Constellation Shaping: Can It be Useful for Datacenter Reach Communication ?

Xiang Zhou and Hong Liu
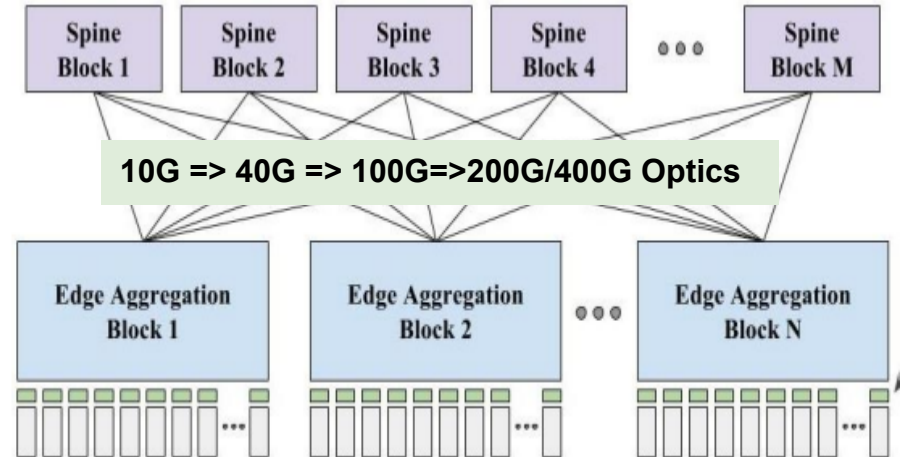
Google Platforms Datacenter Optics

zhoux@google.com
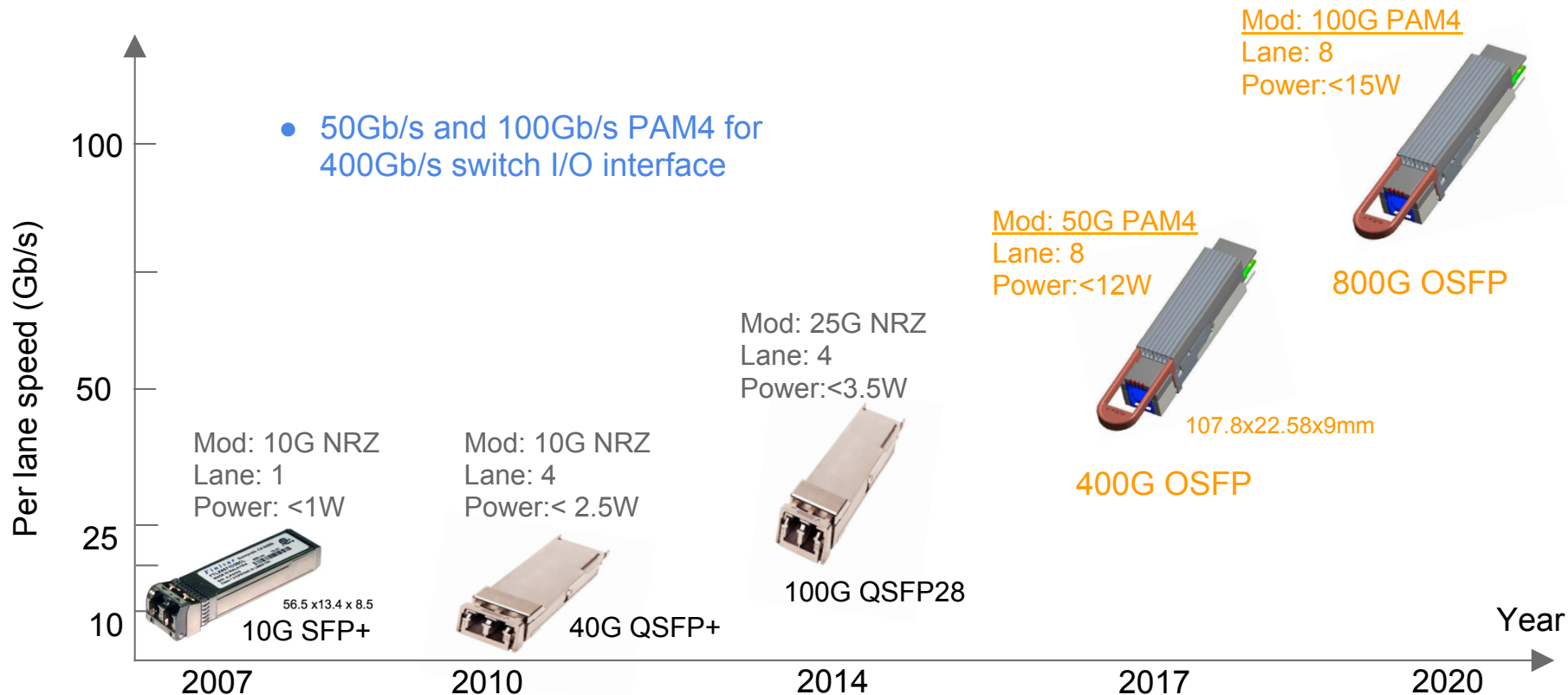
Datacenter (DC) Optics

- Used for networking fabric above servers
- Very large volume
- Pluggable grey optics (PSM4, CWDM4)

- Key performance metrics
  - Bandwidth and cost
  - Power and density
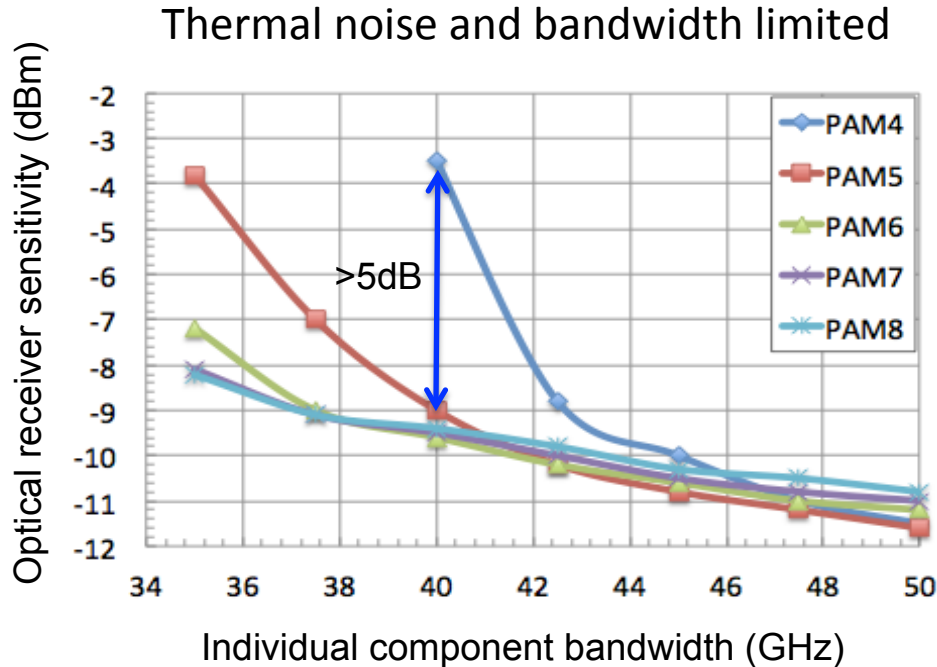 - Serviceability
  - Cabling efficiency
  - Latency

High Efficiency Servers
(www.google.com/about/datacenters)

10G => 40G => 100G=>200G/400G Optics

DC Optics Technology Evolution

Mod: 100G PAM4
Lane: 8
Power:<15W

800G OSFP

Mod: 50G PAM4
Lane: 8
Power:<12W

107.8x22.58x9mm

400G OSFP

- 50Gb/s and 100Gb/s PAM4 for 400Gb/s switch I/O interface

Mod: 25G NRZ
Lane: 4
Power:<3.5W

Mod: 10G NRZ
Lane: 1
Power: <1W

Mod: 10G NRZ
Lane: 4
Power:< 2.5W

100

50

25

10

Per lane speed (Gb/s)

56.5 x13.4 x 8.5

10G SFP+

40G QSFP+

100G QSFP28

Year

2007   2010   2014   2017   2020

Can PAM-M Scale to 200Gb/s Throughput ?

Thermal noise and bandwidth limited

- Shannon Mutual Information theory used for achievable sensitivity calculation

- DSP assumptions
  - 3-tap Tx FFE (ENOB=5.5)
  - 17-tap Rx FFE (ENOB=5.5)

- Optimal modulation format depends on component BW

  - With 40Hz BW, >5dBm sensitivity improvement from PAM4 to PAM5

- Without other level-dependent impairments, PAM8 performs best when component BW<38GHz !

- Identical analog BW assumed for all Individual components (DAC, ADC, Driver, Modulator, PD and TIA)
- MZM with ER=5.5dB, PD R=0.8, TIA=16pA/sqrt(Hz)

Value of FlexPAM (with fine granularity SE)
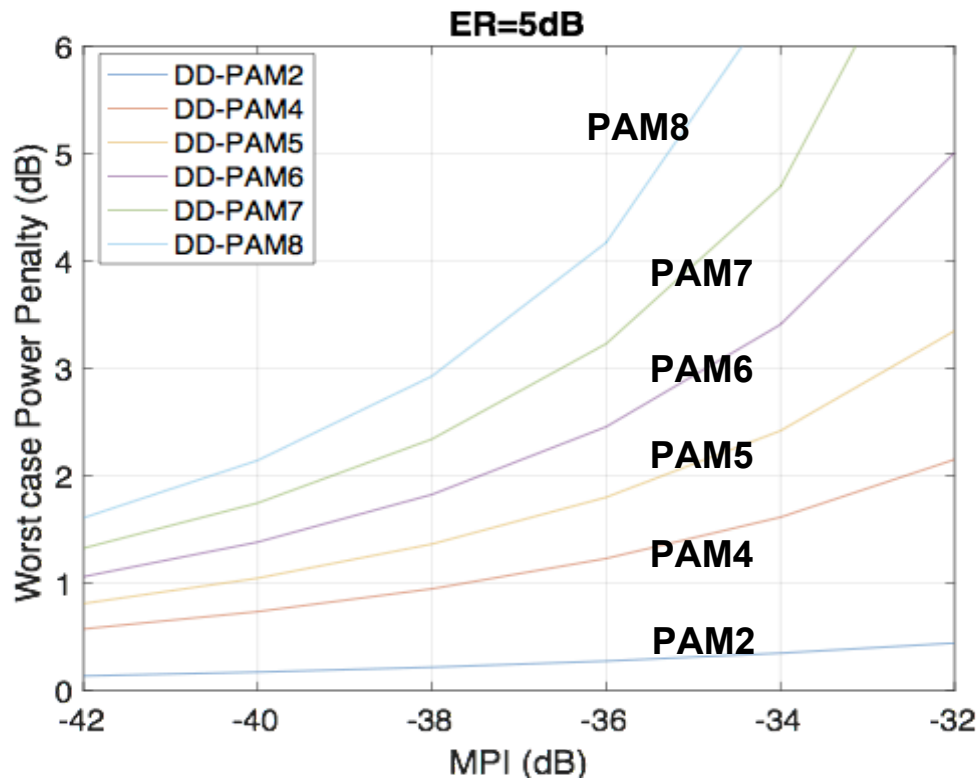
- PAM-M with direct detection (DD) scales poorly toward level-dependent optical impairments: multi-path interference (MPI) and laser RIN

- For similar noise tolerance, should select the modulation with the smallest constellation size

- **FlexPAM with fine SE granularity allows single chip useful for different BW conditions/use cases**
  - **PAM4 for BW>45GHz, LR**
 - **PAM5 for BW=[40 45]GHz, LR/SR**
  - **PAM6 for BW=[35 40]GHz, SR**

SE: spectral efficiency

Probabilistic Constellation Shaping (PCS) ?

Long Haul

- With optical amplifier
- Average power constrained system
- Coherent detection
- Performance limited by OSNR
- To achieve the same SE, PCS with increased constellation size increases Euclidean distance thus noise tolerance
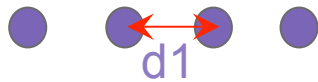
2b/s coherent PAM4

d1
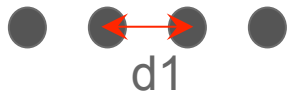
2b/s coherent PCS-PAM8

d2

DC Optics

- No optical amplifier
- **Peak power constrained system**
- Direct detection (DD)
- Performance limited by thermal noise
- **To achieve the same SE, PCS with increased constellation size reduces noise tolerance**
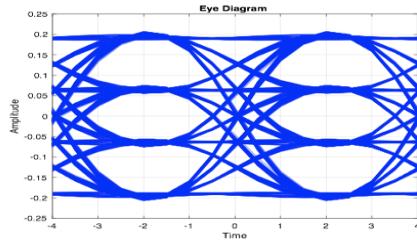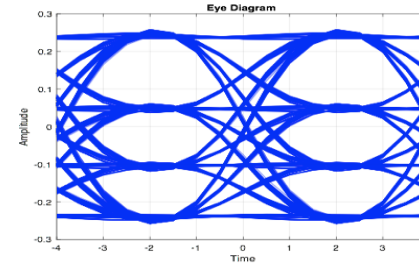
2b/s DD-PAM4

d1

2b/s DD-PCS-PAM8

d2

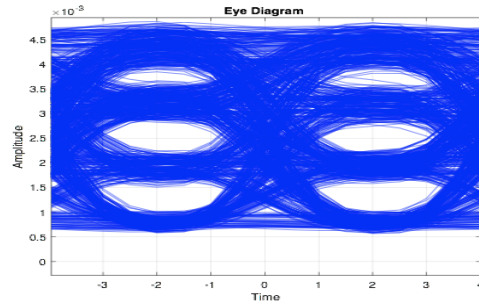# Value of Geometric Constellation Shaping (GCS)

