Innovative R&D by NTT

Optical transmission feasibility for 400GbE extended reach PMD

Yoshiaki Sone NTT

IEEE802.3 Industry Connections NG-ECDC Ad hoc, Whistler, May 2016

Introduction

Innovative R&D by NTT

■Background

Service provider's need for 400GbE extended reach optical PMD

- 400 GbE Extended Reach PMD (NG-ECDC Ad-hoc, Atlanta, Jan. 2016)
- 400GbE Requirement in MBB and FBB (NG-ECDC Ad-hoc, Macau, Mar. 2016)

Technical investigation for 200GbE/400GbE extended reach transmission

- FEC Options for Extended Reach of 50/200/400GbE (NG-ECDC Ad-hoc, Macau, Mar. 2016)

■Purpose of this presentation

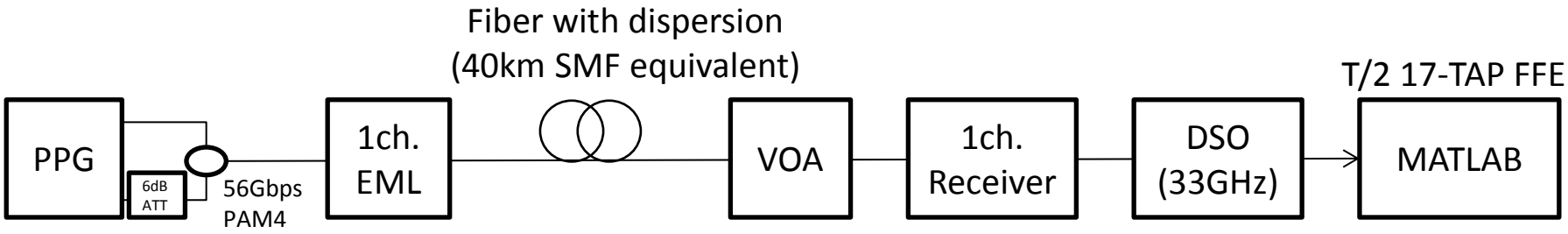
Show technical feasibility for 400GbE Extended reach optical PMD.

- 56Gb/s PAM4 optical transmission experiment assuming 8-lane 400GbE
  - Receiver sensitivity with EML and APD receiver (PIN-PD for reference)
  - Worst-case dispersion penalty assuming 8x56G PAM4 (LAN-WDM) transmission over 40km SMF

NTT

Evaluation overview and summary of results

1ch. 56Gbps PAM4 optical transmission experiments using different EMLs and an APD/PIN-PD receiver. Dispersion of fiber is set assuming worst-case dispersion for LAN-WDM transmission over 40km SMF.



Tx	Fiber dispersion [ps/nm]	Rx	KP4 (limit=2E-4)		Stronger FEC(limit=1E-3 *2)	
			Min. receiver sensitivity*1 [dBm]	CD Penalty [dB]	Min. receiver sensitivity*1 [dBm]	CD Penalty [dB]
EML#1 ER=5.6[dB] 1304.3nm(L6)	-203	PIN-PD receiver	-18.6	~1.5	-19.4	~0.5
	0					
	+38					
EML#2 ER=5.8[dB] 1308.9nm(L7)	-203	APD receiver	-22.8	~1.5	-23.9	~0.5
	0					
	+38					

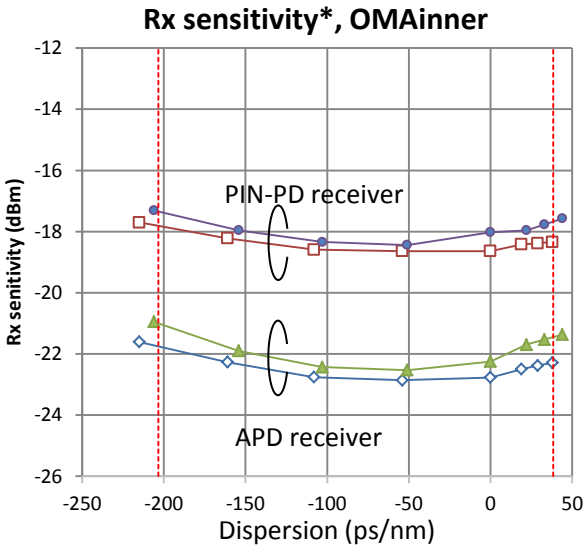
* 1 OMAinner, Without WDM-demux, value at zero ps/nm
* 2 tentative BER limit assuming possible FEC(s) stronger than KP4

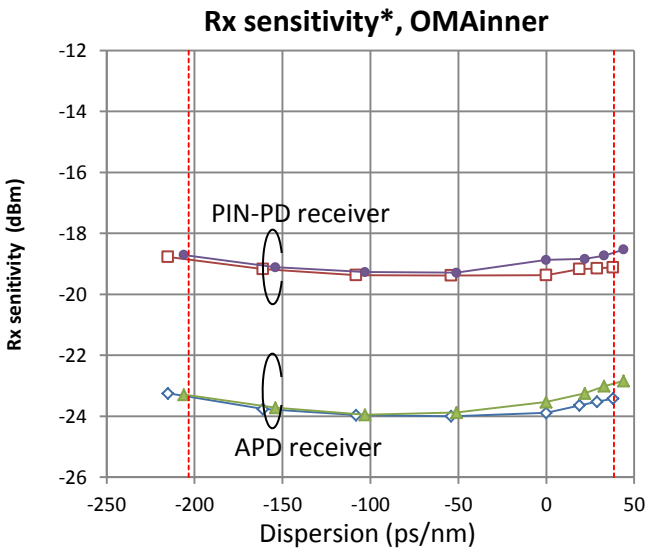
Evaluation results

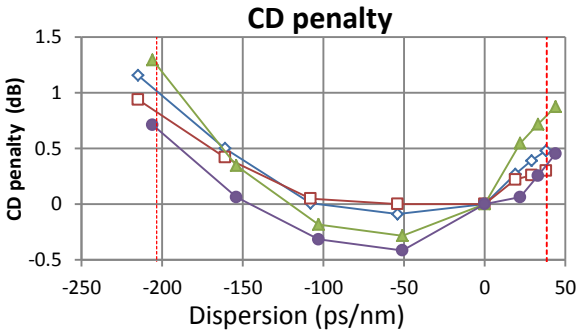
	KP4 FEC (limit = 2E-4)	Stronger FEC (limit = 1E-3)
Min. Rx sensitivity (EML#1):	-22.8 dBm	-23.9 dBm
Min. Rx sensitivity (EML#2):	- 22.2 dBm	-23.5 dBm
CD penalty :	~ 1.5 dB	~ 0.5 dB

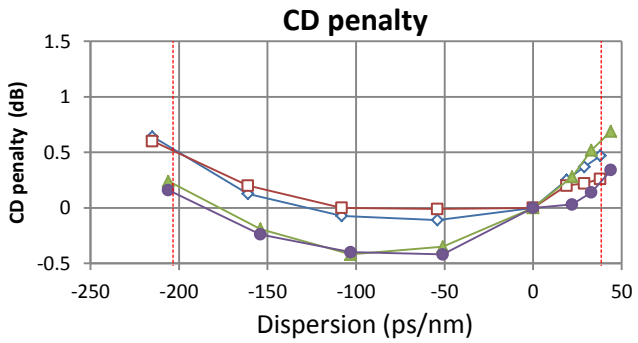
EML#1+APD
EML#1+PIN-PD
EML#2+APD
EML#2+pin-PD
Target dispersion
-203.3 to +38.5ps/nm

* Without 8λWDM demux loss







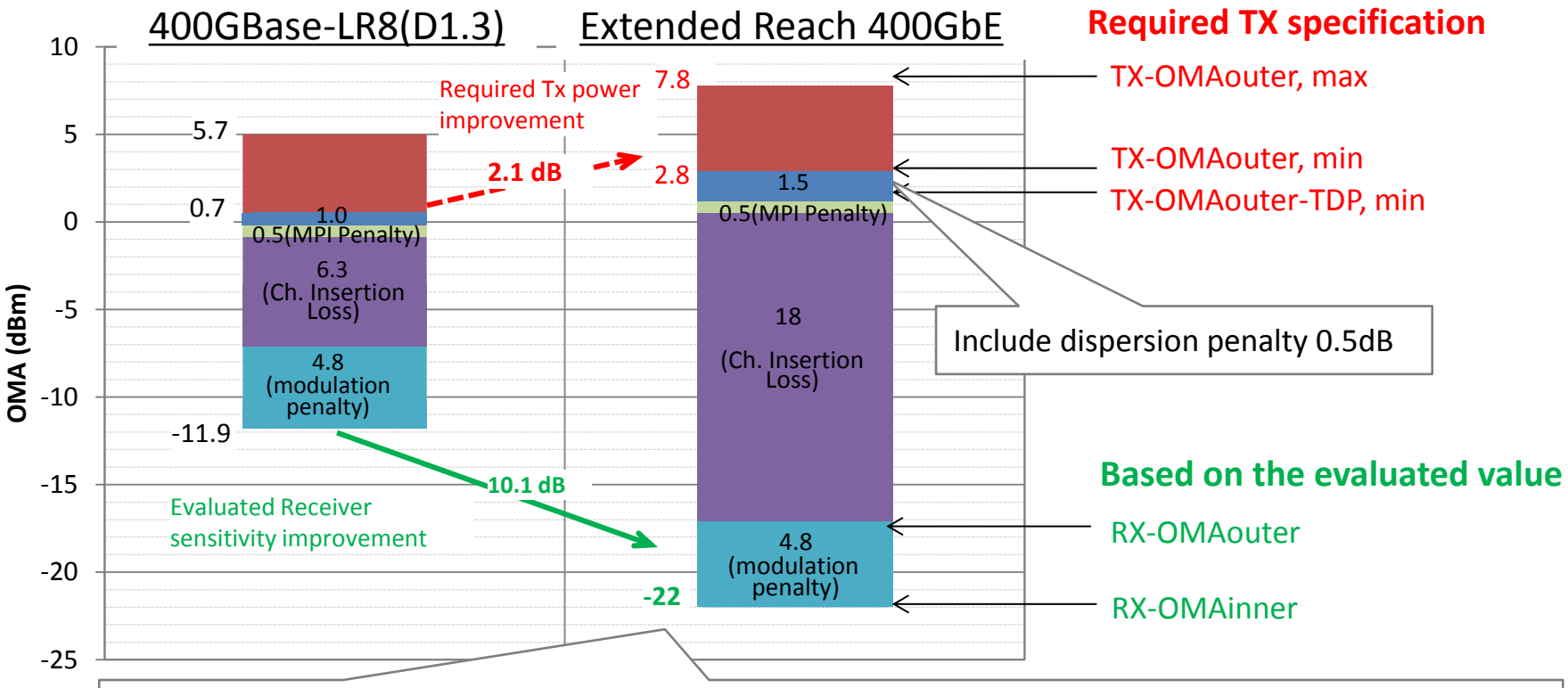


Example link budget consideration

Given the current receiver-sensitivity with 1E-3 FEC limit and FFE 17-TAP, additional 2.1dB budget is required for 18 dB Ch. insertion loss.

Possible approaches:

Higher TX-output power, further improved RX sensitivity, stronger FEC.



FEC limit is BER=1E-3. About 2dB WDM-demux loss is included from the evaluated RX sensitivity of 1.ch. APD receiver in slide #4.

Stronger FEC options

Innovative R&D by NTT

Some kinds of RS-FEC [e.g. RS(864,771,46,10)] or staircase FEC can permit >1E-3 FEC limit with <10% overhead.

Higher Gain RS FEC Option

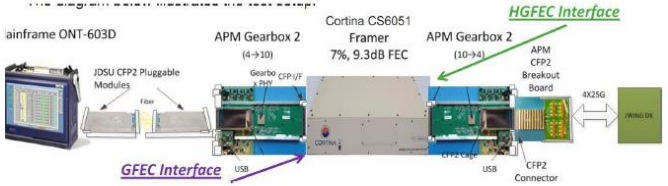
- In "wang_x_3bs_01a_0115", ~7.53dB net coding gain with ~9.09% overhead will be available for RS(864,771,46,10);
- Assuming ~16% overhead, RS(888,744,72,10) will get ~8.1dB net coding gain
- Assuming ~16% overhead, RS(592,496,48,10) will get ~7.9dB net coding gain
- Assuming ~23% overhead, RS(912,720,96,10) will get ~8.2dB net coding gain

RS FEC(n,k,t,m)	CG	NCG*	BERin	Overhead	SerDes Rate	Block Time	Latency**	Area Ratio
Group 1 : Similar RS FEC as KR4 FEC								
RS(528,514,7,10)	5.39	5.28	3.92E-05	0%	25.78125	51.2ns	~87ns	1X
RS(544,514,15,10)	6.64	6.39	3.09E-04	3.03%	26.5625	51.2ns	~112ns	2.9X
RS(560,514,23,10)	7.3	6.93	7.60E-04	6.06%	27.34375	51.2ns	~208ns	14.5X
RS(576,514,31,10)	7.76	7.26	1.30E-03	9.09%	28.125	51.2ns	~258ns	33.4X
Group 2 : Large Block RS FEC								
RS(1056,1028,14,11)	6.07	5.95	1.29E-04	0%	25.78125	102.4ns	~172ns	2.6X
RS(1088,1028,30,11)	7.12	6.88	6.06E-04	3.03%	26.5625	102.4ns	~315ns	16.7X
RS(1120,1028,46,11)	7.7	7.33	1.20E-03	6.06%	27.34375	102.4ns	~414ns	54.8X
RS(1152,1028,62,11)	8.11	7.61	1.90E-03	9.09%	28.125	102.4ns	~514ns	129.5X
Group 3 : RS(255,239) Like RS FEC								
RS(255,239,8,8)	6.12	5.83	1.39E-04	6.7%	27.5	18.9ns	~49ns	1.1X
RS(510,478,16,9)	6.85	6.57	4.21E-04	6.7%	27.5	42.5ns	~162ns	5.3X
RS(1020,956,32,10)	7.34	7.06	7.95E-04	6.7%	27.5	93.1ns	~304ns	27.2X
Group 4 : 256/257b coding friendly RS FEC***								
RS(800,771,14,10)	6.29	6.13	1.83E-04	1.01%	26.04	76.8ns	~140ns	2.6X
RS(816,771,22,10)	6.95	6.71	4.84E-04	3.03%	26.5625	76.8ns	~232ns	9.4X
RS(840,771,34,10)	7.58	7.22	1.10E-03	6.06%	27.34375	76.8ns	~306ns	30.6X
RS(864,771,46,10)	8.02	7.53	1.80E-03	9.09%	28.125	76.8ns	~379ns	72.1X

High Gain FEC Proposal in 802.3bs

- In "corbeil_01_1114_smf", staircase FEC is tested with DMT modulation SMF link

The framer used was a Cortina CS6051 which has a (9.39dB NCG) staircase FEC with ITU-G.975.1 compatible, 7% overhead a latency of <20us and a 1E-15 FEC threshold of 4.62E-3



- For ~7% over head, NCG=~8.37dB with Pre-BER=~4.7E-3 and Post-BER=1E-12

Latency	BERI for BERo=1E-12	Net Coding Gain @1E-12	BERI for BERo=1E-15	Net Coding Gain @1E-15
2.25Mb	4.70e-3	8.37dB	4.62e-3	9.41dB
2Mb	4.66e-3	8.36dB	4.55e-3	9.39dB
1.75Mb	4.62e-3	8.35dB	4.50e-3	9.38dB
1.5Mb	4.20e-3	8.25dB	3.80e-3	9.19dB

Refer to : http://www.stupi.se/Standards/100G-long-haul4.pdf

Ref. FEC Options for Extended Reach of 50/200/400GbE(NG-ECDC ad-hoc, Macau, Mar. 2016)

