Summary of Proposed Optical Reach Objectives

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IEEE 802.3 400 Gb/s Ethernet Study Group

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Foreword

- **This deck is a summary of material presented only, and should not be considered support on my part of any proposals.**

- **I have focused on objectives related slides.**

Reach Objectives – 40G/100G Historical Perspective

Objective	.3ba	.3bg	.3bj	.3bm	.3bq
XLAUI / CAUI (n X 10 Gb/s)	✓				
CAUI (4 x 25 Gb/s)				✓	
Backplane – 40 Gb/s	✓				
Backplane – 100 Gb/s			✓		
TwinAx – 40 / 100 Gb/s (nx10 Gb/s), 7m	✓				
TwinAx – 100 Gb/s (4x25 Gb/s) , 5m			✓		
Twisted pair – 40 Gb/s, 30m					✓
MMF 40/100 Gb/s (nx10 Gb/s) , 100/150m	✓				
MMF 100 Gb/s (4x25Gb/s), 20/100m				✓	
~~SMF 100 Gb/s, 500m~~				✓	
SMF 40 Gb/s, serial 2km		✓			
SMF 40 Gb/s (4x10 CWDM), 10km	✓				
SMF 100 Gb/s, (4x25 WDM), 10km	✓				
SMF 40 Gb/s (4x10 CWDM), 40km				✓	
SMF 100 Gb/s (4x25 WDM), 40km	✓				

May 2013 Straw Polls

PMD	Chicago Rules (#2)*	Choose 1 (#5)
400 GbE Backplane	25	2
400 GbE Twin-Ax	15	2
400 GbE MMF	39	9
400 GbE SMF	62	49
No PMDs	2	0

Presentation	100m	500m	1km	2km	10km	40km
maki_400_01a_0513	x	x				
song_400_01_0513	x					
trowbridge_400_01_0513	x	x		x	x	x
hirai_400_01_0713					x	x
issenhuth_400_01_0713		x	x	Beyond 1km		
jewell_400_01a_0713	X (200m)	x				
nicholl_400_01_0713	←	→	←	—	—	→
palkert_400_01_0713	x	x		x	x	x
song_400_01a_0713				x	x	
takahara_400_01_0713		x			x	x
vijn_400_01a_0713		←	—	—	—	→
wenyu_400_01_0713		x		x	x	x
palkert_400_01_0913	←	—	→			
song_x_400_01_0913				x	x	x

High Level Summary

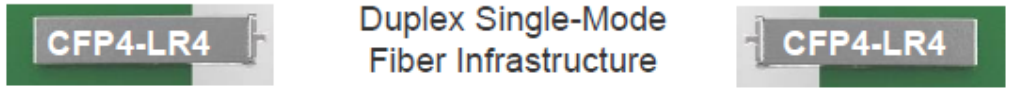
- **Data Centers –**
  - **MMF – Short Reaches up to 200m proposed**
  - **SMF – 300m to 1km**
- **Internet Exchanges**
  - **MMF – none**
  - **SFM – up to 40km**
- **Service Providers**
  - **2km, 10km, 40km**

May 13 Meeting

maki_400_01a_0513

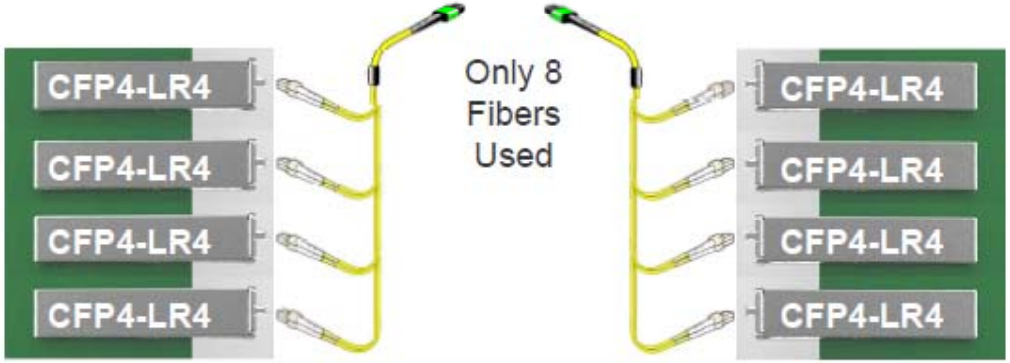
400GE over SMF by using the 100GBASE-LR4 PMD

