

OFC 2007, Anaheim, CA

Workshop on 40 Gig Networks: The Actual World PMD Challenge

PMD as Bottleneck Problem for the Introduction of 40Gbit/s
and Future 100Gbit/s Ethernet into German WDM Backbone

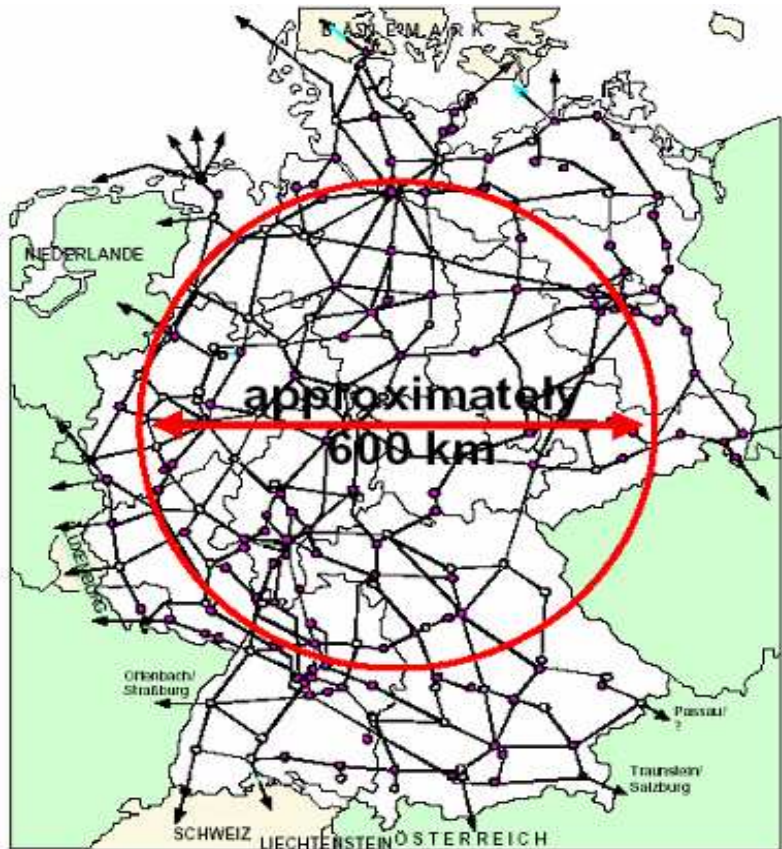
W. Weiershausen, D. Breuer
T-Systems, Deutsche Telekom

Outline

- DT's network dimensions
- Vintage fibers in DT's network
- Bottleneck for 40 Gbit/s (and 100 GEthernet) backbone introduction
- Results from measured PMD dynamics in DT's network. Requirements definition for active PMDC

German Fiber Network: The Distances

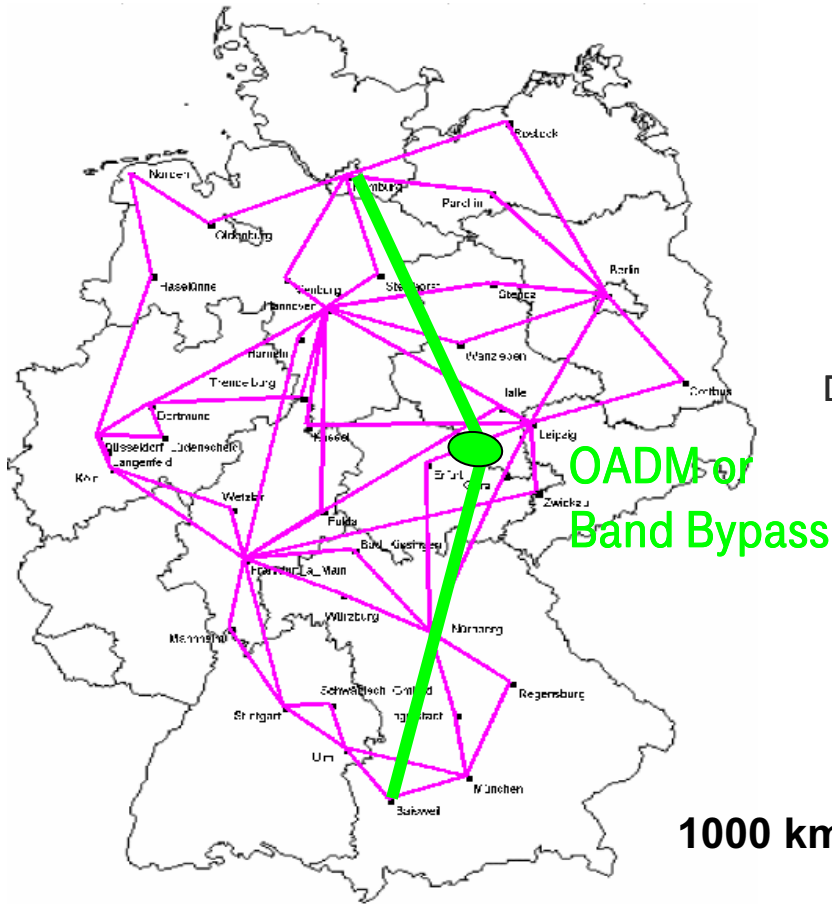
Are 40G/100GE as 40GBaud/100GBaud possible ?



