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Photonic Accelerators for Edge Computing Applications: The PROMETHEUS Project Approach

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Need for 800G in the Edge-Cloud Approach

RAN Fronthaul

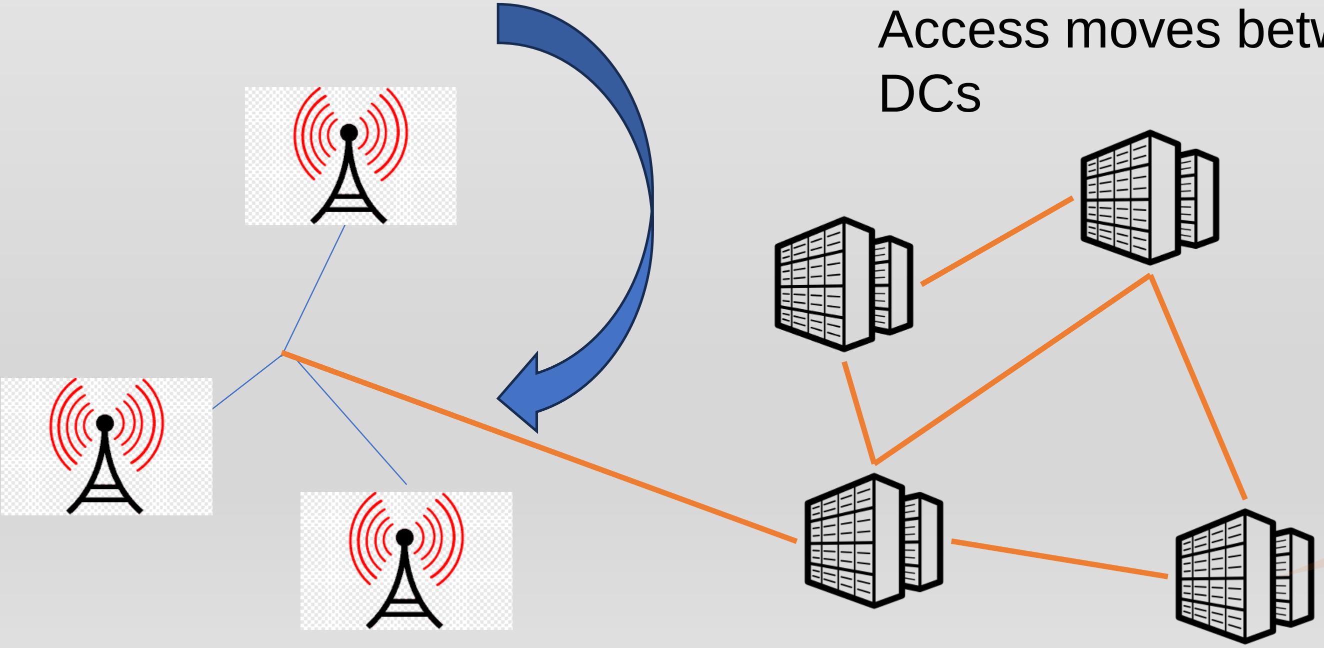
- 6G at 7 GHz spectrum
- 1024 units with 400 MHz carriers are envisioned
- >400 Gbps per RRU
- 800G-1.6T in the fronthaul for 2-4 RU cell sites