NTT

Emerging technologies for reach extension

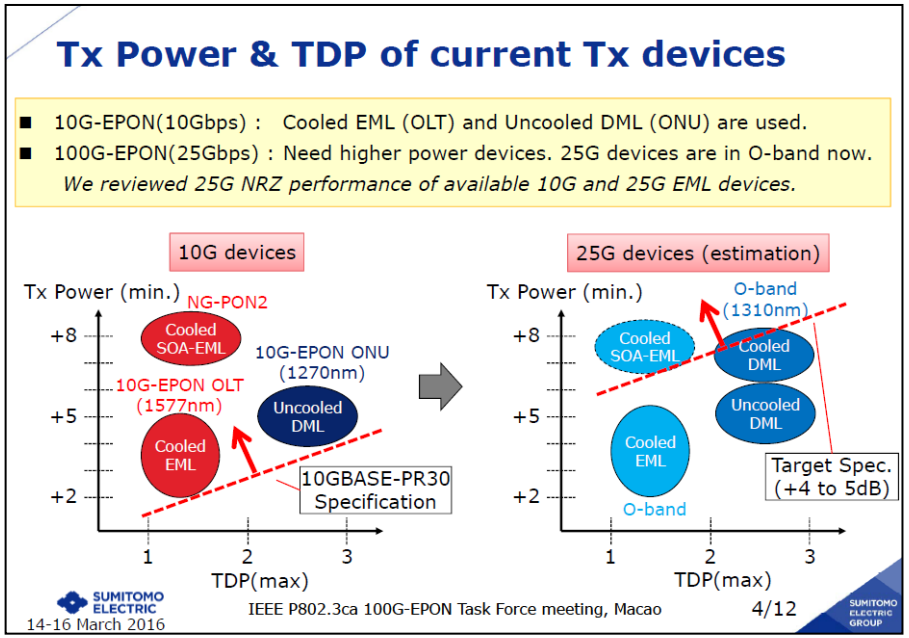
Innovative R&D by NTT

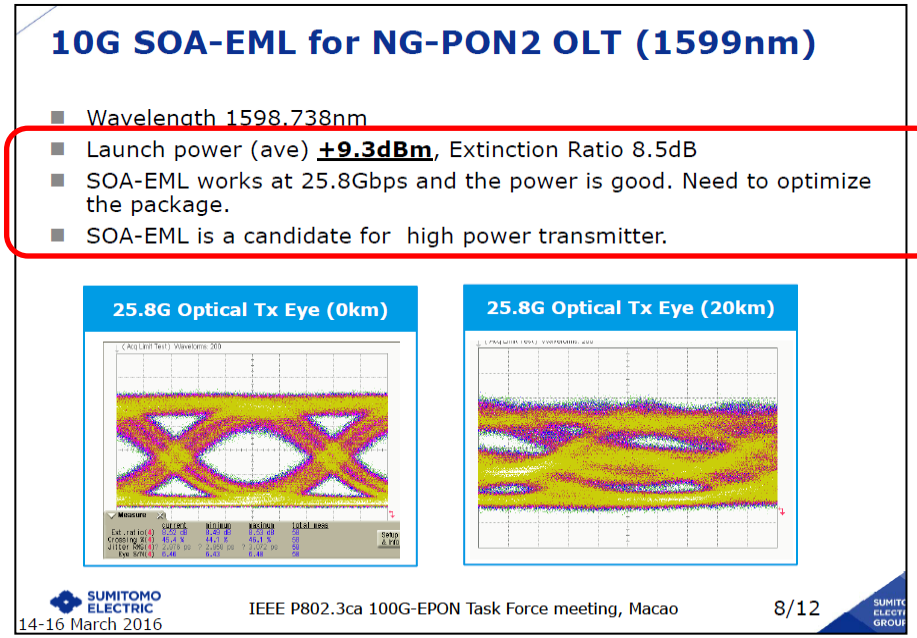
Required >2.1dB Tx-power increment is possible.

- Optimization of EML design or implementations
- Emerging technologies (SOA-EML)

[SOA-EML]

- Current public data show performance for 1.599μm (TX-OMA = 11dBm).
- Same performance is expected(in principal) for 1.3μm-band.





Ref. [25G NRZ Transmission](802.3ca, Macau, Mar. 2016)

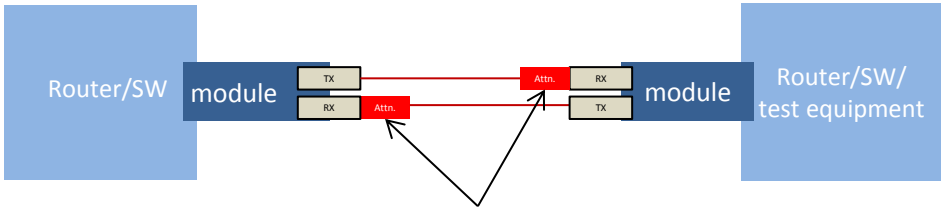
NTT

Operational constraint consideration

For ER module, some operational constrains can be relaxed if they enable low-cost implementations or increase implementation flexibility.

Minimum channel insertions loss

Support for optical back-to-back operation (Minimum attenuation = 0) is not mandatory.
Insertion of optical attenuators is acceptable.



Insertion of optical attenuators is acceptable.