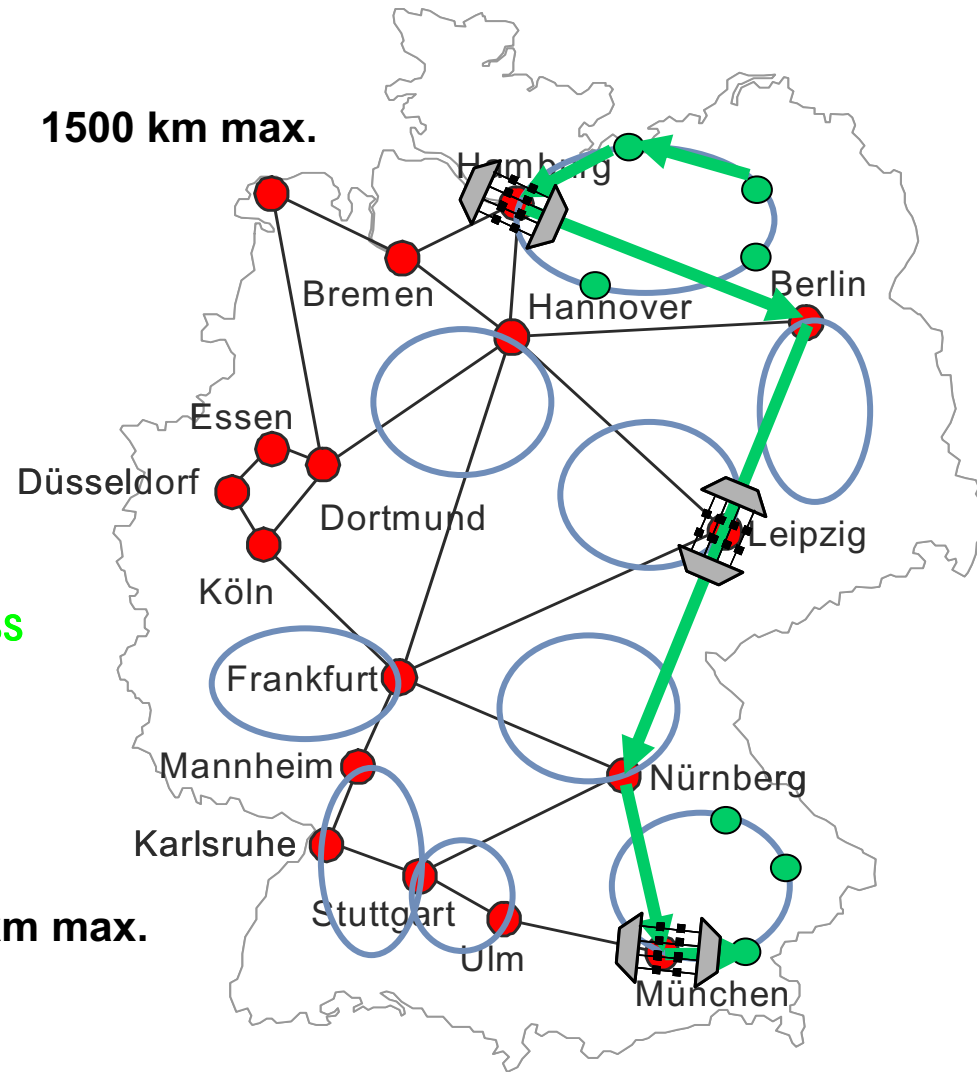
Statistical analysis of paths in DT Network	
Parameter	Value
Max path length	951 km
Min path length	36 km
Mean path length	413.5 km
Standard deviation path length	201.6 km
Max length of 90% of paths	675 km
Max path hops	7
Mean path hops	2.85
Standard deviation path hops	1.45
Max hops of 90% of paths	4.5

Future Option for Fully Transparent Leased Line OTH Channel Feed Through Between Regional Metro Rings via Backbone Link

Transit bypass

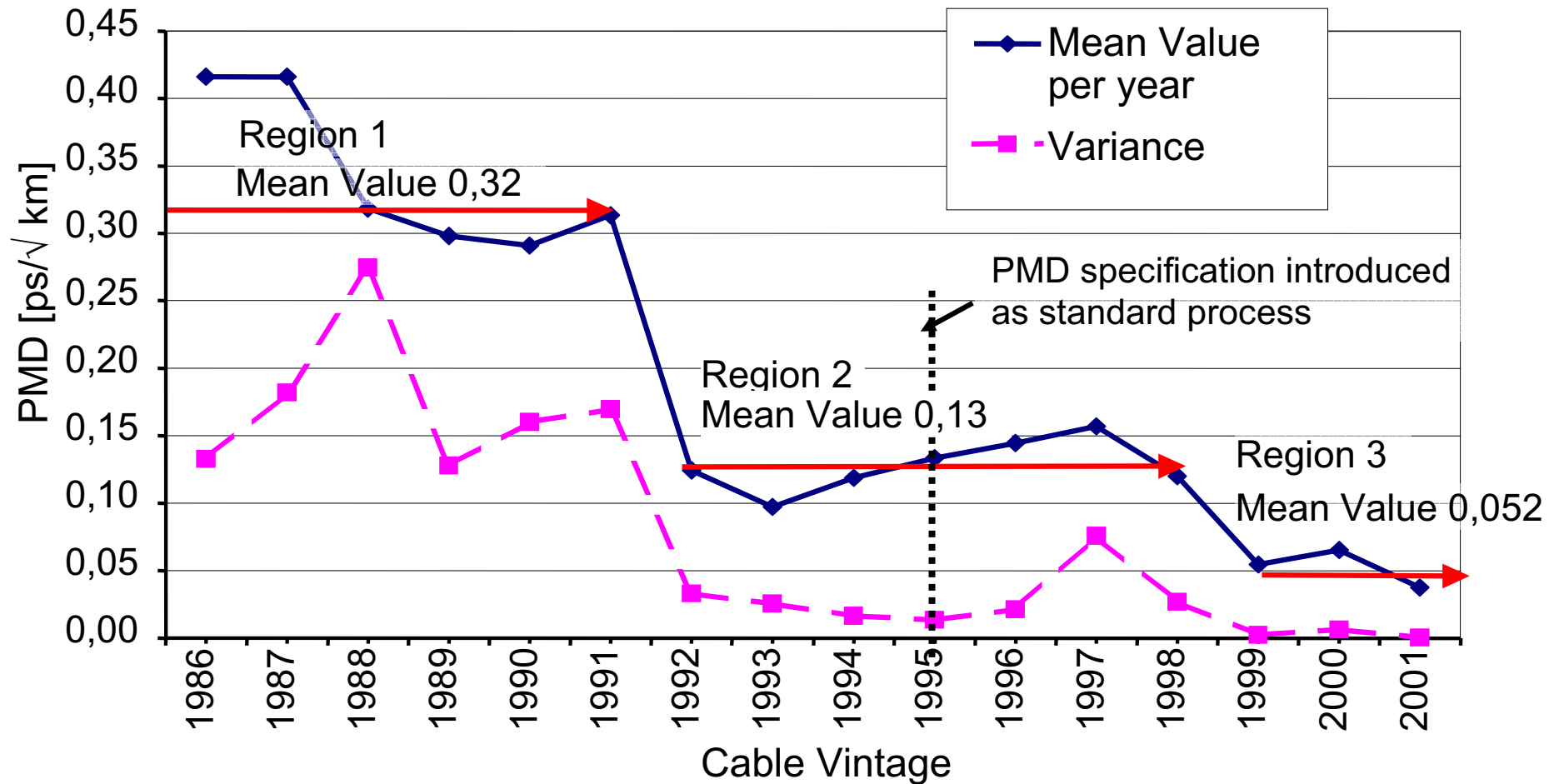


1500 km max.