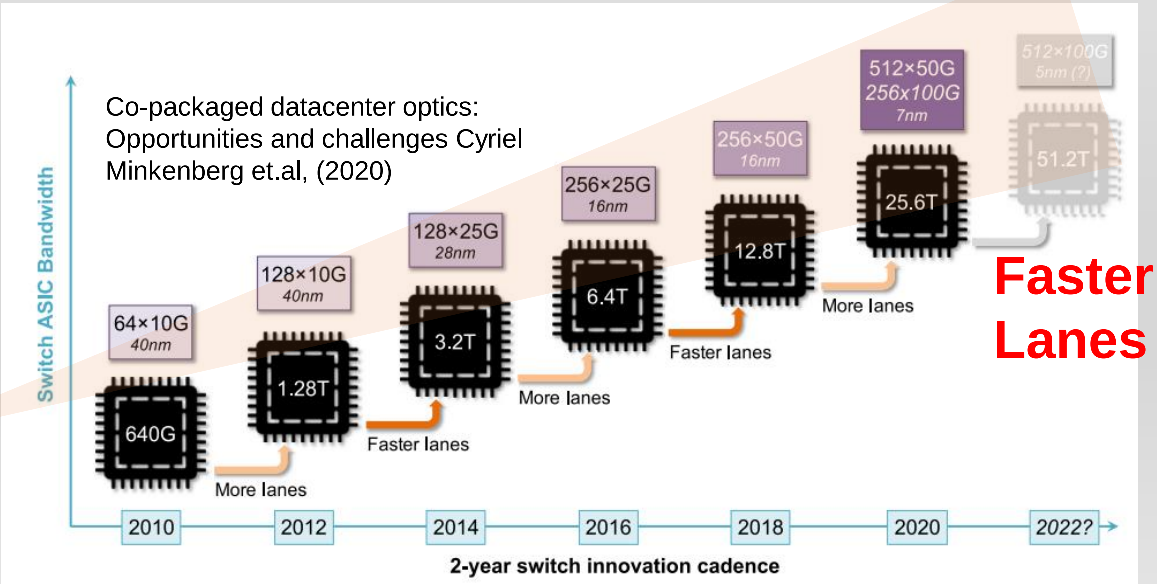
Edge Data Center Interconnects

- Traffic in the edge skyrockets
- Multiple Edge DCs utilized for steady/low latency
- Aggregated data traffic from Access moves between Edge DCs

Data Centers

- Transitions beyond 25.6G Switch cannot rely on increased port density
- Optics in the Rack should be contained to 64 pluggables
- Faster lanes is the only way to go





The industry will quickly transition from 800G to 1.6T

Marvell Launches Industry's First 800G ZR/ZR+ Modules for Data Center Interconnects

- COLORZ® 800 is the industry's first family of 800 Gbps ZR/ZR+ coherent pluggable optical modules for connecting data centers up to 1,200km apart.

At the market in 2023

- 800G 2xFR4/LR4 at 53 Gbaud, 800G ZR/ZR+
- 800G and 1.6T PAM4 DSP with 112G Serdes (Marvell, Broadcom)
- 224G Serdes (Cadence)

224G-LR SerDes PHY

Enables 1.6T and 800G networks

MARVELL

Product Brief

Nova™ 1.6T PAM4 DSP for Optical Transceiver Applications

Optics are ready to go!

- >100 GHz EMLs, PDs
- >60 GHz linear amplifiers

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Optical Amplification-Free 310/256 Gbaud OOK, 197/145 Gbaud PAM4, and 160/116 Gbaud PAM6 EML/DML-based Data Center Links

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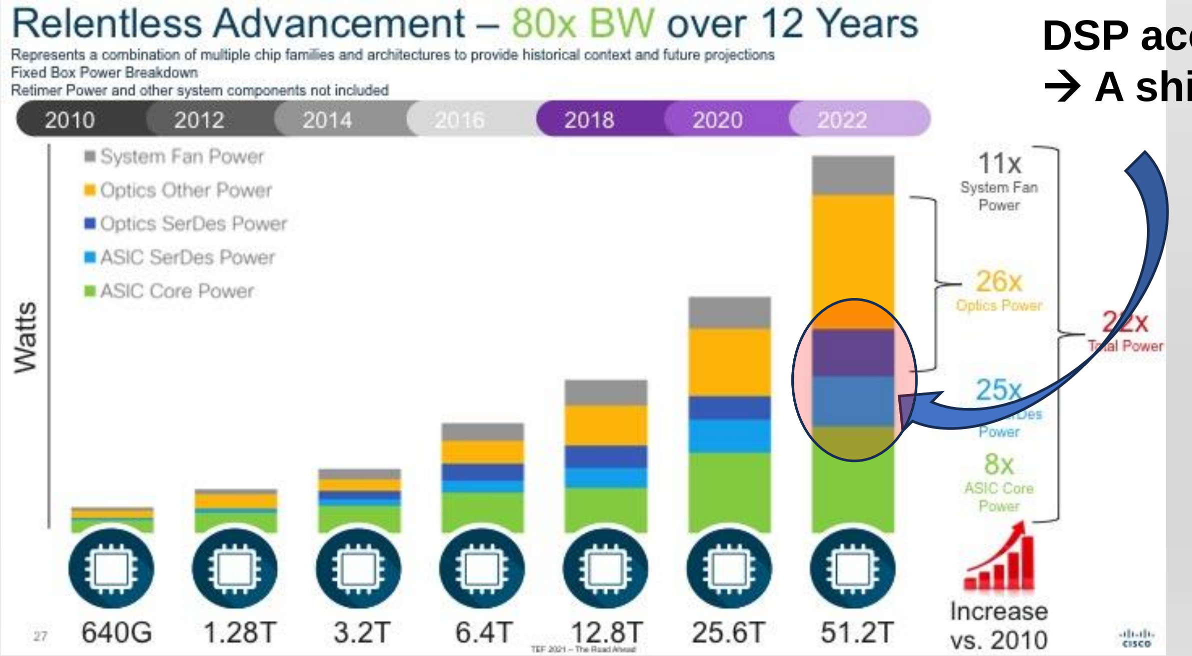
280 Gbit/s PAM-4 Ge/Si Electro-absorption Modulator with 3-dB Bandwidth beyond 110 GHz