100G Ethernet up to 10 km



400G Ethernet up to 10 km

Parallel Single-Mode Fiber Infrastructure
(Actual distance limited by market adoption)



JUNIPER NETWORKS

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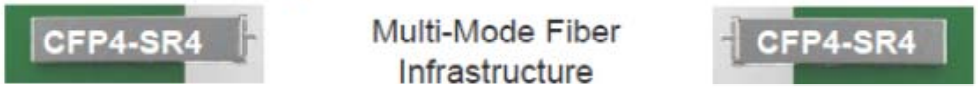
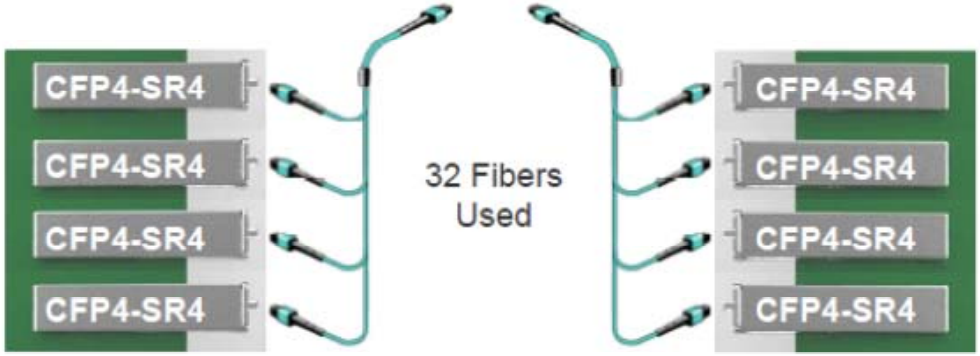
400GE over MMF by using the 100GBASE-SR4 PMD

100G Ethernet up to 100 m on OM4



400G Ethernet up to 100 m on OM4

Parallel Multi-Mode Fiber Infrastructure



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Potential Objectives for 400 Gb/s Ethernet Task Force

Define 400 Gb/s PHY for operation up to at least 500-meters of SMF

Define 400 Gb/s PHY for operation up to at least 100-meters of MMF

song_400_01_0513

Options for 400GbE MMF optical interfaces

- If 100GBASE-SR4 will work at 100m reach w/ FEC over OM4, then the 400GBASE-SR16 will also work at 100m over OM4.

- But the contributors are of the opinion that it may be difficult to agree on a useful objective for 400GbE multimode fiber applications because it may require one (or a combination) of the following solutions:
  - Extending the total number of fibers per module from 2x4 to 2x16 which is 32 fibers per link which seems rather challenging.
  - The introduction of WDM solutions on multimode fiber, not "easy" for the 850nm window of operation.
  - Increase of the bit-rate per fiber, which will be difficult in view of the limited bandwidth of multimode fibers.

HUAWEI TECHNOLOGIES CO., LTD. IEEE 802.3 400 GbE Study Group Page 4 HUAWEI

Single Mode Fiber Objective(s)

- Study and Debate required to identify feasible combinations of reach, modulation (not written in objective), and cabling type
- Dimensions to be studied:
  - Feasible modulation formats (bits per symbol)
  - Feasible number of wavelengths per fiber
  - Feasible number of fibers per cable at a given reach
- Possible objectives/objective forms – any or all of the following might be appropriate
  - At least 40km over duplex SMF
  - At least 10km over duplex SMF
  - At least 2km over duplex SMF
  - At least 500m over (parallel) SMF

7

trowbridge_400_03_0513

MMF – possible objective forms

- If 100GBASE-SR4 has 100m reach over OM4, then a 400GBASE-SR16 would also work at 100m over OM4, however 32 strands of fiber could exceed what is considered to be a practical implementation
- Questions to be answered:
  - What cable size(s) would be acceptable to end users?
  - What alternative modulation (e.g., PAM4) or multiplexing (e.g., WDM) could be used over MMF to reduce the number of lanes, and what reach could be achieved based on those techniques?
- Based on those answers, agree on an objective to provide 400 Gb/s operation over:
  - At least **y** m over OM**x** MMF (determining the values of **x** and **y** appropriately)

8

July 13 Meeting

flatman_400_01_0713

3

Need to Assess Acceptance/Reluctance of PSM in the Data Centre

- PSM4 is 1 of 5 candidates for P802.3bm 500m SMF objective
- *mixed messages* being received on PSM
  - a question of system cost effectiveness?
  - will it fit with existing SMF infrastructure?
  - does PSM offer evolutionary potential?
- need for an independent assessment
- no conclusions have been drawn by the authors - this is intentional!
- survey also relevant to 400G Study Group

Contribution to IEEE 802.3 400G SG; 16-18 July 2013, Geneva, CH

hirai_400_01_0713

1. Motivation & Scope

HITACHI
Inspire the Next

Motivation

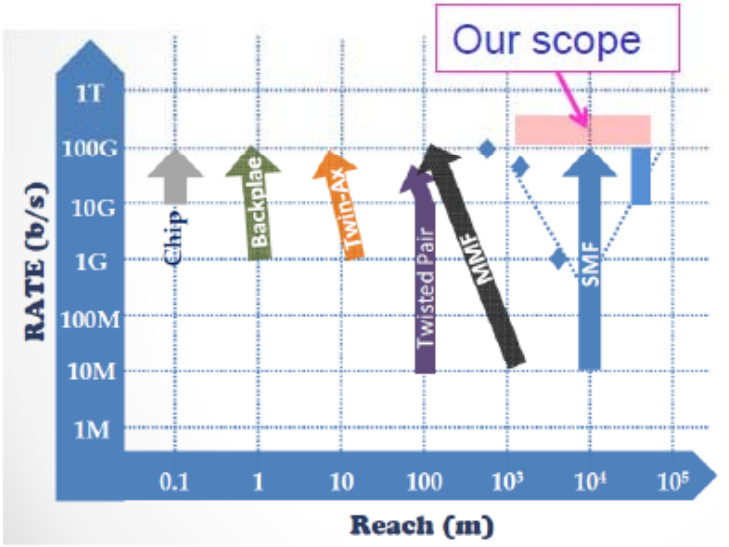
Increase of data rate over SMF 10-40km would be required, similar to other PHYs.

So, we think simultaneous discussion about over 100G transceiver for LR & ER is needed.

Scope

Towards a discussion about 400GbE LR & ER transceiver, we will show our thought regarding the followings;

- Number of lanes
- Symbol rate (Modulation speed)
- Modulation format & FEC



http://www.ieee802.org/3/400GSG/public/13_05/dambrosia_400_02_0513.pdf

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Interconnections

- Multiple interconnection lengths are required
- There are multiple colo areas per data center so the total number of links will vary
- All link quantities are per colo area

A End	Z End	Link Quanity	Link Length	Type of interconnection
Server	TOR	10,000s	.5-3m	TwinAx
TOR	LEAF	1,000s	1-20m	AOC
LEAF	SPINE - local	100s	20-300m	SM fiber
LEAF	SPINE - inter building	1,000s	100-400m	SM fiber
SPINE	DCR	100s	100-1,000m	SM fiber
INTRA METRO		100s	1,000m+	SM fiber

Global Foundation Services

jewell_400_01a_0713

Longer-wavelength Gen1 options for 400GbE

- 16x25Gb/s at ~950nm
  - 100m reach on OM4
  - back-compatible with 4X100GbE (2nd-gen) modules*
  - ~200m reach on "OM4-950" (OM4-quality MMF optimized for 950nm) with 16ps rise/fall time
  - **200m reach objective?**
  - 100m reach on "OM4-1060"
  - Better-suited for future-gen faster line rate (CEI-56)
- 16x25Gb/s at ~1060nm
  - <100m reach on OM4
  - back-compatible with 4X100GbE (2nd-gen) modules*
  - ~250m reach on "OM4-1060" with 16ps rise/fall time
  - **200m reach objective?**
  - Better-suited for future-gen faster line rate (CEI-56)

* Requires broadband (840-1060nm) detectors on 100G modules

nicholl_400_01_0713

"Within the building"