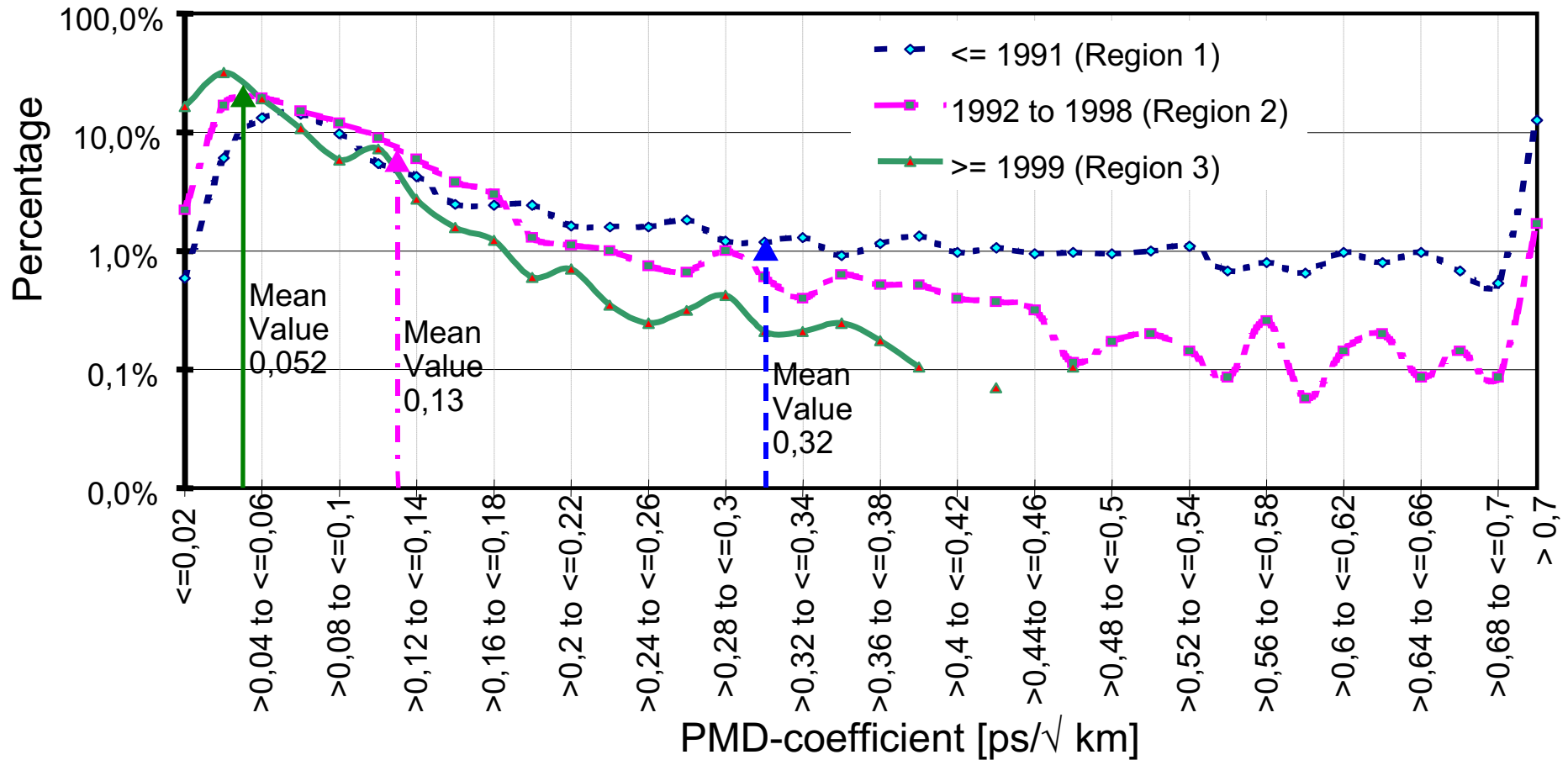
PMD in DT Network: Cable Vintage Dependence

Mean and variance of PMD coefficient as a function of cable installation year



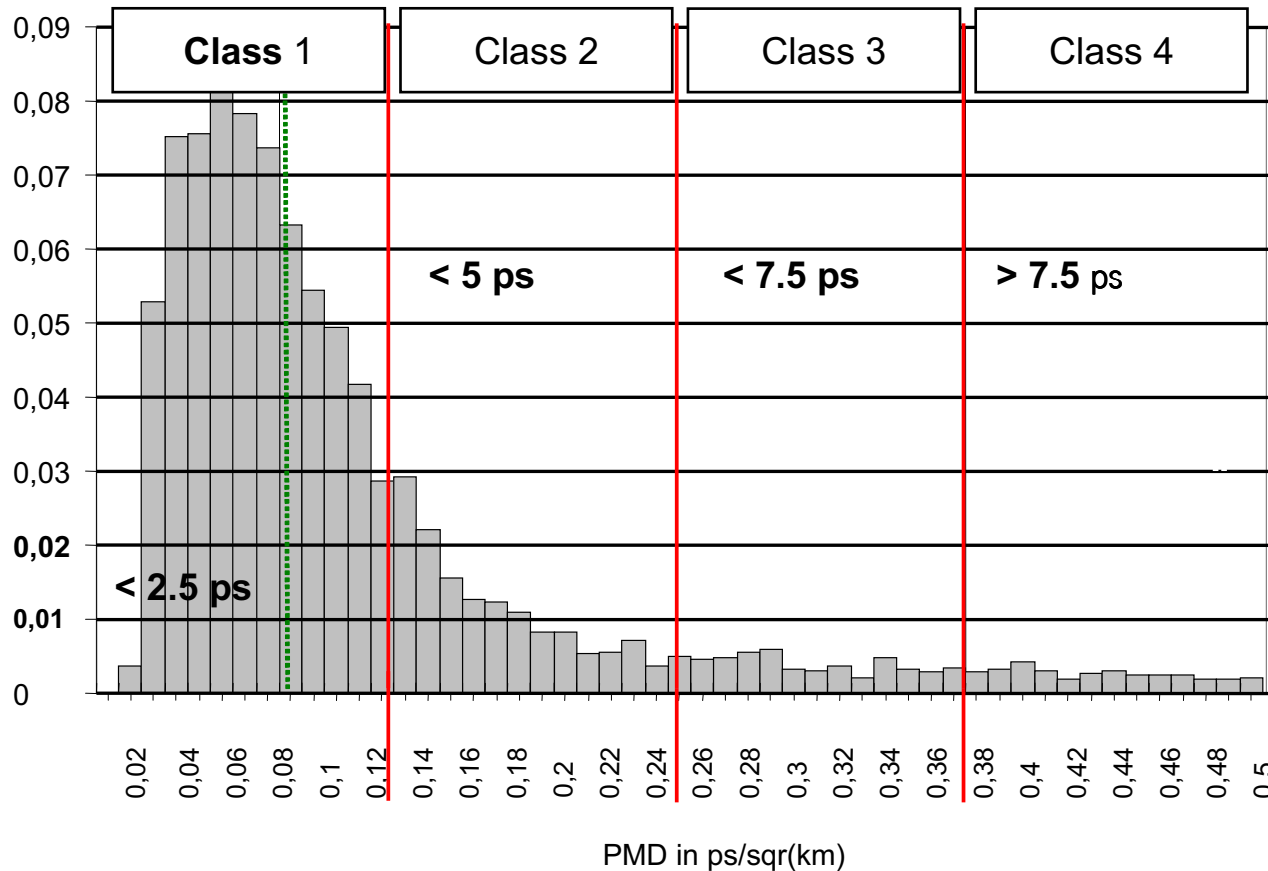
PMD in DT Network: Cable Vintage Dependence

Percentage of fibers in different PMD classes and cable installation years



PMD as Bottleneck for 40Gbit/s Long-Haul Systems Introduction

Mean Value 0,079 ps/sqr(km)



