Consideration on 200G per lane 500m and 2km objectives

Huanlu LI, Yan ZHUANG, Weiyu WANG, Shuangxing DAI, Qi DING, Yuchun LU

Huawei Technologies

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Observation of adopted physical layer objectives

Ethernet Rate	Signaling Rate	Electrical			Optical					
		AUI	Backplane	Copper Cable	MMF 50m	MMF 100m	SMF 500m	SMF 2km	SMF 10km	SMF 40km
200Gbps	200Gbps	Over 1 lane 200GAUI-1	TBD 200GBASE-KR1	Over 1 pair 200GBASE-CR1			Over 1 pair 200GBASE-DR1	Over 1 pair 200GBASE-DR1-2		
400Gbps	100Gbps							Over 4 pairs 400GBASE-DR4-2		
	200Gbps	Over 2 lanes 400GAUI-2	TBD 400GBASE-KR2	Over 2 pairs 400GBASE-CR2			Over 2 pairs 400GBASE-DR2			
800Gbps	100Gbps	Over 8 lanes 800GAUI-8	Over 8 lanes 800GBASE-KR8	Over 8 pairs 800GBASE-CR8	Over 8 pairs 800GBASE-VR8	Over 8 pairs 800GBASE-SR8	Over 8 pairs 800GBASE-DR8	Over 8 pairs 800GBASE-DR8-2		
	200Gbps	Over 4 lanes 800GAUI-4	TBD 800GBASE-KR4	Over 4 pairs 800GBASE-CR4			Over 4 pairs 800GBASE-DR4	Over 4 pairs 800GBASE-DR4-2 Over 4 lambdas 800GBASE-FR4	TBD Over 4 lambdas 800GBASE-LR4	**TBD Over 4 lambdas 800GBASE-ER4**
1.6Tbps	100Gbps	Over 16 lanes 1.6TAUI-16								
	200Gbps	Over 8 lanes 1.6TAUI-8		Over 8 pairs 1.6TGBASE-CR8			Over 8 pairs **1.6TBASE-DR8**	Over 8 pairs **1.6TBASE-DR8-2**		

https://www.ieee802.org/3/df/proj_doc/objectives_P802d3df_220317.pdf

Overview

Objectives of Interest: 200G/L SMF standards at 500m and 2km

- 200GE: 200GBASE-DR1, 200GBASE-DR1-2
- 400GE: 400GBASE-DR2
- 800GE: 800GBASE-DR4, 800GBASE-DR4-2
- 1.6TE: 1.6TBASE-DR8, 1.6TBASE-DR8-2

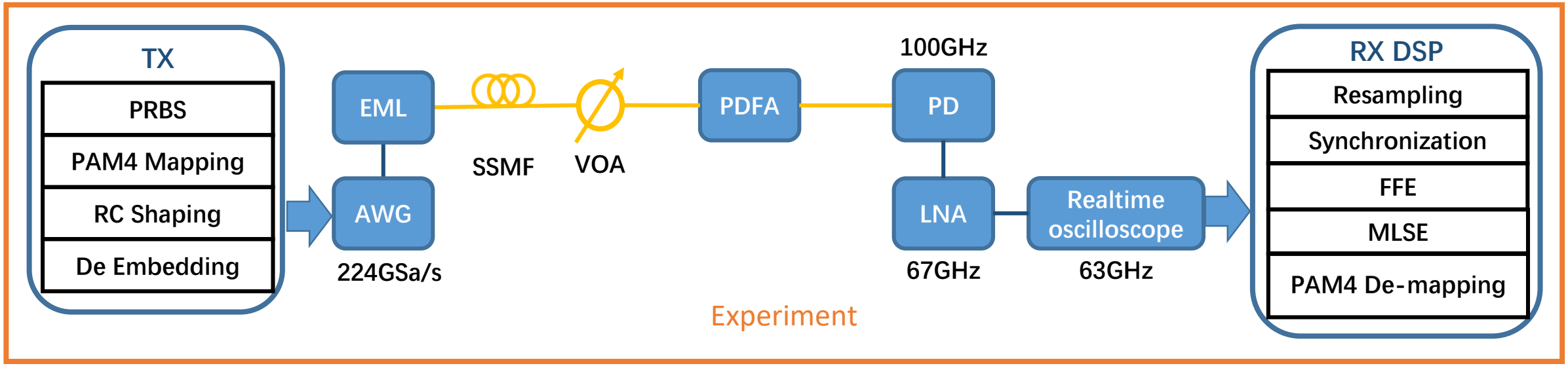
Primary Intent:

- Link performance and comparison of different rates
- Equalization options for 200G/L at 500m and 2km
- FEC options for 200G/L at 500m and 2km