DSP is here to stay, but…

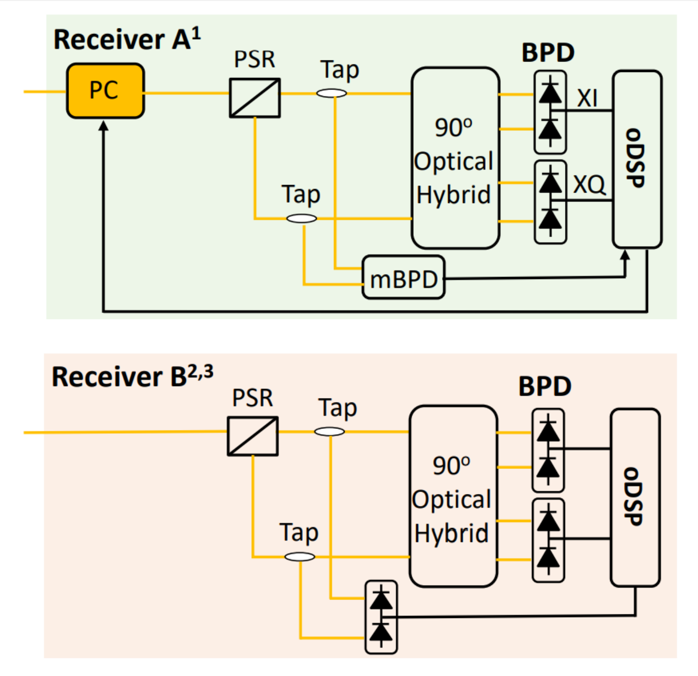
More DSP has been added even to the IM-DD portfolio:

- Faster than-Nyquist (FTN) precoding and equalization (THP, MLSE)
- Probabilistic constellation shaping (PCS)
- Multicarrier entropy loading (EL)
- Volterra nonlinear equalization (VNE)



DSP accounts for almost 60% of a 800G pluggable (~8W for 2xLR4)
→ A shift to coherent-lite (10 km) will employ even more!

Analog counterparts



1. Analog Coherent i.e. self-homodyne (SHD) coherent optical transceiver

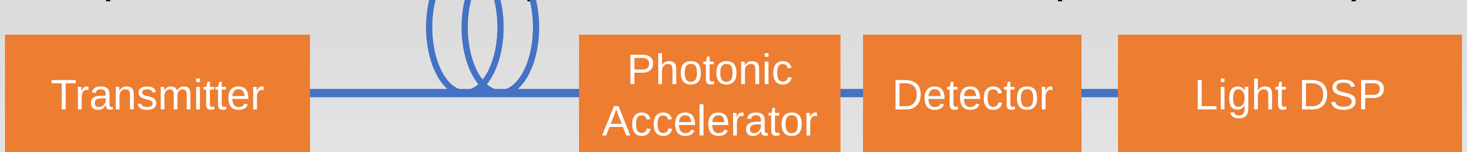
- ➢ Remove carrier and frequency correction by sending the LO along with the signal
- ➢ Ignore PMD and PDL and track Pol rotation with low-speed analog circuitry removing MIMO
- ➢ O-band operation eliminates CD compensation
- ❖ It is still ADC based with reduced DSP load
- ❖ It requires custom optics increasing costs