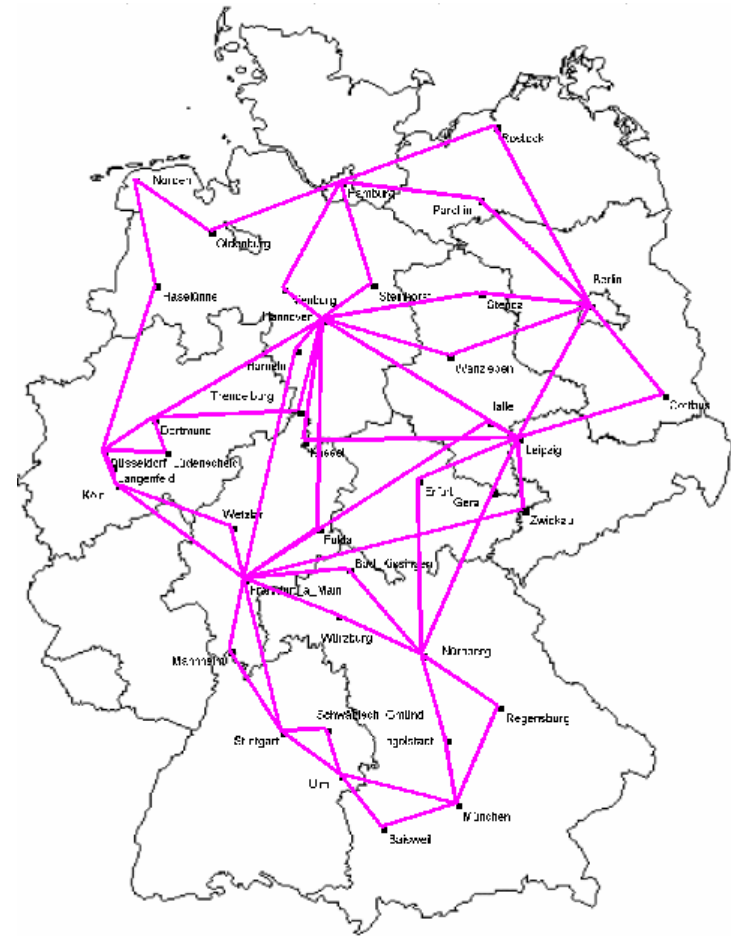
- Less than 50% of fibers usable for 40 Gb/s
- Adaptations needed
 - Enhanced receiver robustness
 - PMD compensation
 - Equalizer
 - New modulation formats, with multilevel symbols and reduced symbol rate.

PMD as Bottleneck for 40Gbit/s Long-Haul Systems Introduction

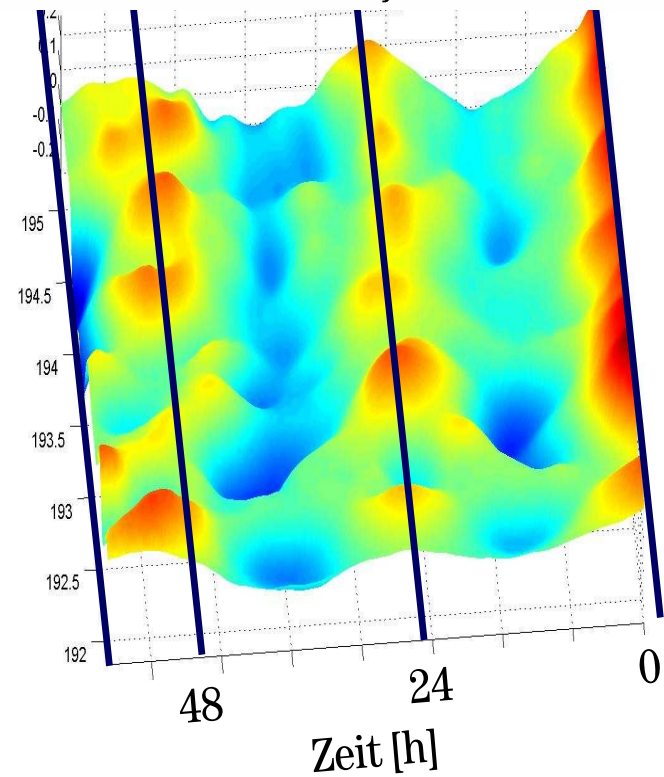
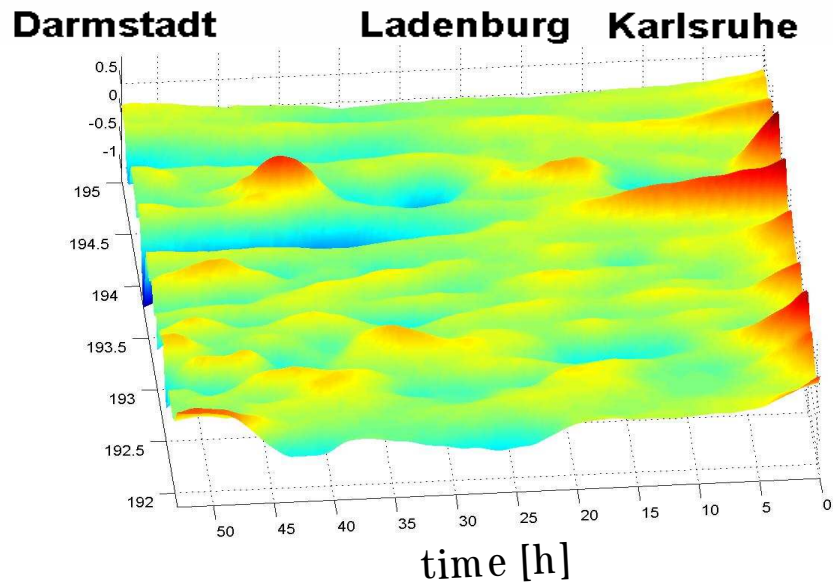
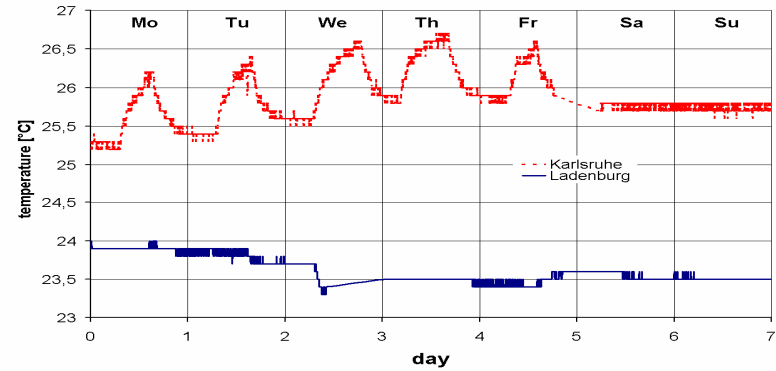
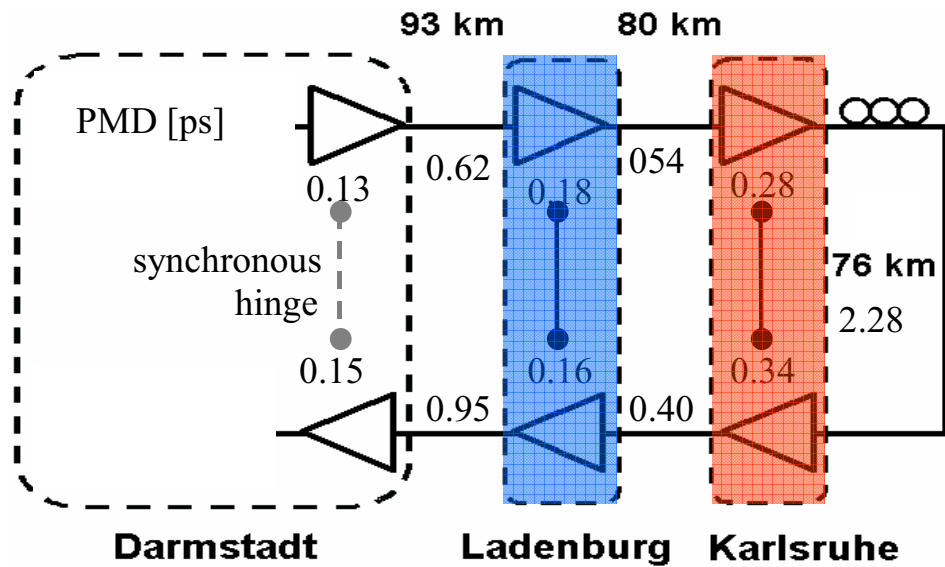
- Detailed survey of all usable fiber combinations to install 40 Gbit/s in DT's backbone network: Best case approach
- Result is that less than 50% of the routes can be used for 40Gbit/s
- Solutions: Detect and remove dominating high-PMD cable segments or using robust WDM (e.g. low baudrate techniques)

Real usability of fibers is much worse than expected from overall statistics:

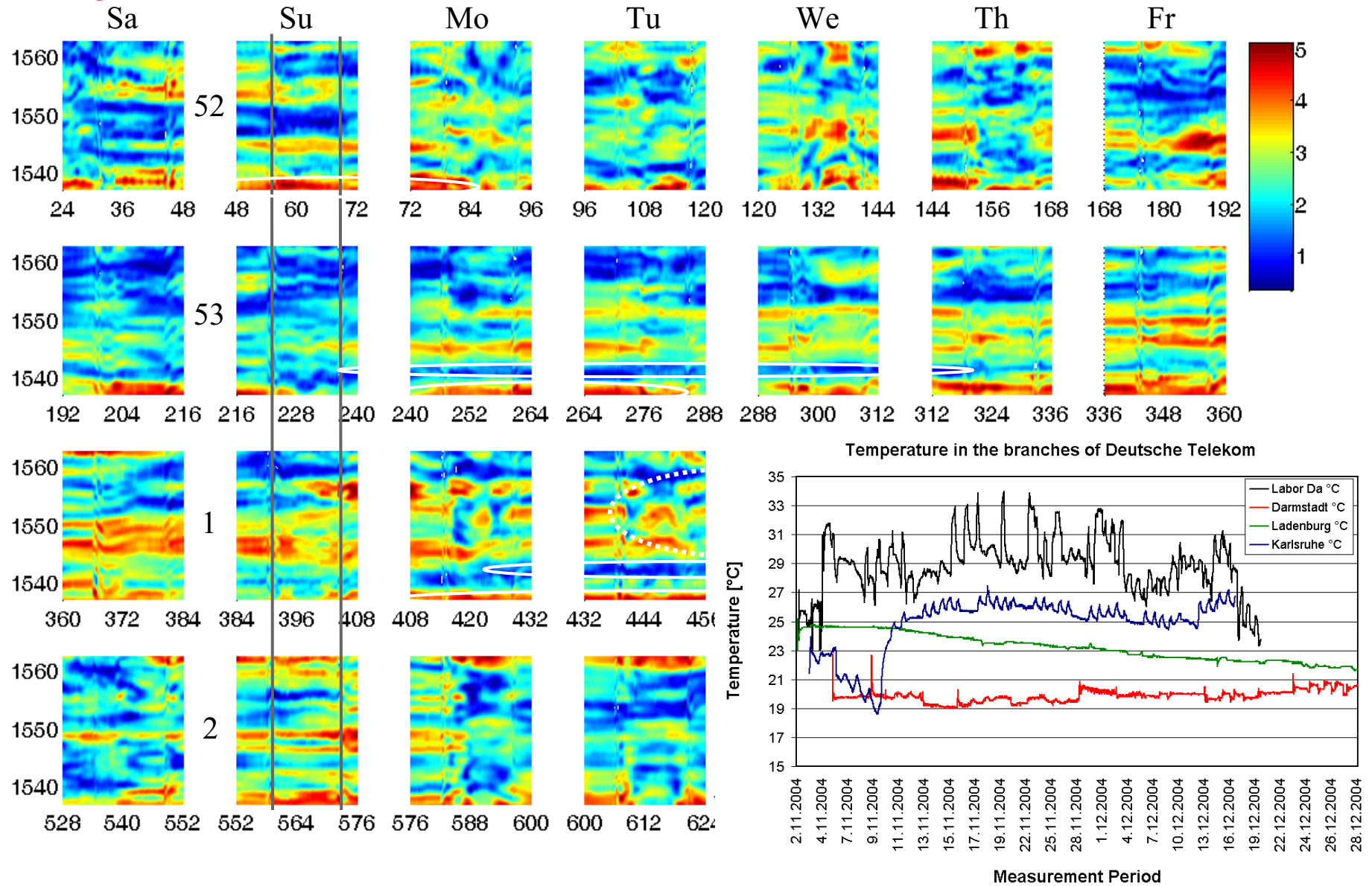
- typically: 40 km link statistics
- More realistic: Link Design Value (LDV) for real links
- Realistic: Real connections: Dominating bad fiber segments