Uniform constellation

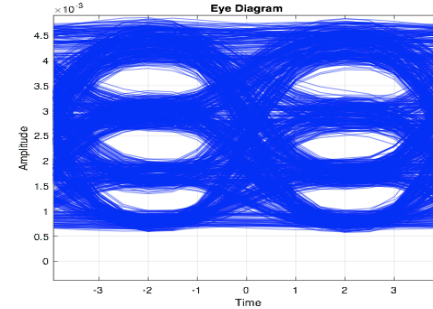Non-uniform constellation

Tx electrical signal

Bigger upper eye opening
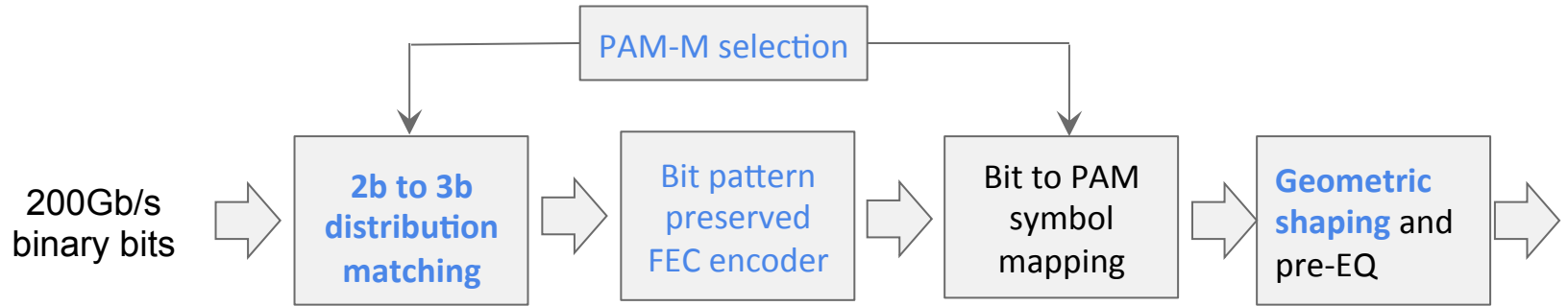
Tx optical signal
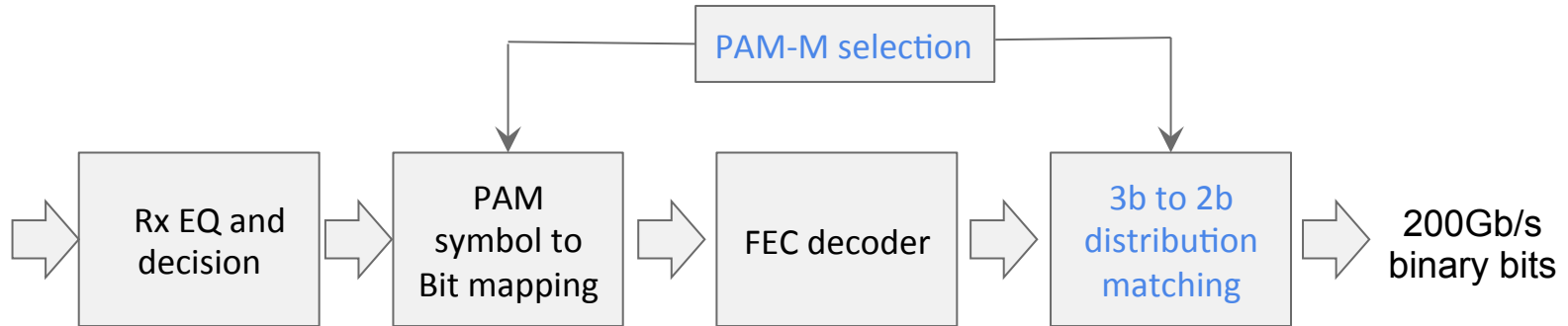
MPI=23dB, ER=7.5dB

MPI=23dB, ER=7.5dB

- **GCS useful for alleviating level dependent impairments such as MPI and RIN**

FlexPAM DSP: One Example

Tx DSP

Rx DSP

- **Irregular PAM such as PAM5 can be treated as a special case of PCS-PAM8 with equal probability for level 1 to 5 while zero probability for level 6 to 8**

Conclusions

◆ Conventional probabilistic shaping not useful for peak power limited short reach optical systems

◆ Geometric constellation shaping can be utilized to mitigate level dependent optical impairments such MPI and RIN

◆ FlexPAM with fine granularity SE might be needed to scale per lane rate beyond 100Gb/s

  ✧ Enable single chip for different bandwidth conditions/use cases