2. Analog FIR Blocks (FFE, CPE)

- ❖ Immature with low speed capabilities (<25 Gbaud) and low tap numbers (<20)

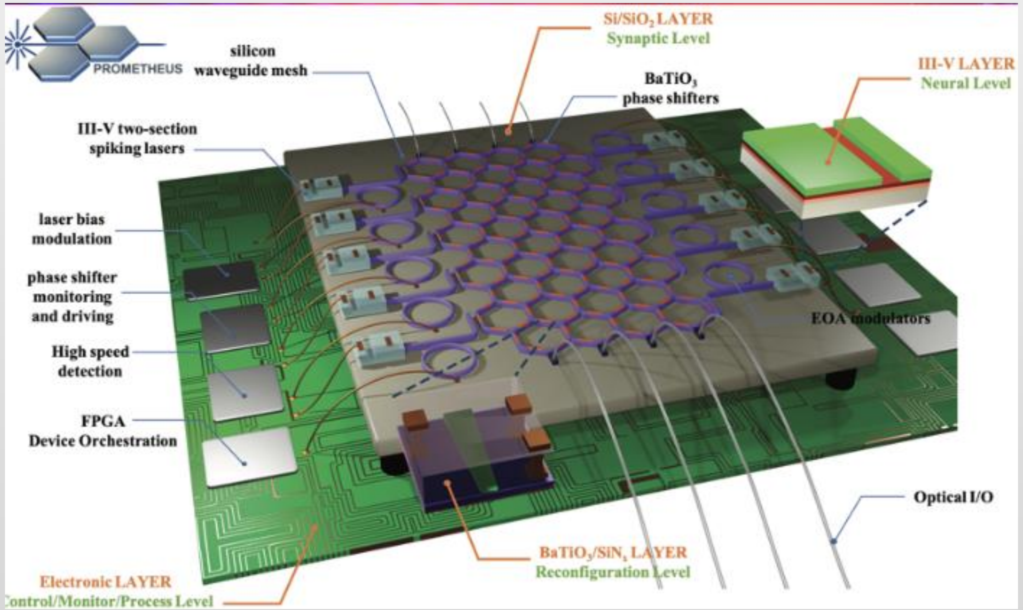
3. Photonic Accelerators

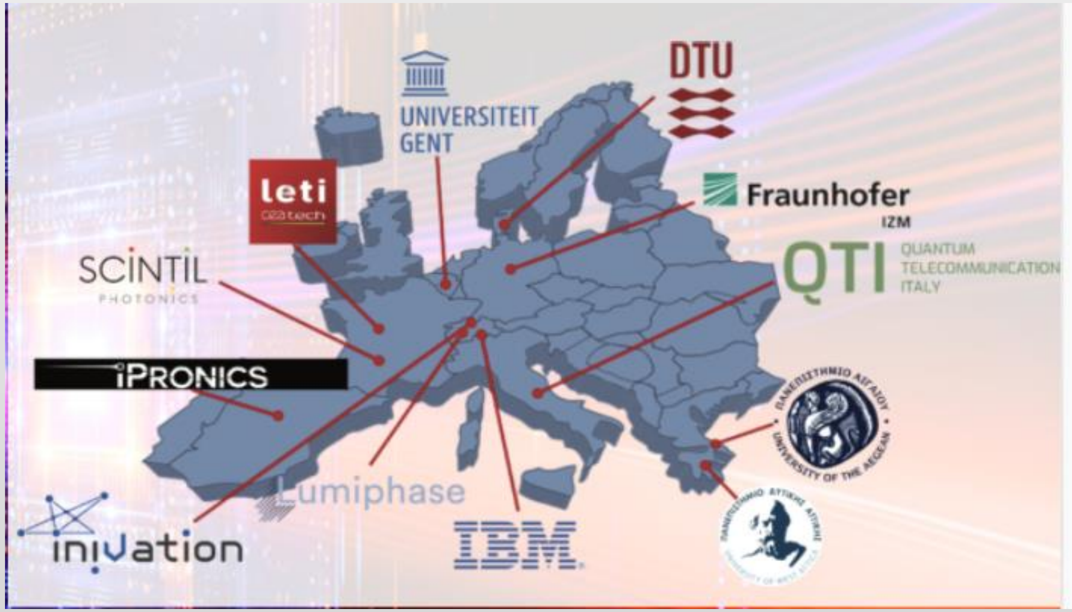
- ➢ Equalization based in photonic unconventional pre-detection processing