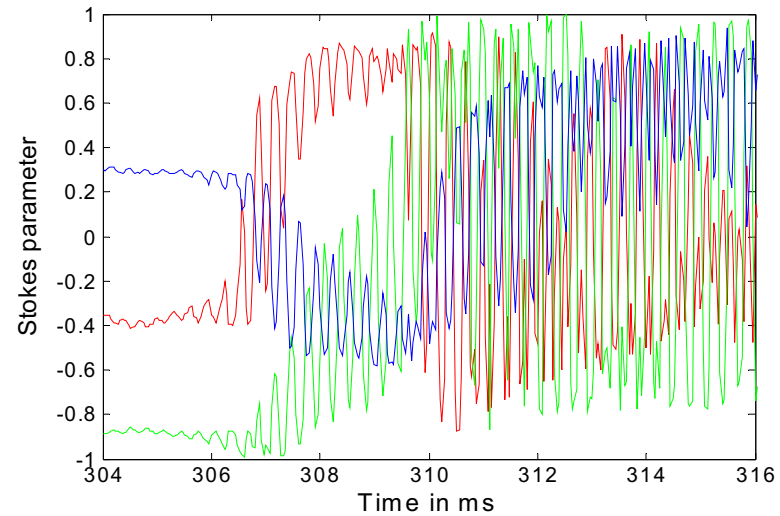
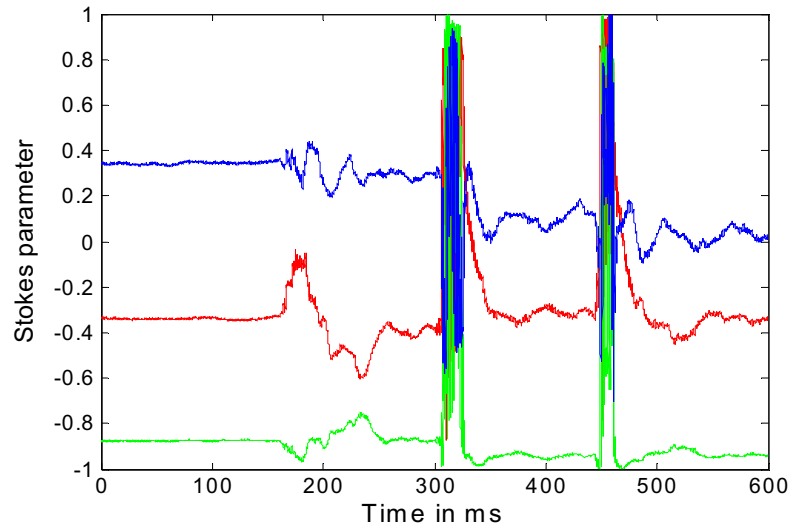
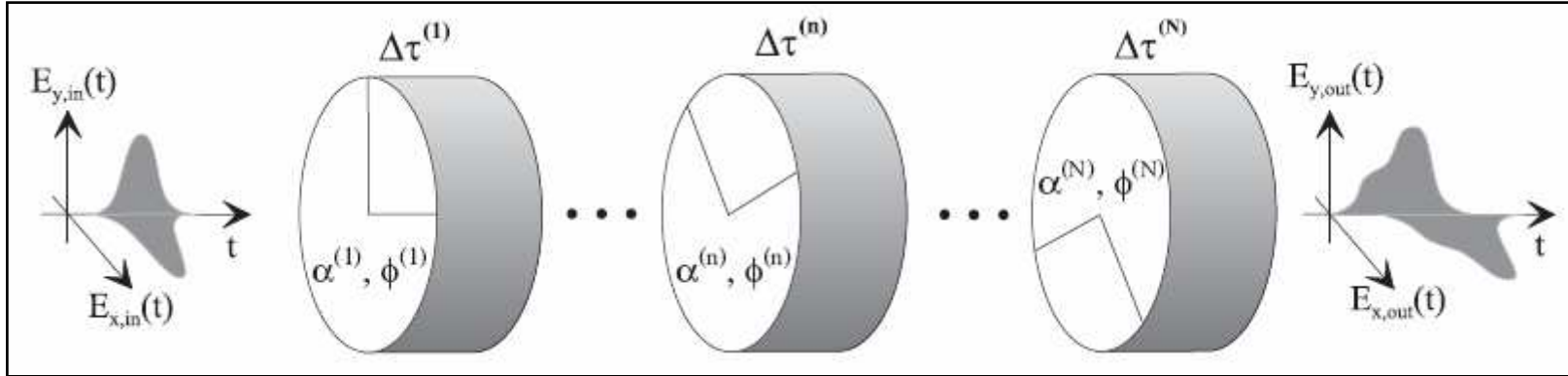
Long Term DGD Field Measurements: Hinge Behavior in DT's Network



Longterm Measurements of PMD Fluctuations DT Fiber Infrastructure



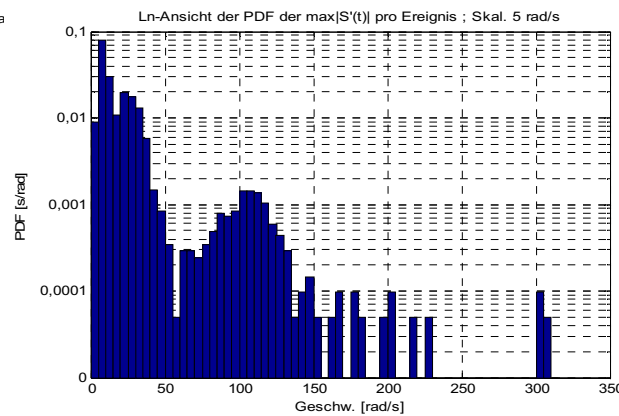
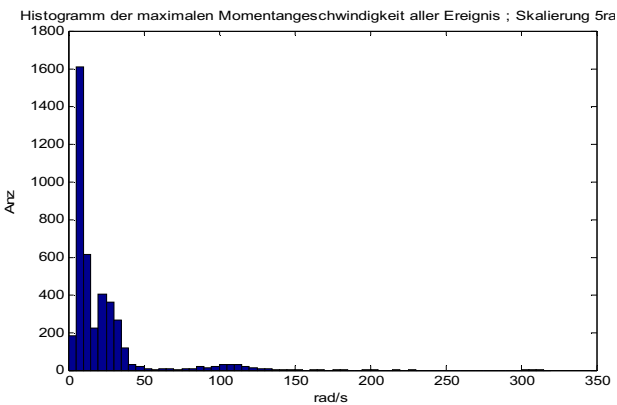
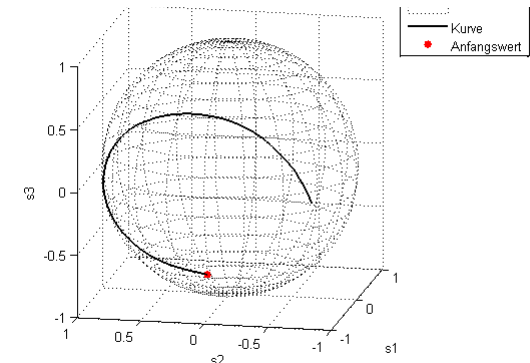
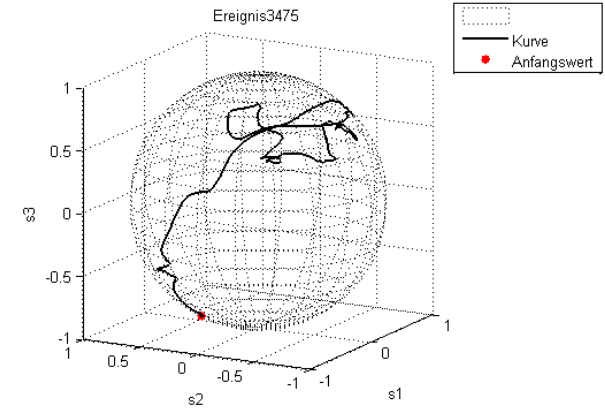
Measured Fast SOP/DGD Changes in DT's Network



Dynamic PMD Behavior: Fast SOP/PSP/DGD Fluctuations (ms)

- Longterm measurements on DT link over 18 months
- Further studies follow
- Critical region: some ms
- PMDC should be able to track strong SOP and PSP excursions, as well as its full DGD dynamics within some milliseconds.
- In case of lower-speed tracking, active PMDC can introduce oscillating intrinsic element DGD which can lead to complete system outage until retracking
- Passive PMD suppression from robust system design, like DQPSK low baudrate modulation format is a reasonable alternative to actively controlled PMDC