Introduction

- Focus on 200G/L applications ≤2km, which has been previously discussed, kuschnerov_3df_01_220222, mi_3df_01a_2211, johnson_3df_01a_221011
- Leveraging 100G/L specs (ie, 400G-DR4), and shifting to 200G/L
- KP4/RS(544,514) may be viable for 200G/L, welch_3df_01b_220602
- This contribution presents simulations and experiments of 200G/L 500m and 2km DR transmissions with an offline DSP equalization(FFE/MLSE).
- This presentation shows what is feasible for DR links. The results predict that it is possible to use end-to-end KP4 FEC for 200G/L at 2km. Segmented or concatenated FEC inside optical modules can be used to cover difficult scenarios.

Experimental setup(EML)



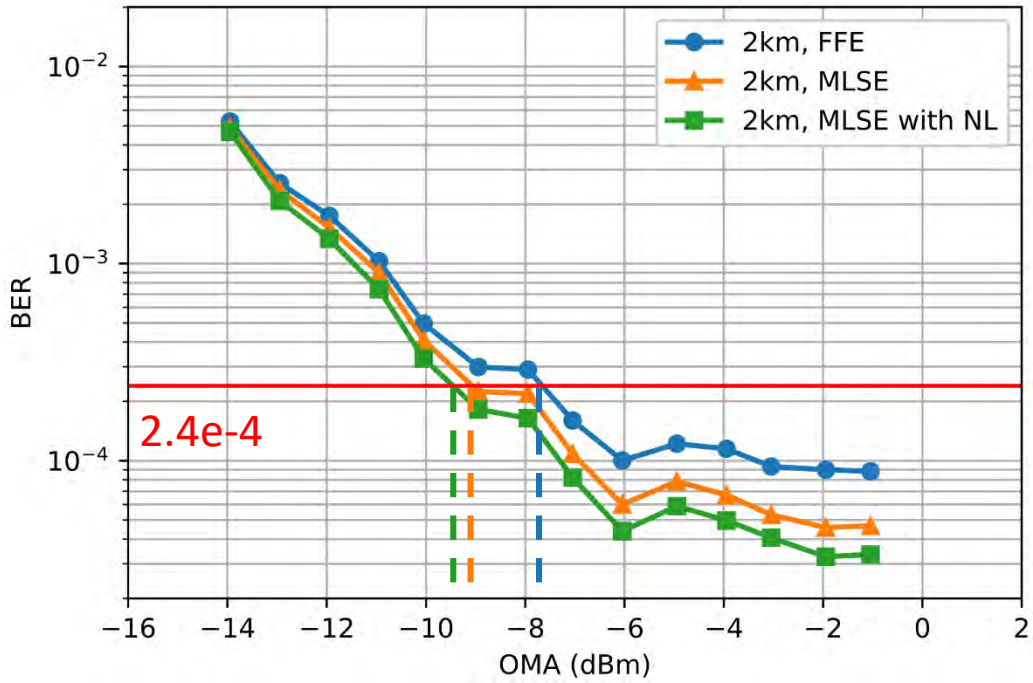
Transmitter:
AWG: 224GSa/s
EML: 1270nm, >50GHz
Pattern: PRBS15, Vpp=1.2V
ER: 3.5 dB

Optical fiber:
Fiber ZDW: 1306nm(2km)

Receiver:
PD: 100GHz
LNA: 67GHz, gain: 11dB
Real-time oscilloscope: 63GHz, 160GSa

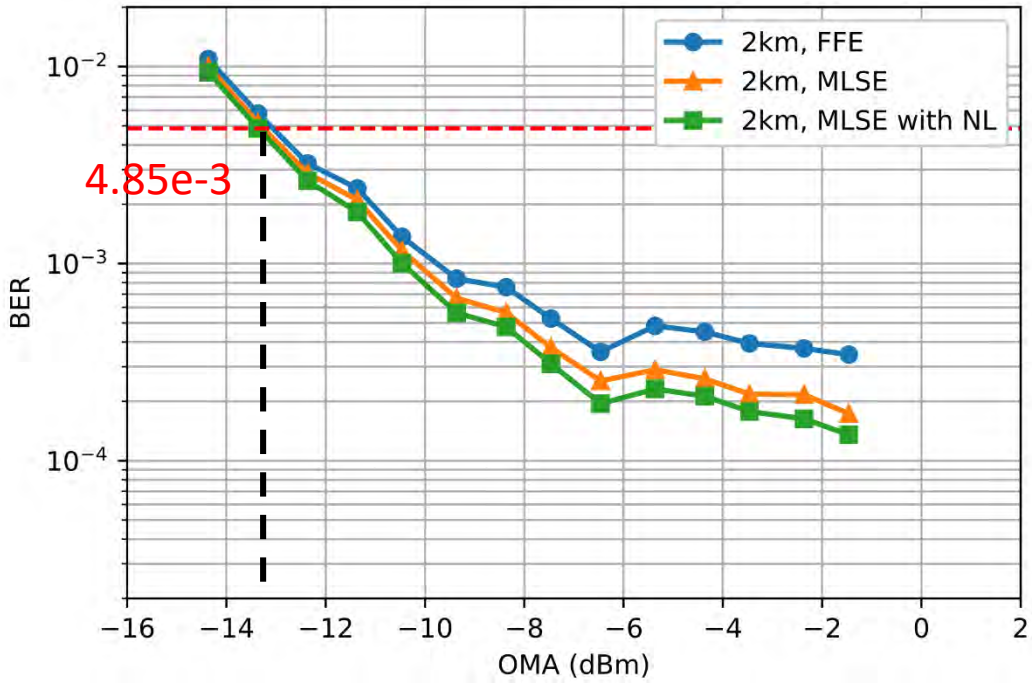
Offline DSP:
FFE: 25-tap(10tap-pre + 14-tap post)
MLSE: 16 trace back length