Existing market experiences

	Minimum Attenuation
10GBase-ER	5 dB
40GBase-ER4	9 dB
100GBase-ER4*	0 dB

*The average receive power, each lane (max) for 100GBASE-ER4 is larger than the 100GBASE-ER4 transmitter value
to allow compatibility with 100GBASE-LR4 units at short distances.

Eye safety consideration

Considering ER module applications, class 1M(<16.3dBm*) is acceptable.
In the early market, ER modules will be deployed only in the private buildings such as service provider's buildings.

*For 1310nm from non-parallel-SMF

Conclusion

- Worst case dispersion penalty evaluated assuming 8x56Gbps PAM4(LAN-WDM) with EML over 40km SMF was <1.5dB.

- 400GbE Extended Reach(>10km) optical interface is technically feasible with APD receiver.

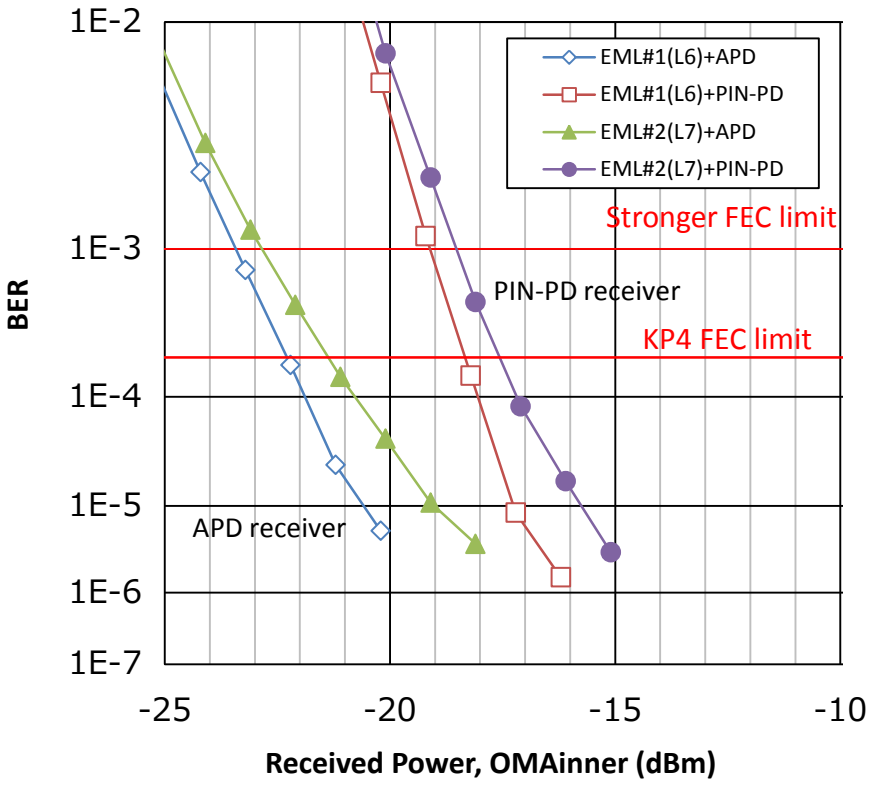
- Given latest technologies for transmitter, receiver and FEC, 40km reach is worth investigating for 400GbE Extended Reach PMD.

Backup slides

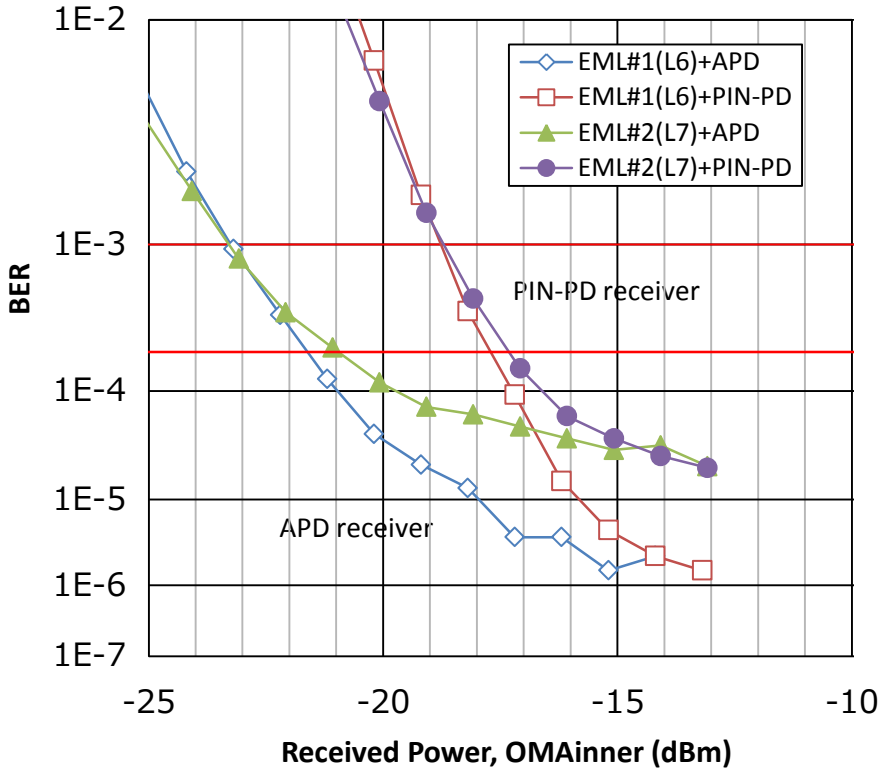
Measured BER at worst case dispersion

Innovative R&D by NTT

Worst-case positive dispersion:
+38ps/nm@L6, +44ps/nm@L7



Worst-case negative dispersion:
-215ps/nm@L6, -206ps/nm@L7



Without 8λWDM demux loss

NTT

400GbE 40km application

Extended reach interface is essential for inter-building connections in service providers networks.

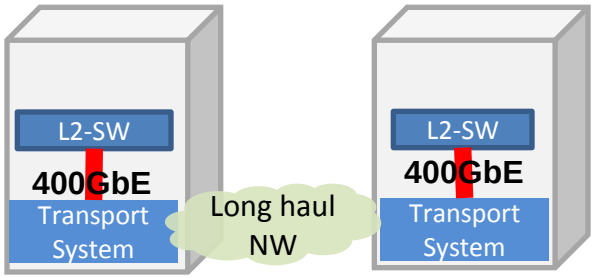
Media	Duplex single mode fiber		
Transmission distance	2km	10km	40km
Application	Intra-building Inter-building usage #1		Inter-building usage #2
802.3bs Objectives	✔	✔	-

10km reach:
Covers 50% of inter-building links
40km reach(For example):
Covers almost 100% of inter-building links

・low-cost solution for some metro areas
・low-latency

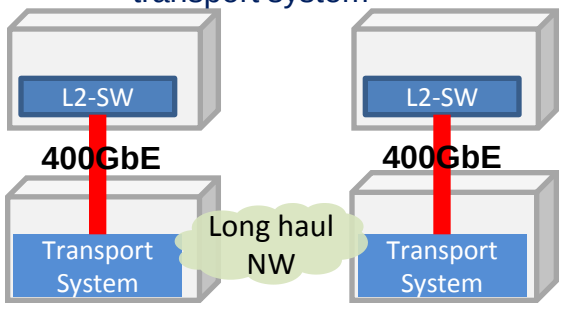
Intra-building usage
2km and 10km

L2SW/Router to long-haul transport system



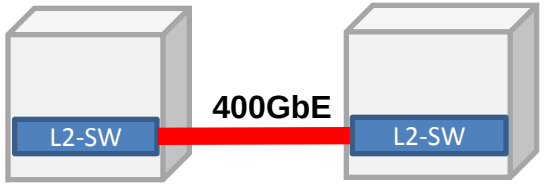
Inter-building usage #1
2km and 10km

L2SW/Router to long-haul transport system



Inter-building usage #2
10km and 40km

Direct connection without long-haul transmission system



Worst-case dispersion for 40km SMF transmission

Innovative R&D by NTT

Worst-case dispersion for SMF transmission

- Negative dispersion

$0.93 \cdot \lambda \cdot [1-(1324/\lambda)^4] = -203.3$ ps/nm

- Positive dispersion

$0.93 \cdot \lambda \cdot [1-(1300/\lambda)^4] = +38.5$ ps/nm

4 x LR8-value

Table 123–5—Wavelength-division-multiplexed lane assignments

Lane	Center frequency	Center wavelength	Wavelength range
L_0	235.4 THz	1273.54 nm	1272.55 to 1274.54 nm
L_1	234.6 THz	1277.89 nm	1276.89 to 1278.89 nm
L_2	233.8 THz	1282.26 nm	1281.25 to 1283.27 nm
L_3	233 THz	1286.66 nm	1285.65 to 1287.68 nm
L_4	231.4 THz	1295.56 nm	1294.53 to 1296.59 nm
L_5	230.6 THz	1300.05 nm	1299.02 to 1301.09 nm
L_6	229.8 THz	1304.58 nm	1303.54 to 1305.63 nm
L_7	229 THz	1309.14 nm	1308.09 to 1310.19 nm

Table 123–12—Transmitter compliance channel specifications

PMD type	Dispersion[a] (ps/nm)		Insertion loss[b]	Optical return loss[c]	Max mean DGD
	Minimum	Maximum			
400GBASE-FR8	$0.0465 \cdot \lambda \cdot [1-(1324/\lambda)^4]$	$0.0465 \cdot \lambda \cdot [1-(1300/\lambda)^4]$	Minimum	19.8 dB	0.8 ps
400GBASE-LR8	$0.2325 \cdot \lambda \cdot [1-(1324/\lambda)^4]$	$0.2325 \cdot \lambda \cdot [1-(1300/\lambda)^4]$	Minimum	17.6 dB	0.8 ps

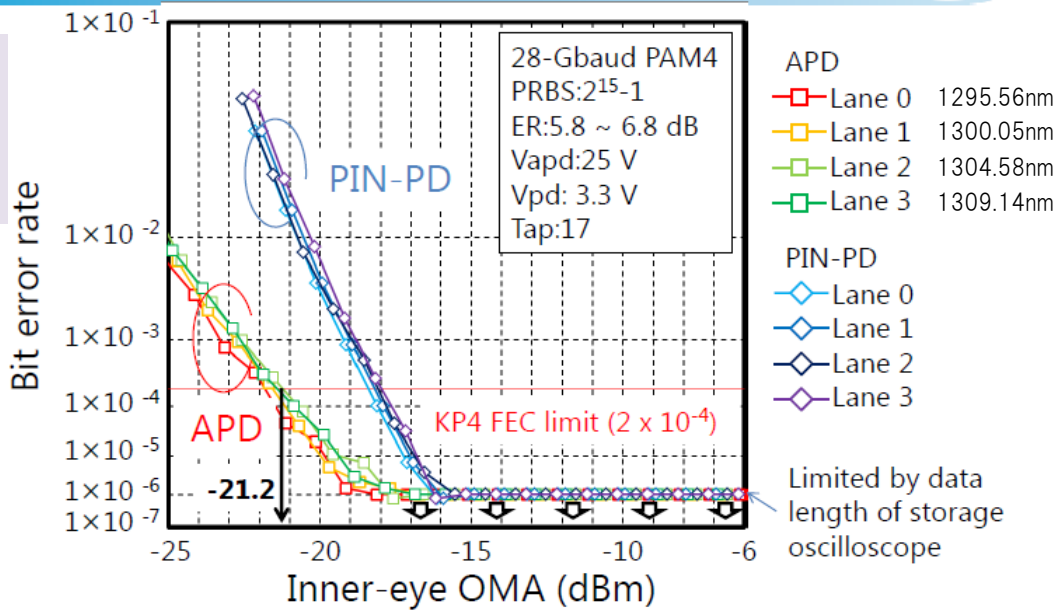
NTT

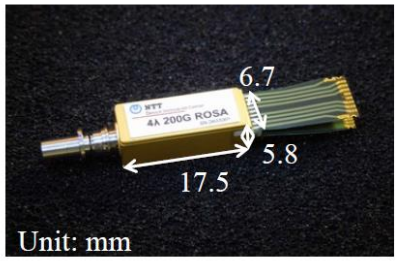
APD-ROSA performance example

Minimum receiver sensitivity (Inner-eye OMA) showed by the latest conference (OECC2015).
-21.2 dBm with KP4 FEC.　-23.7 dBm with BCH (9193, 8192) FEC,　-22.8dBm for 1E-3 limit

BER characteristics in back-to-back configuration

Source was modulated with a LN-MZ modulator of PRBS15





Receiver sensitivity: ≤-21.2 dBm for BtoB
Improvement of sensitivity: around 3.3 dB

Ref. Nakanishi, "4 × 28 Gbaud PAM4 Integrated ROSA with High-Sensitivity APD", OECC2015 PDP