SOP dynamics



200 rad/s = 7,8 ms per 90°
 100 rad/s = 15,6 ms per 90°

Summary

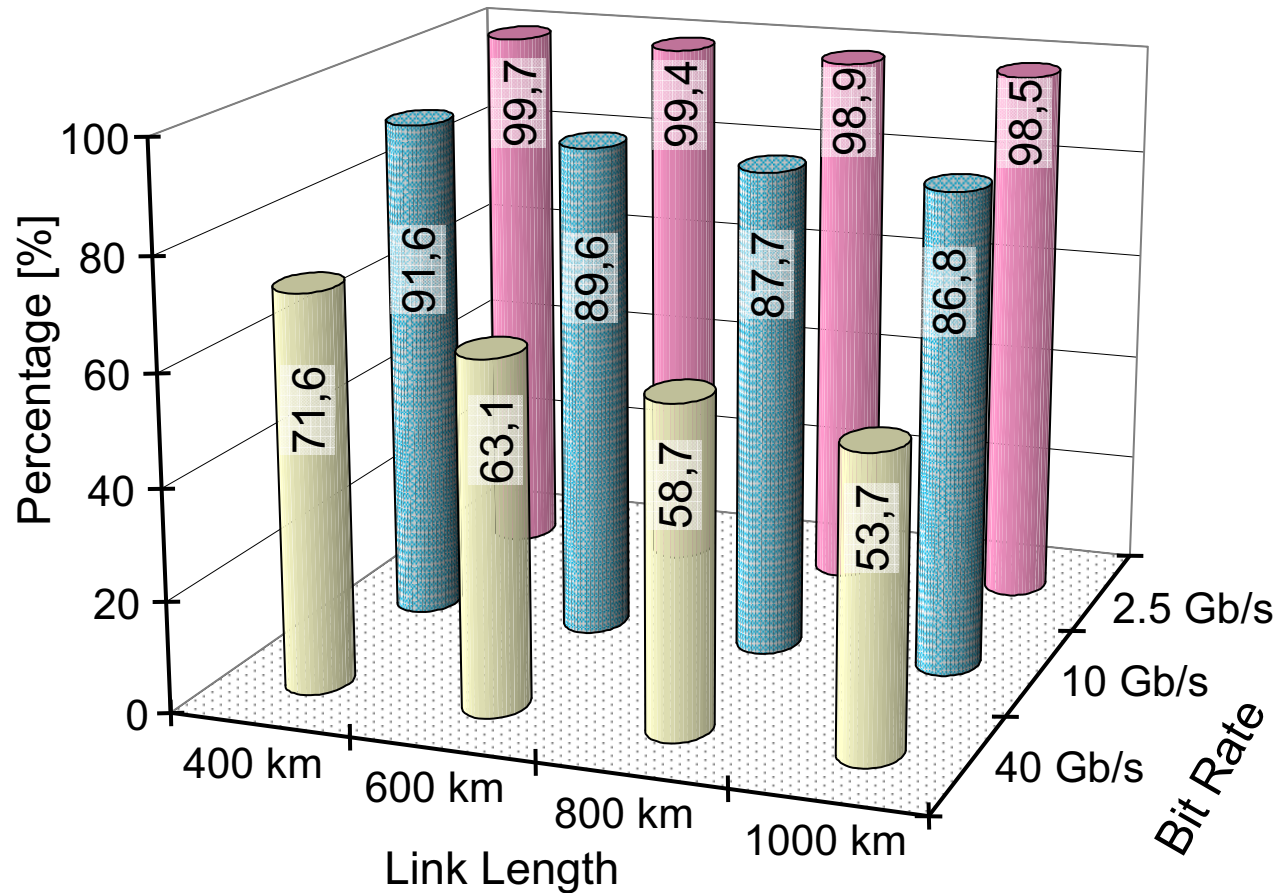
- DT's network equipped with three classes of vintage fibers
- Problems to install 40 Gbit/s in the backbone network
- Temporal statistics in DT network has been measured (& is on further study): high speed requirements for active PMDC
- Robust low baud rate transmission systems are a key for logical 40G and 100GEthernet employment in the backbone (DT=600 km, ULH=1000 km)



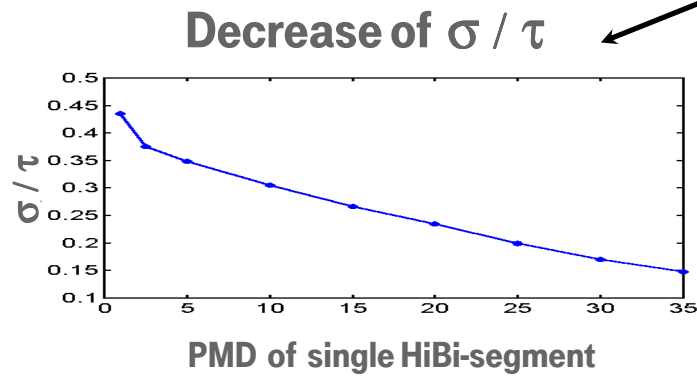
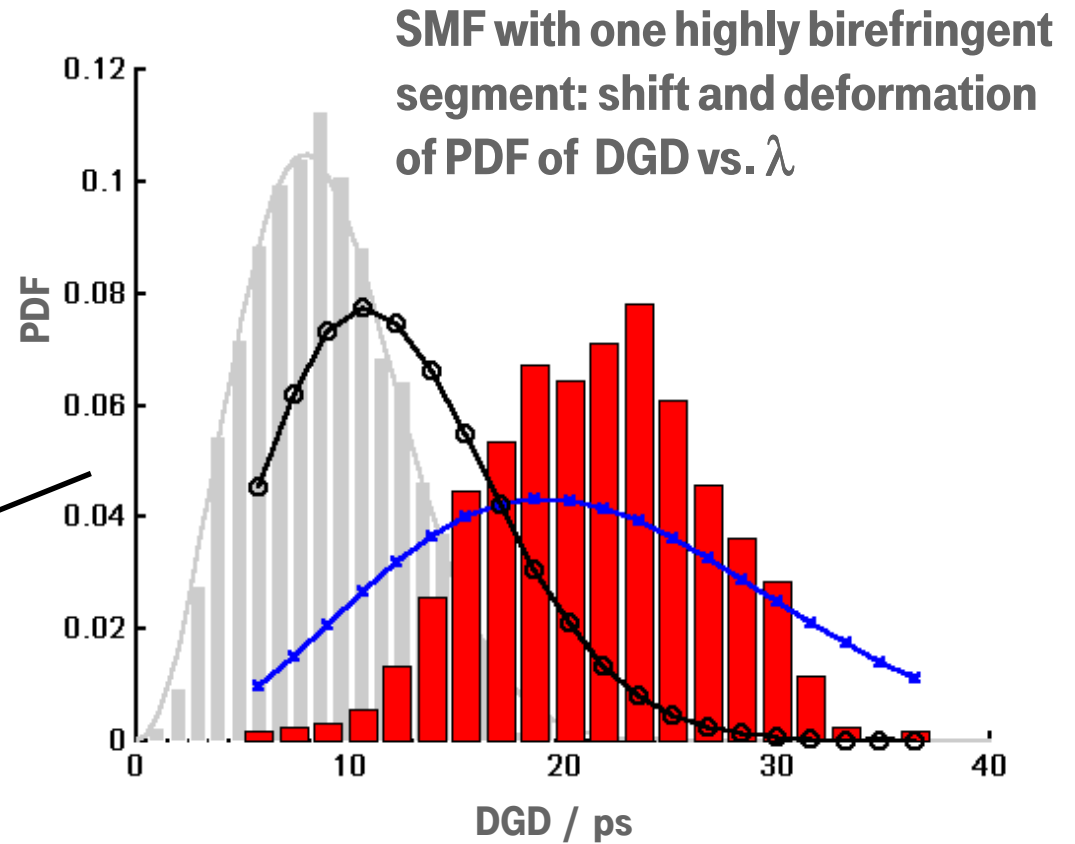
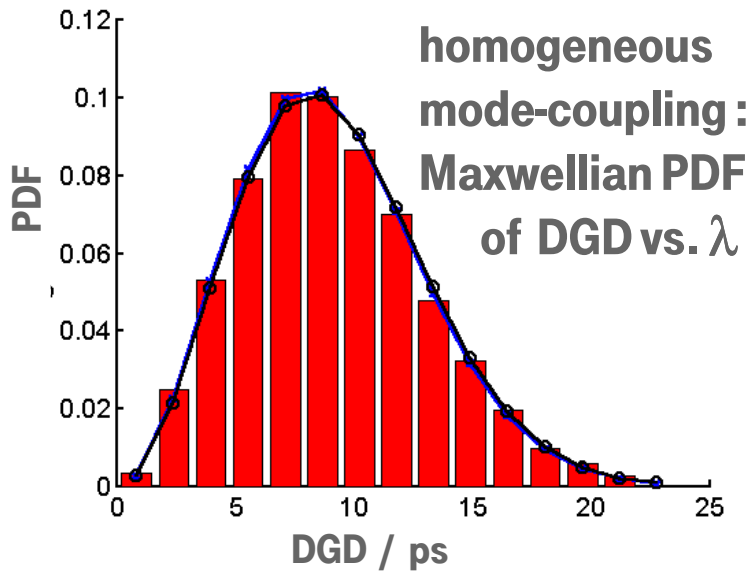
BACKUP