Experimental results (2km, 106.25/112.5GBd)



106.25GBd:

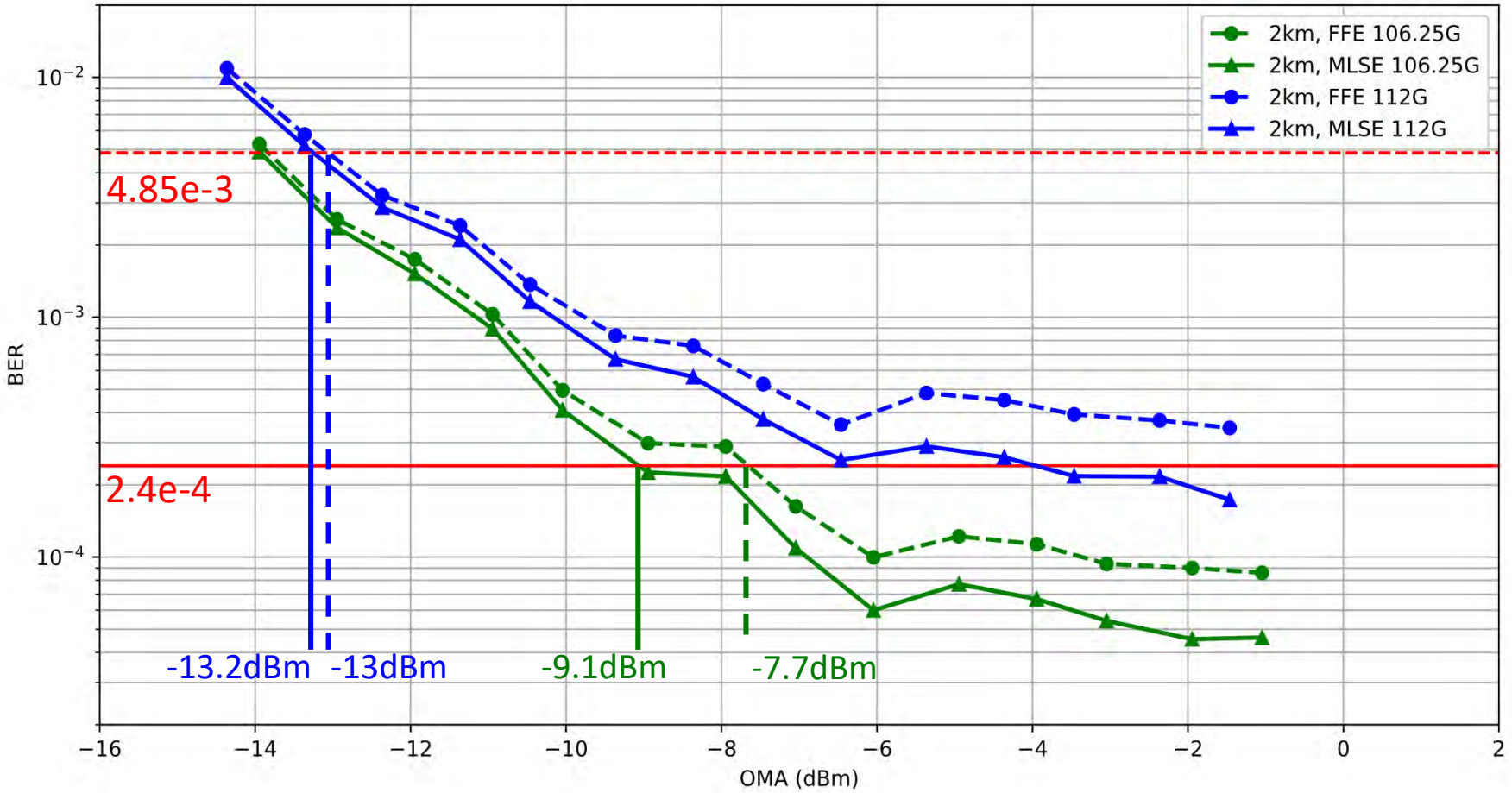
- 2km can meet the KP4 standard from -9.5dBm with FFE, and MLSE or MLSE with nonlinear compensation.