Source: Google Search

- 0-500m
- Addressing interconnect among equipment within the data center and service provider central office
- Historically a mix of MMF and SMF solutions, but trending towards SMF only as data rates increase.
- Likely to be the dominant optical 400GbE PMD (think 10GBASE-SR)
- A duplex, SMF solution is preferred (all else being equal)
- Solution likely to be based on 4 x WDM 100G Adv mod
- Will likely require a different coding structure and significantly more powerful FEC than 802.3 bj (e.g. DSQ coding, MLC FEC)

8

"Outside the building"

Source: Google Search

- 500m – 40km
- Addressing campus and metro interconnect space
- Typically connecting buildings over single, dark fiber, SMF links
- Duplex, SMF a hard requirement
- Solution likely to be based on some combination of WDM / Adv Mod
- Will again require a significantly more powerful FEC than 802.3bj, and likely a more powerful than the 500m "data center interconnect' solution,

9

palkert_400_01_0713

What reaches should be considered?

- 3-7m for intra rack
- 30-100m for inter rack
- 500m for data center
- 2km for telecom central office
- 10km for long reach
- 40km for extended reach

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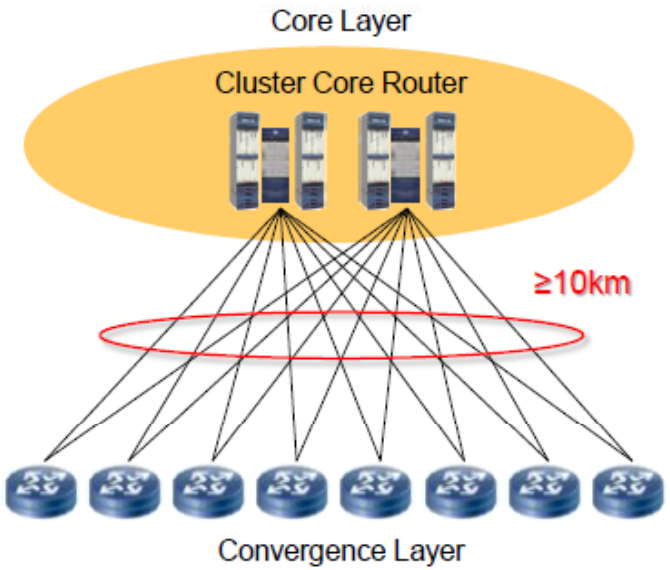
Scenario 1: Optical Interconnection of IP Core



- **The typical application:** the interconnection between the cluster core Router in the core layer and the router in convergence layer.
- **The typical reach:** from 10km of SMF and above.

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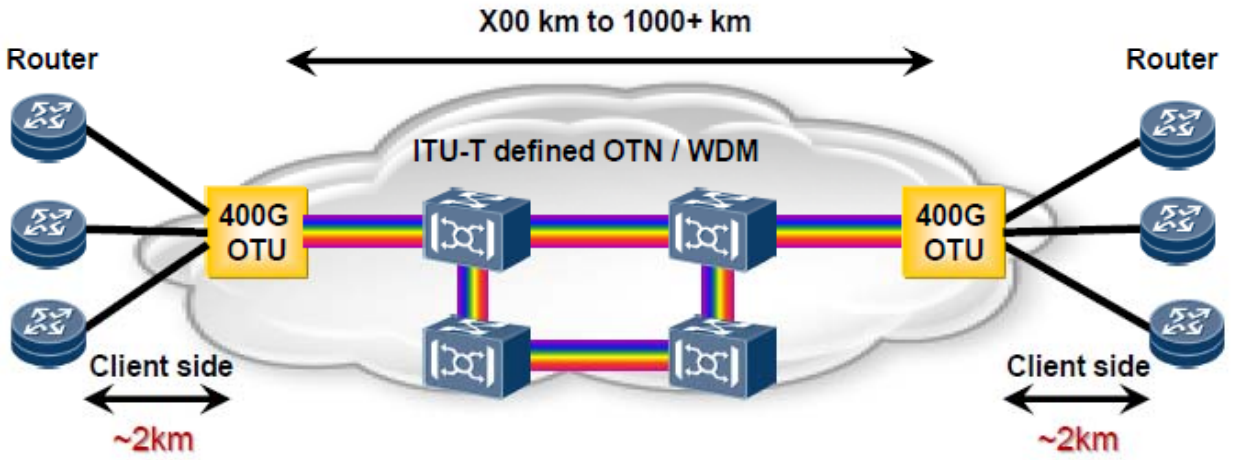
Scenario 2: Optical Interconnection between IP Core & Transport



- **The typical application:** the interconnection between core Router and OTN transport inside the central office of Carrier.
- **The typical reach:** the Router and the OTN are always in the different site (office), the most application is about 2km and some of the scenario may over 2km. Carriers are interested in the usage of duplex SMF, except for some shorter reach interconnections.

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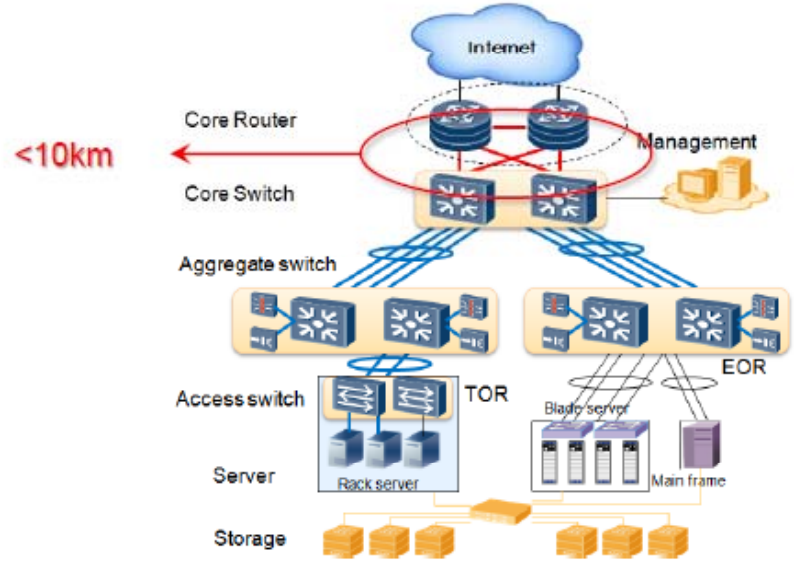
Scenario 3: Optical Interconnection of Intra Data Center



- <10km optics is typically deployed for the application between Core Router and Core Switch.
- Market demand from Intra-DC is a cost-effective solution and the 500m SMF objective from BM satisfied the needs from data centers.

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The Perspective on 400GbE SMF PMD Objectives

- **Taking into consideration the "lessons learned" from previous standards:**
  - Define a 400 Gb/s PHY for operation up to at least 10km of SMF.
  - Define a 400 Gb/s PHY for operation up to at least 2km of SMF, with the note "if it can be shown that a SMF PMD with a shorter reach than 100GBASE-LR4 has sufficient cost, density, or power difference to justify an additional SMF PMD type".
- **In this way there is an opportunity to investigate potentially different solutions for 2km and 10km, one being a "quick" solution, e.g. for 10km, and a lower cost solution, e.g. for 2km, operating with fewer optical lanes than 16.**
- **In this way it may be possible to avoid waiting for 400GE modules enabling a higher density.**

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Summary

- To provide the perspective of a networking equipment vendor with considerations for application space and objectives for 400Gb/s PMDs.
- To enable quick time to market, to define a near term solution by scaling up mature 100Gb/s PMD, in order to address the emerging needs for initial 400GbE applications.
- Define an improved medium term solution enabling lower cost and a higher port density by reducing the number optical lanes based upon advanced modulation.
- **Proposed Objectives for SMF PMDs for the 400GbE Study Group**
  - At least 10km over duplex SMF
  - At least 2km over duplex SMF

takahara_400_01_0713

From the Single Mode Fiber 100GbE

PMD	100GbE Standard	400GbE Standard
SMF (At least 500 m)	On-going discussions	Required
SMF (At least 10 km)	100GBASE-LR4	Strongly required
SMF (At least 40 km)	100GBASE-ER4	Strongly required
SMF (At least 80 km)	None	?

For client side interface of transport, transmission distance is an important factor to specify the equipment performance.
Especially 10 km and 40 km will be “must” two categories.

takahara_400_01_0713

Summary

- 10 km & 40 km are needed for 400GbE from the view point of industry demand.
- Single fiber solution will be the point, especially for 10km and 40km, from the extension feasibility of early adopters solution.
- Discrete Multi-Tone feasibility for 100 Gbps transmission was already reported to the group, with the evidence of data.
- DMT with combined WDM technology is a promising feasible solution for 400GbE.

vijn_400_01a_0713

Cabling

- Duplex single mode fibre
  - Don't bother about multi mode
- Fibre lengths
  - Up to 40km, direct or with low costs amplifiers or transmission equipment

wenyu_400_01_0713

工业和信息化部电信研究院
China Academy of Telecommunication Research of MIIT

400GE SMF target distance discussion(2)

400GE SMF major application field and target distance

1.Large scale data-center intra-connections
500m may be enough in data-center application and at the same time it may reuse 100GE target distance.*(300m will meet most of all data center intra-connections demand in near future in China.)*
2. Metro inter-connections between IP routers
For metro IP application, IP router may use 400GE interface as the PHY to connect directly, and reuse existing10km & 30~40km target distance may be preferred.
3. IP routers and WDM/OTN transport inter-connections
Typical distance between IP routers and WDM/OTN transport equipment is 2km. A few will be between 2km and 10km as equipment room rearrangement .Thus 2km may be another option for 400GE SMF target distance.

400GE SMF target distances are proposed as follows:
(1)500m (2)2km;(3)10km;(4) 40km; and 2km is the competitors with 10km in some ways.

wenyu_400_01_0713

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Summary

1.100G has begun its scale deployment in carriers and research networks in China. It is expected that 100G have the similar life cycle as 10G.

2.China telecom backbone capacity will be up to 37Tb/s in 2017. Currently data-center dominant bit-rate is 10G and 400G demand may appear firstly in long-haul application in China.

3.Target distance may be the balance among application demand, cost, size ,power etc., and (1)500m (2)2km;(3)10km;(4) 40km are proposed as the target distance for 400GE SMF.

4. 400GE SMF have several possible optical transmission solutions , and they are closely related with transmission distance , 16 × 25G WDM and 8 × 50G PAM-4 may be the major proposal candidates in short term. System performance & cost evaluation of these competitors can be investigated in detail in the next step.

Sept 13 Meeting

palkert_400_01_0913

Data center media usage

- Some data centers use mixed media
  - Uses MMF for shorter reaches, SMF for longer reaches
    - Past solutions have taken advantage of lower cost MMF modules
- Some data centers have SMF only
  - Use SMF for both short and long reaches
    - Takes advantage of cost savings of a single media

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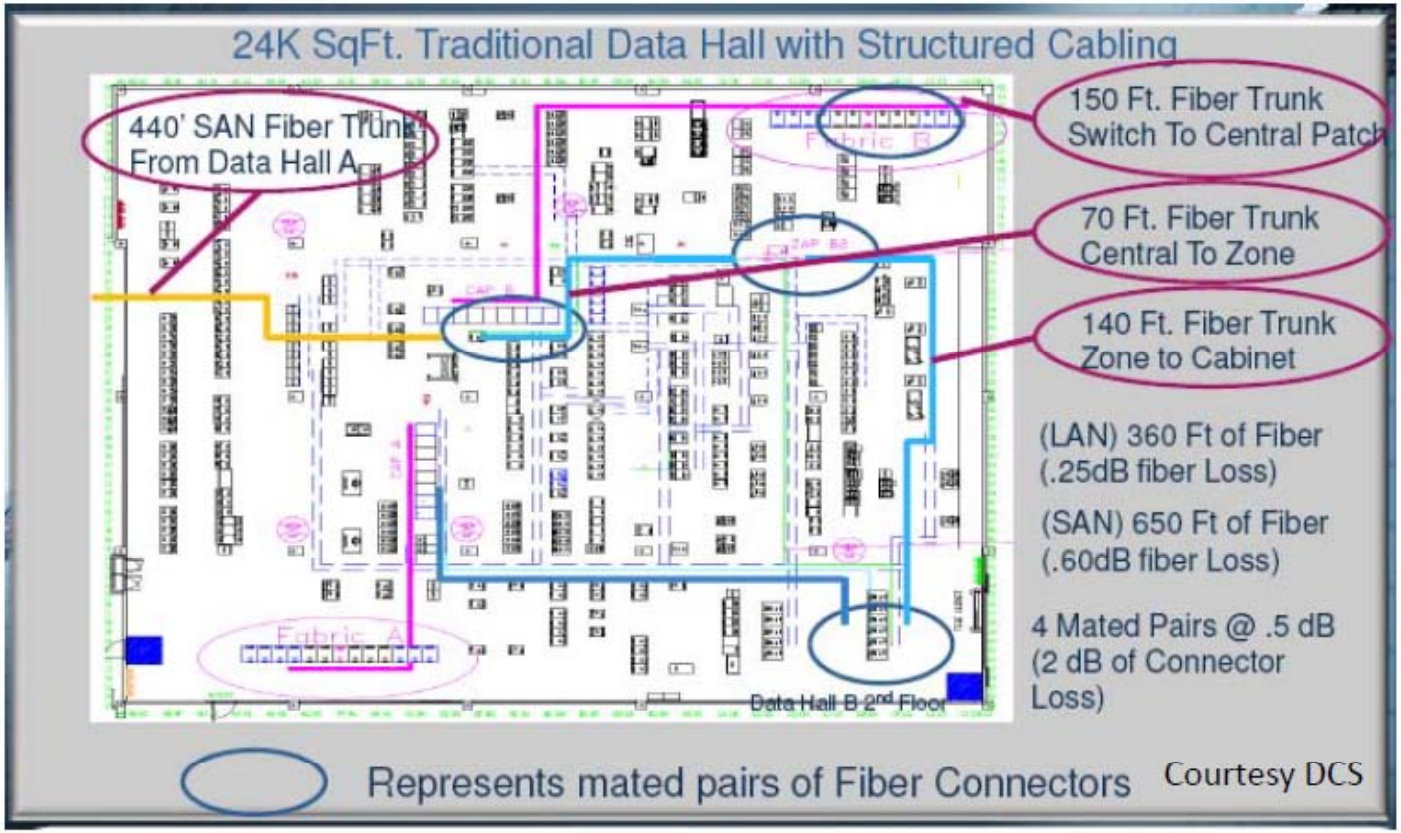
Mixed Media Data Center



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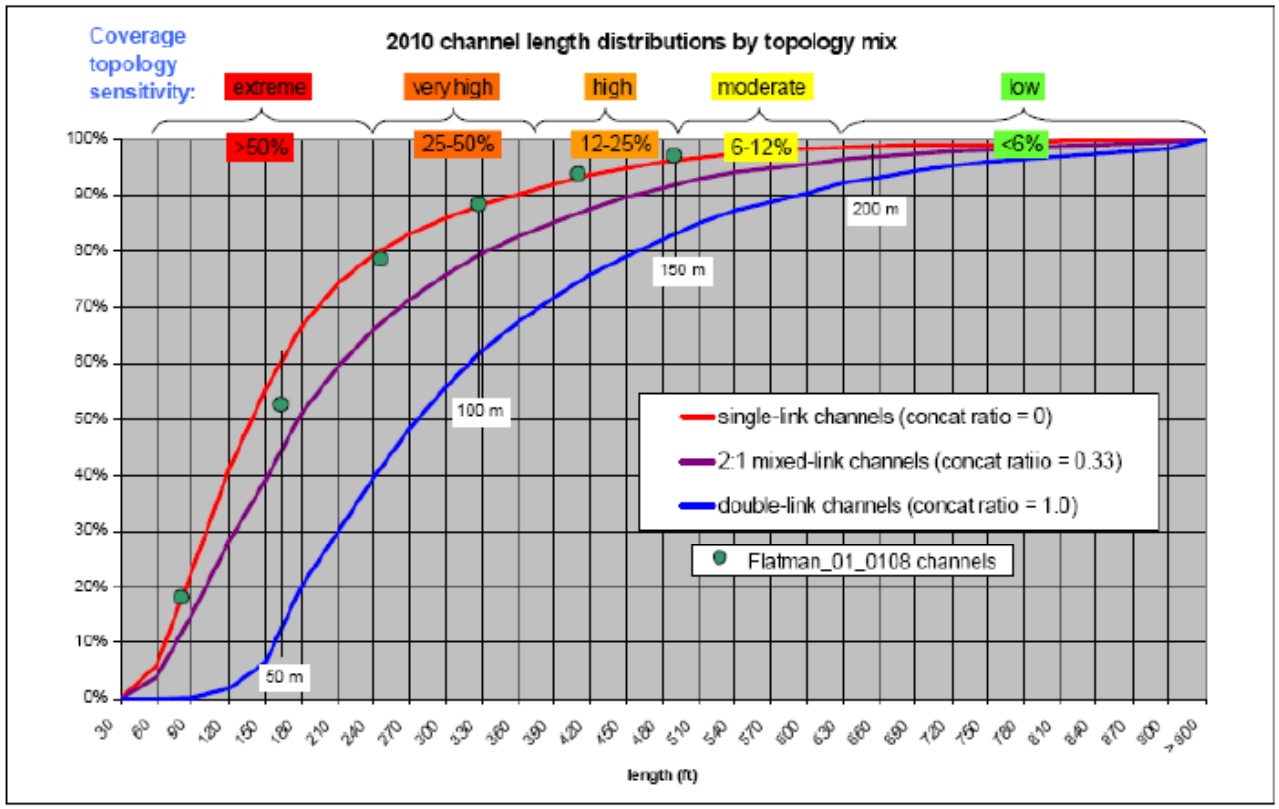
Link Distributions in 2010
(We need this for 2015)



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Conclusion

- For Broad Market Potential 400G should consider objectives that minimize the overall interconnect cost of the data center.
  - Data centers require:
    - a mix of MMF, SMF
    - all SMF
  - We should not shy away from multiple objectives

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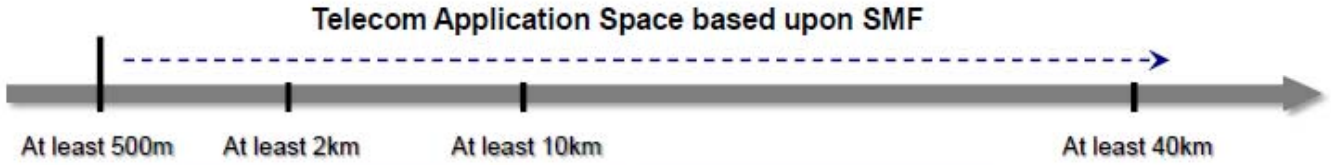
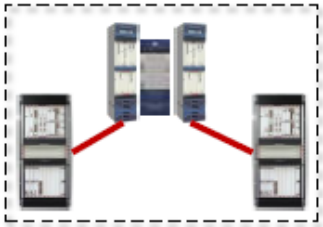
Motivation and Application Space of 400GbE SMF



Connections between IP Core Routers and OTN

Connections between IP Routers



- Telecom application is an important domain for the first adoption of 400GbE.
  - Connections between IP Routers suggest an SMF distance objective of 10km, and additionally 40km for some of the Metro applications. Duplex fiber solutions are regarded necessary for both applications.
  - Connections between IP Core Routers and OTN equipments, suggest SMF distance objective of 2km. Also in this case Duplex fiber solutions are regarded necessary.
- So we definitely need an SMF distance objective of 10km.
- If we can generate a specification for at least 2km which enables a significantly lower cost solution than for 10km then a 2km SMF objective should be added.

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Summary

- Proposed Objectives of SMF PMDs for the 400GbE Study Group:
  - At least 2km over duplex SMF
  - At least 10km over duplex SMF
  - At least 40km over duplex SMF (1st or 2nd generation?)
- To enable the quick time to the market, a 8x50Gbps PAM4 architecture, scaling up mature 25/28Gbps platforms and leveraging the technology of 100GbE generations, may be a promising candidate to satisfy a 10km SMF objective, 400GbE telecom applications and the fast growth Ethernet bandwidth.
- A four lane solution based upon a 4x100Gbps PAMn architecture, with potential economic advantages in the future, may be a candidate solution for 2km applications and not for 10km because of expected performance limitations.
- DMT and Multi-CAP may be potential candidates to satisfy 40km SMF objectives, but research is needed on the modulation format and the algorithm to ensure the interconnection and interworking. We may need to discuss to put a 40km objective in the second generation of the 400GbE specification.