PMD as Bottleneck for 40Gbit/s Long-Haul Systems Introduction

Percentage of fibers suitable for 2.5 Gb/s, 10 Gb/s and 40 Gb/s over various link length
(Additional PMD contribution due to OLAs, DCF's neglected)

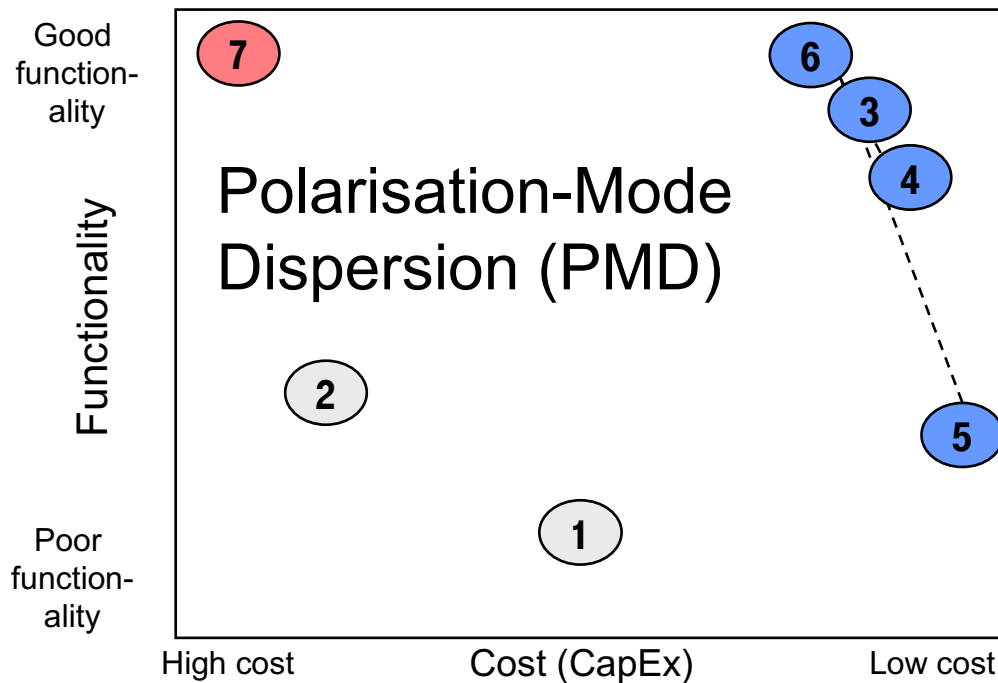


Probability Distribution with Strongly Inhomogeneous Birefringence Distribution



Solutions against PMD

Assessment of solutions against PMD (for bitrates of 40Gbit/s and beyond)



Type of approach	
●	Robust technology enhancements
○	Performance limitation
●	Network transformation

Solution Approaches

- 1 ■ Limit transmission speed per channel to 10 Gbit/s
- 2 ■ Limit optically transparent distance by using O/E/O conversion (transponders)
- 3 ■ Optical or electrical compensation schemes
- 4 ■ Develop modulation schemes with less bandwidth requirements
- 5 ■ Develop codes for correction of PMD caused errors
- 6 ■ Combine solutions 3, 4, 5
- 7 ■ Install new fibres

Typically Expected Gain from Different PMD Mitigation Approaches

- Pure receiver tolerance, NRZ (5 min/year outage) 10%...12% PMD/T_{bit}*
*) PMD is the average <DGD>, Tbit is the bit period.
 For the Rx tolerance limit the system outage (>1 dB BER penalty) of 5 min/year (DT internal standard) was applied. See also ITU-T G.691.
- 1+1 protection scheme +4%
- RZ instead of NRZ +4% (med.size duty cycle)
- FEC inband (SDH/SONET) +1% (more if noisy)
- FEC outband Reed Solomon(7%OH),ITU-T G.709 7+10%
- Super-FEC / double stage FEC (10dB OSNR gain) 7+15% ca.
(1st-order approximation, only, regarding vertical eye closure due to horizontal eye closure)
- Nonlinear Kerr trapping (PM-XPM) +10%
- 1st-order PMD-compensator +20%
- 1st+higher-order PMDC (diff.No.of degr.of freedom) +25%...+30%...>+30%
- New fibres (LDV>0.1ps/sqrt(km)) replacing ITU-T standard 0.5 ps/sqrt(km)
 7++40%** (++ of already obtained)
- **) the values are obtained by a comparison of relaxed PMD impact at the receiver due to the use of better fibres with the effective impact mitigation obtained by using,e.g., PMDC.
- DQPSK (and other multi-level formats) ++10% (++ of already obtained)
- Further: FFE+DFE, MLSE, λ-protection/restoration, FEC+Scramblers
 +10% +13% +% depends +??%

Status partly from 2003, later maybe improved values