112.5GBd:

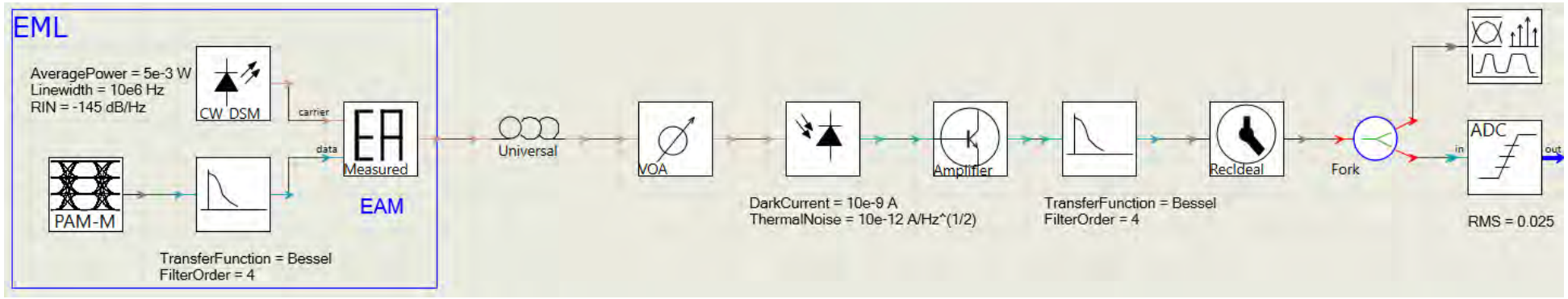
- 2km can meet the RS(544,514) + Hamming(128,120) threshold from -13.2dBm OMA

Experimental results (2km, 106.25/112.5GBd)



- By using MLSE, -9.1dBm OMA Rx sensitivity for 106.25GBd with RS(544,514)
- -13.2dBm OMA Rx sensitivity for 112.5GBd of RS(544,514)+Hamming(128,120)
- The OMA gap between FFE and MLSE is bigger than 1dB at KP4 FEC threshold for 106.25GBd

Simulation setup



Simulation (VPI)