PROMETHEUS Horizon Europe

Presents a holistic approach in integrated programmable photonics as a proliferating platform for neuromorphic/quantum computing and applications in edge computing/industrial imaging/cybersecurity.





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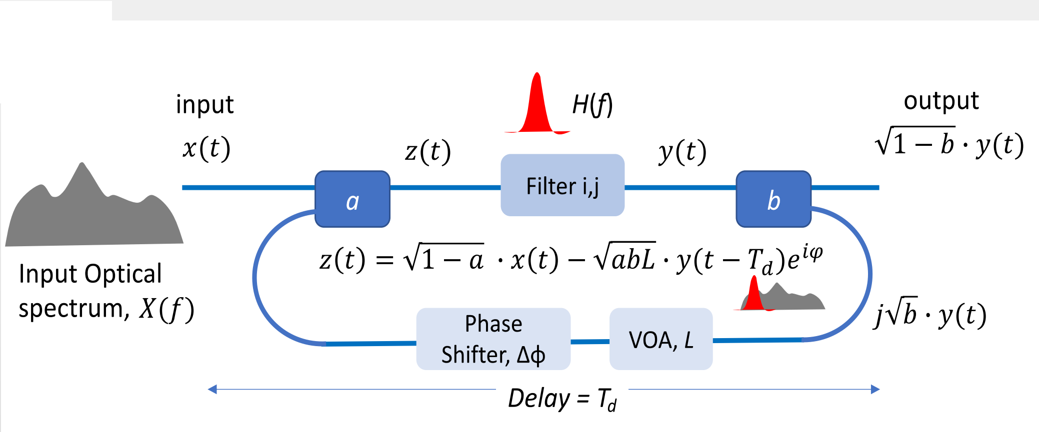
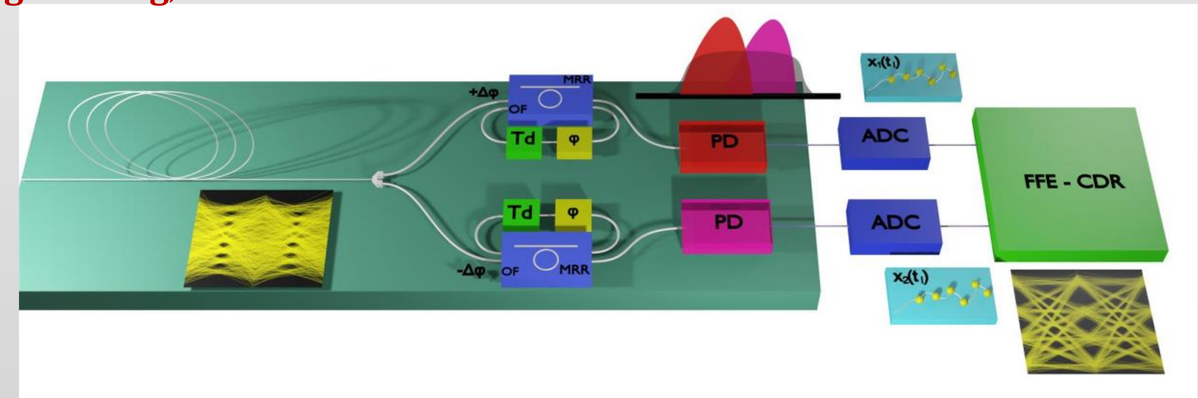
PROMETHEUS

Horizon Europe

Photonic Accelerator based on Recurrent spectrum slicing



K. Sozos et al, