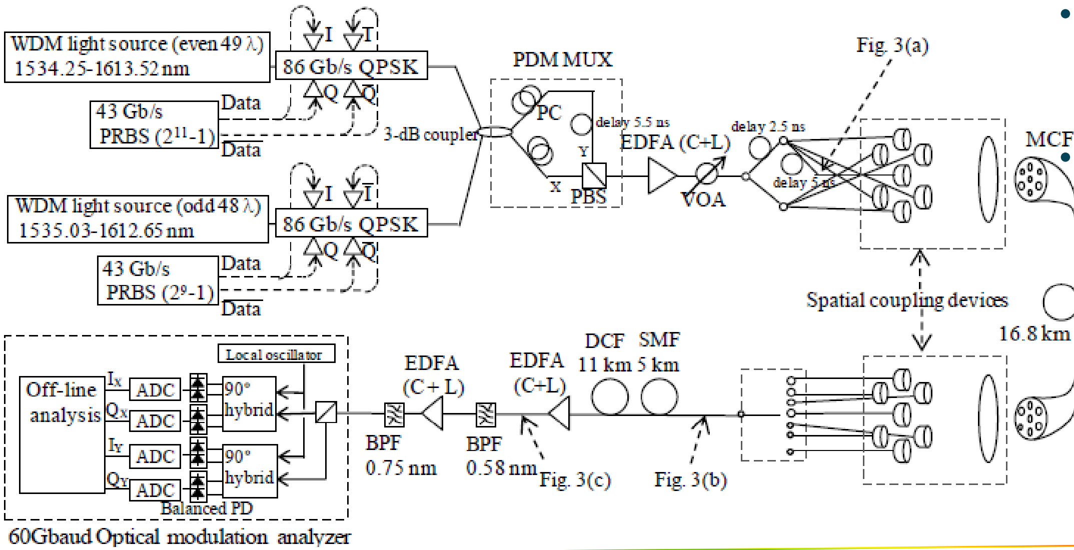
[Jun Sakaguchi, Proc. OFCNFOEC2011, OWJ2]

Table 1. Propagation characteristics.

	Core 1	Core 4	Core 5
Attenuation [dB/km]	0.212	0.199	0.194
Dispersion [ps/nm/km]	17.5	19.4	14.7
D. Slope [ps/nm^2/km]	0.056	0.058	0.054



Recent *Spatial Multiplexing* experiments based on *multi-core* fiber

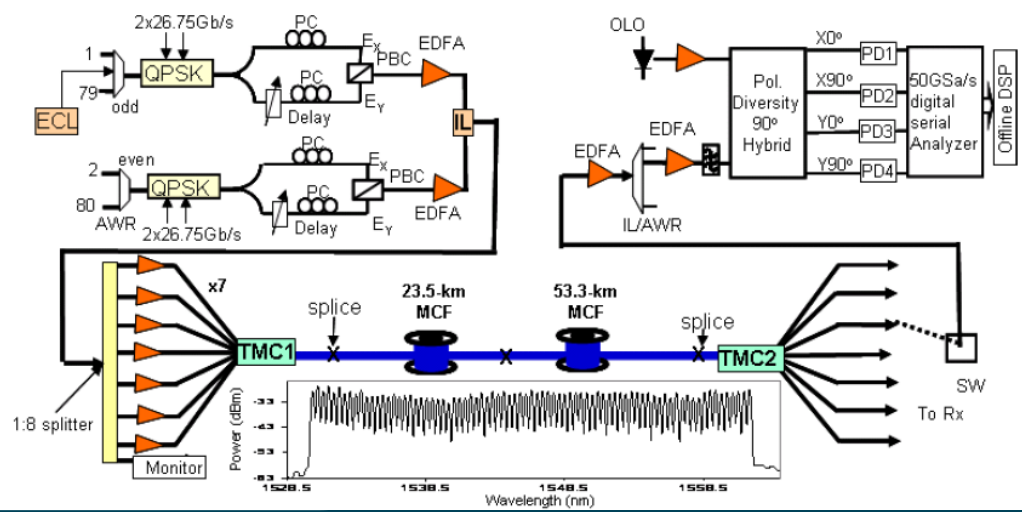


- 109Tb/s transmission of spatial division multiplexed (SDM) signals over 16.8 km using a seven-core fiber.
- Each SDM channel contains 97 WDM channels on a 100GHz grid and 2×86-Gb/s polarization-multiplexed QPSK signals.

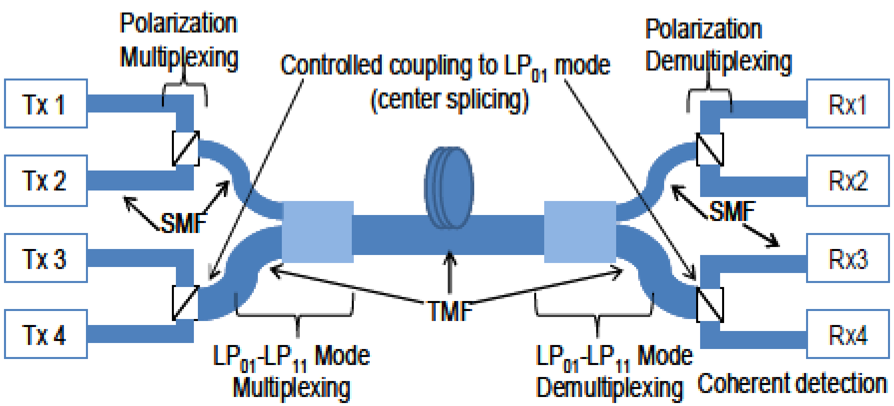
[OFCNFOEC2011, PDPB6]

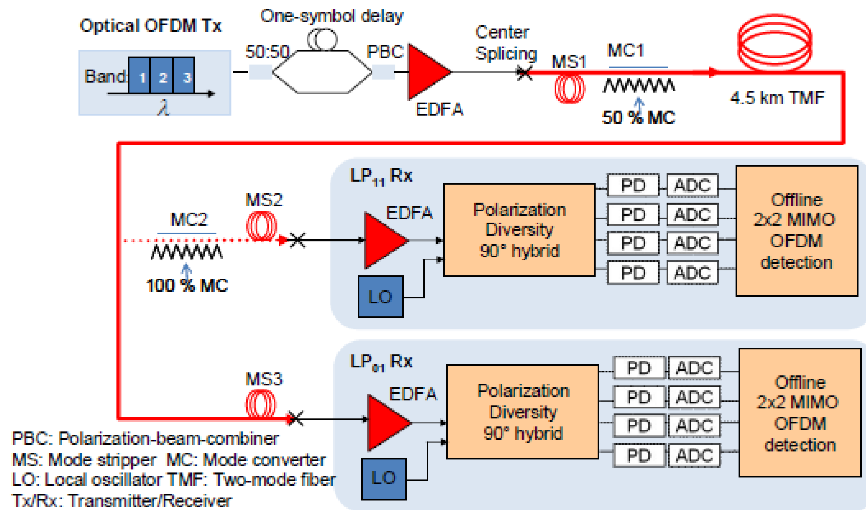
- SDM and DWDM transmission of PDM-QPSK channels over a multicore fiber.
- A total capacity of 56-Tb/s (7×80×107-Gb/s) is transmitted over a 76.8-km seven-core-fiber with a record spectral-efficiency of 14-b/s/Hz

[OFCNFOEC2011, PDPB7]

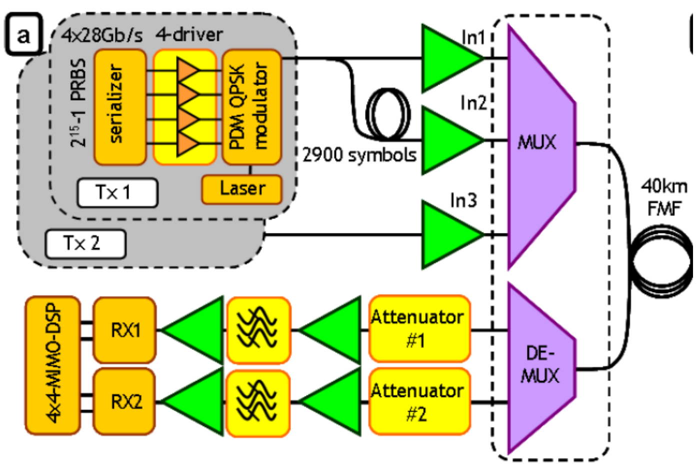


Recent *Spatial Multiplexing* experiments based on *multi-mode* fiber





LP01/LP11 dual-mode and dual-polarization coherent OFDM detection at 107 Gb/s. [OFCNFOEC2011,PDP



Transmission at 2x100Gbit/s over Two modes of FMF over 40km [OFCNFOEC2011,PDPB9]

Summary

- Shift in complexity from the optical domain to electrical domain
  - E.g. doing dispersion compensating at the receiver side on DSP level
- Using unused physical dimension
  - such a ‘space’ by employing spatial division multiplexing
- Using broader single band to carry capacity.
  - Need flexi-grid band
- New fiber type will be needed to handle futures capacity demand

Thank you for your time.

?