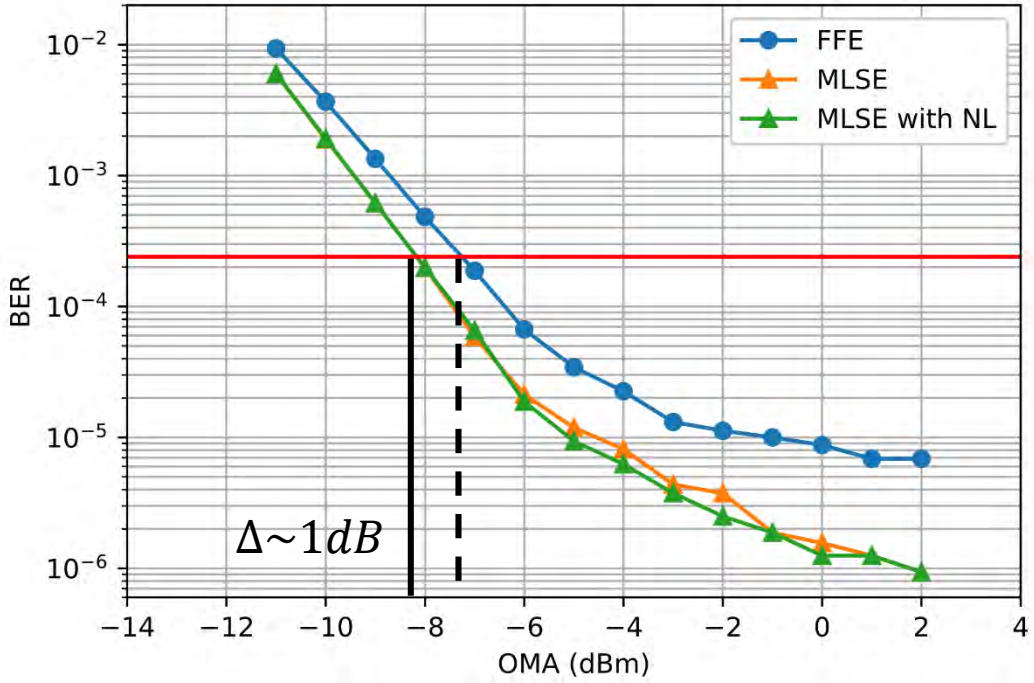
Offline DSP

Transmitter
Signaling Rate: 106.25GBd/112.5GBd
Modulation Format: PAM4
Bandwidth: 40/56 GHz
Linewidth: 10 MHz
RIN: -145 dB/Hz
Average launch power: 4dBm
TDECQ: 3.4 dB
ER: 3.65 dB
OMAouter: 3 dBm
Pattern: PRBS15

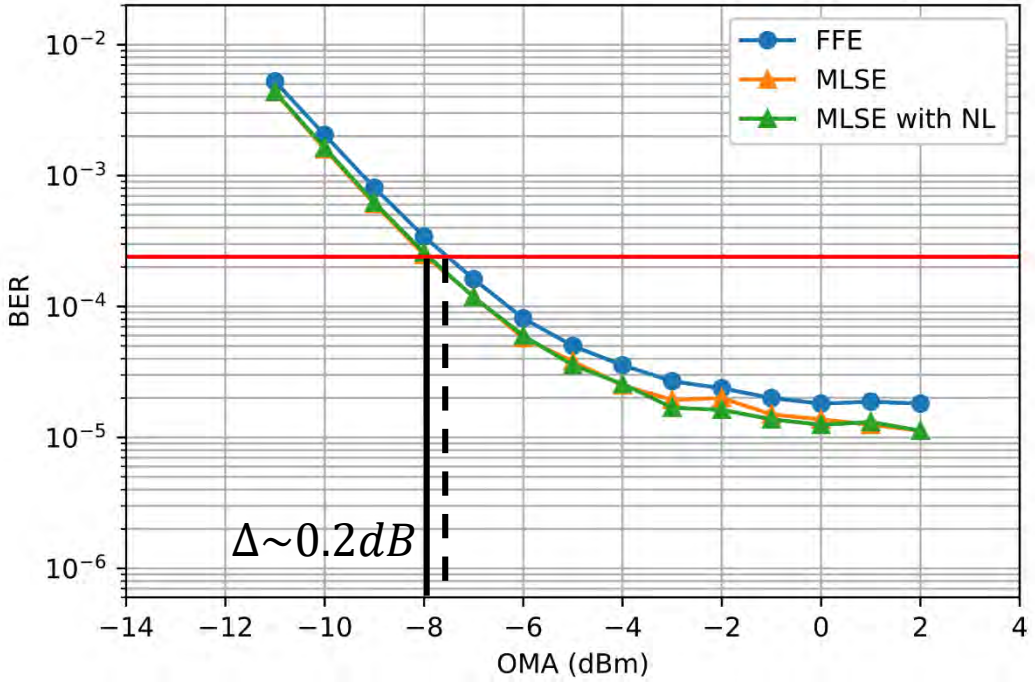
Optical Fiber
Operating distance: 500m, 2km
Lane Wavelength: 1310nm
ZDW: 1300nm/1324nm
DGD: 2.24ps

Receiver
Responsivity of PD: 0.7
Dark Current: 10e-9 A
Thermal Noise: 10e-12 A/Hz^(1/2)
Bandwidth: 40/56 GHz
TIA: 10 dB
ADC Jitter: 0.025 UI

Simulation results (link BW 40/56GHz, 2km, 106.25GBd)



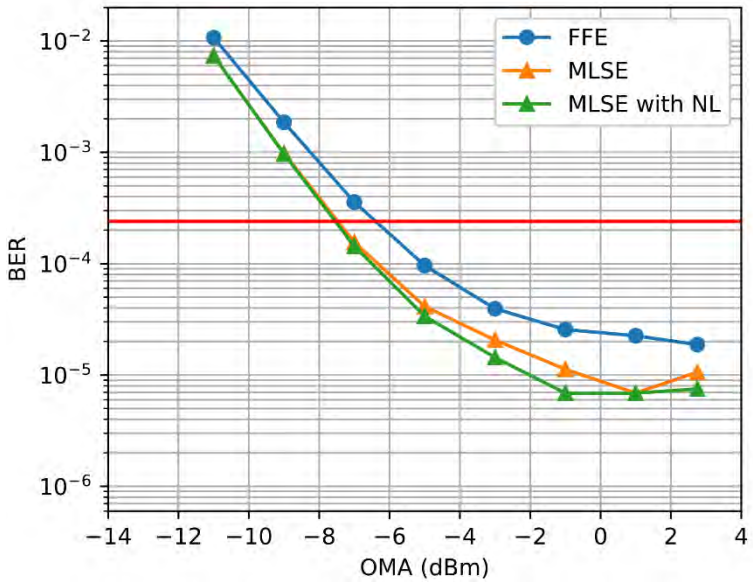
106.25GBd, 40GHz



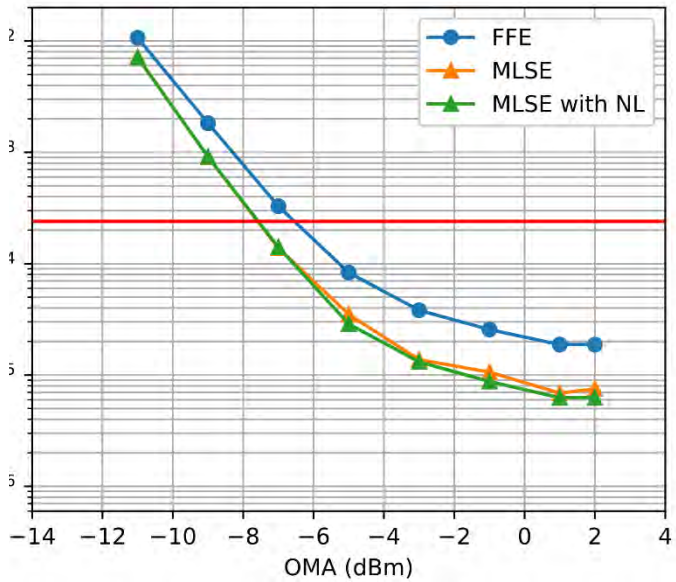
106.25GBd, 56GHz

- A higher link bandwidth(56GHz) leads to a slightly better FFE performance but worse MLSE performance
- The OMA gap between MLSE and FFE is around 1dB at the KP4 threshold, and the gap is bigger at higher OMAs

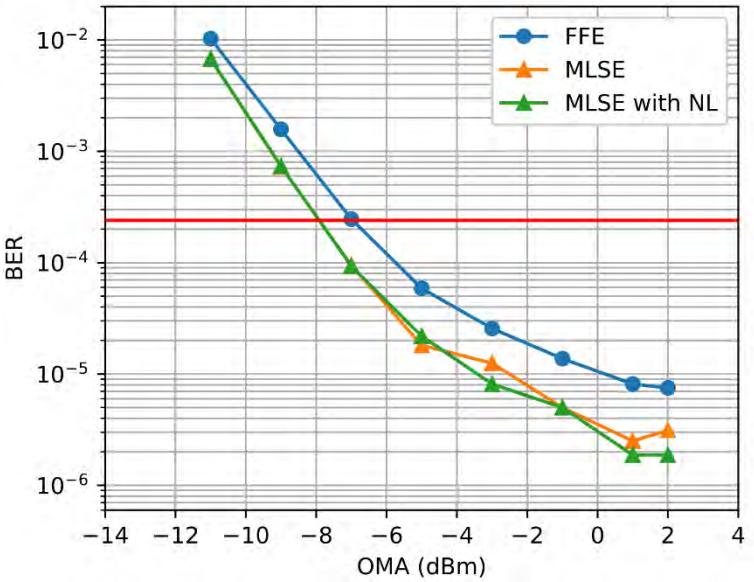
Simulation results (500m, 2km with ZDW1300nm and 1324nm)



106.25GBd, 500m, ZDW1300nm



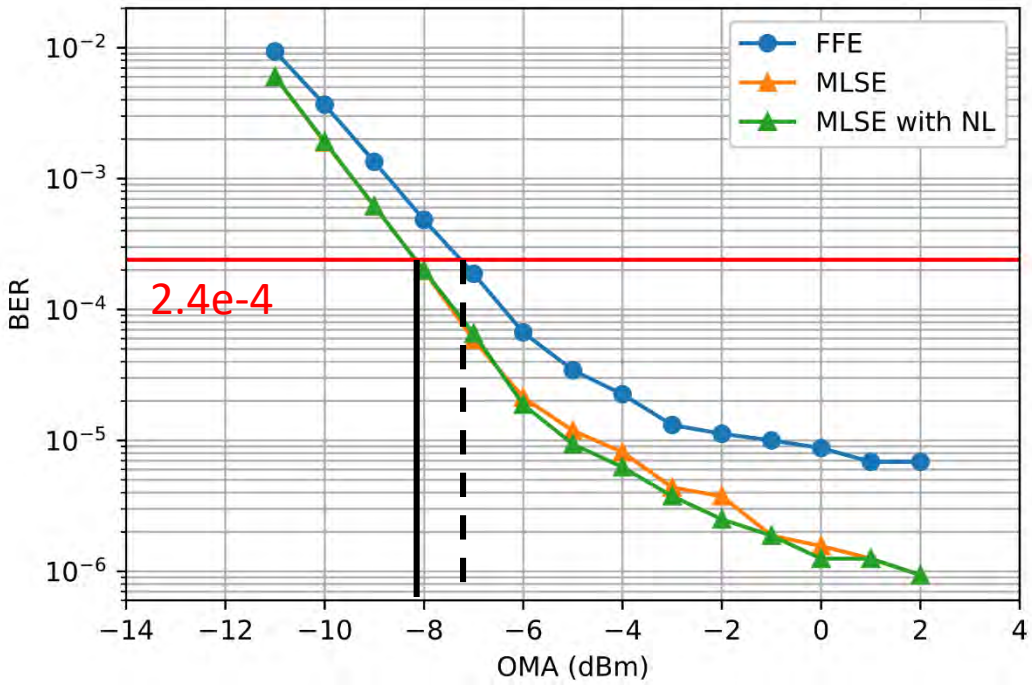
106.25GBd, 2km, ZDW1300nm



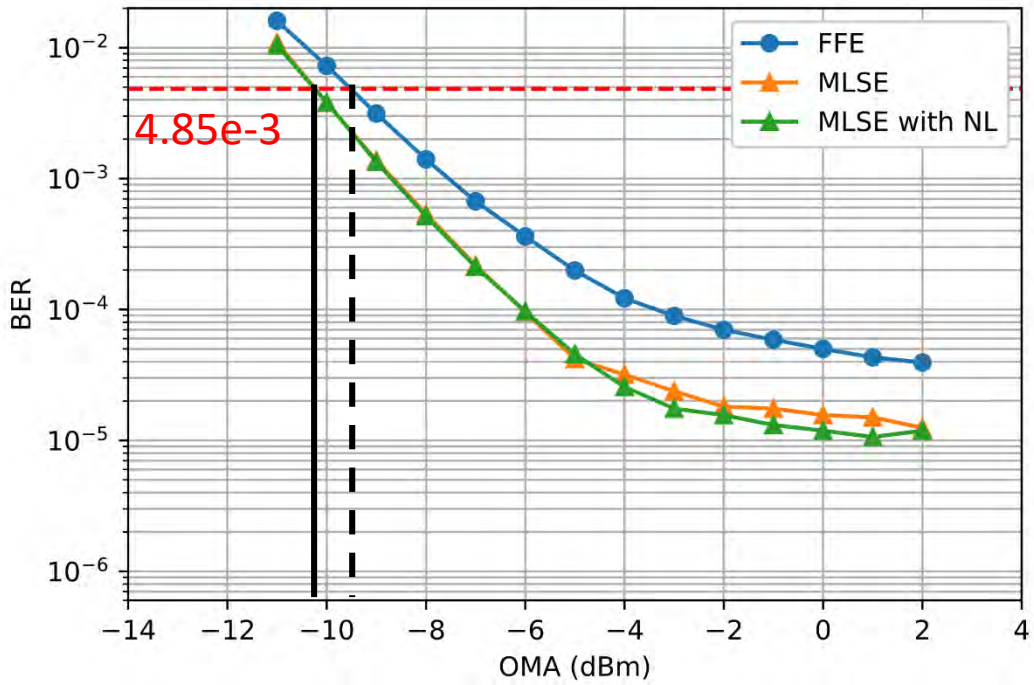
106.25GBd, 2km, ZDW1324nm

- BER performances of 500m and 2km are similar with the same fiber ZDW
- ZDW 1324nm is better than ZDW 1300nm at 2km but at a same BER level
- Use ZDW1300/2km for the following tests

Simulation results (2km, 106.25/112.5GBd)



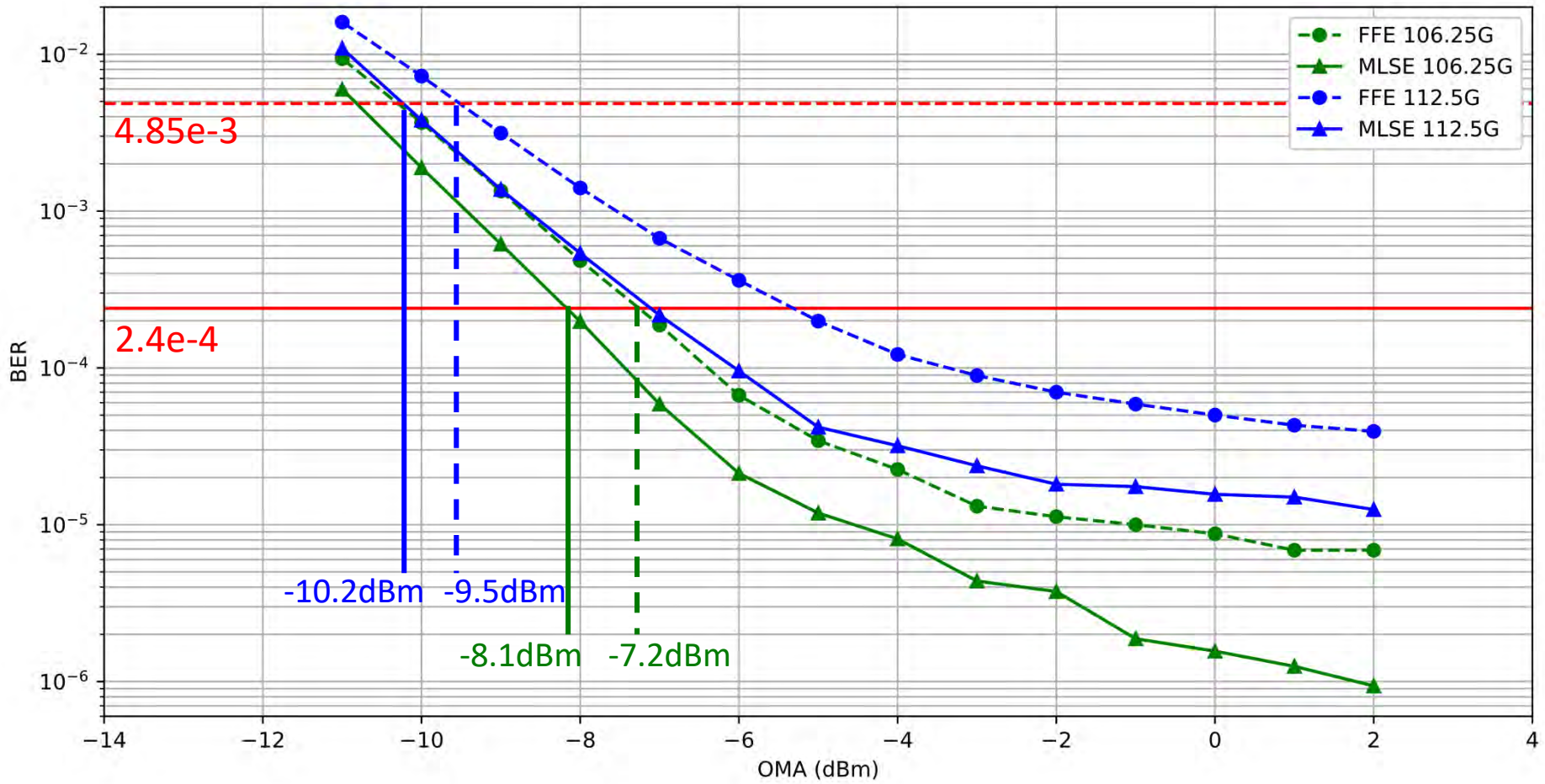
106.25GBd, 2km



112.5GBd, 2km

- -8.1dBm for 106.25GBd with RS(544,514) FEC and -10.2dBm for 112.5GBd of RS(544,514) + Hamming(128,120) can be achieved with MLSE
- The OMA gap between FFE and MLSE is about 1dB under KP4 FEC threshold

Simulation results (2km, 106.25/112.5GBd)



- -8.1dBm Rx sensitivity with MLSE for 106.25GBd can meet RS(544,514) BER standard
- -10.2dBm Rx sensitivity for 112.5GBd of RS(544,514)+Hamming(128,120)
- Considering 1dB EOL aging margin, OMA Rx sensitivities of -7.1dBm and -9.2dBm could be feasible for two signaling rates, respectively

Discussion and Summary

- Simulations and experiments use EML devices and offline DSP(FFE, MLSE and MLSE with nonlinear compensation) for 200G/L PAM4 transmission at 500m and 2km DR transmissions, with worst case ZDW fibers. From the preliminary results, the DR channel (2km, SMF) could meet the KP4-FEC threshold, with the link budget closed with -7.1dBm.
- The results show a better OMA Rx sensitivity using RS(544,514) + Hamming(128,120) but it predicts that signaling rate of 106.25GBd could be viable for 200G/L 2km parallel fiber, which could leverage existing 100G/lane KP4 FEC and no need for additional overhead.
- End to end KP4 FEC may be enough for 200G/L 2km DR links to achieve low cost, low power consumption, low latency and flexibility. Segmented or concatenated FEC can be used to cover worst cases, which can be bypassed in modules if not required.

Thank you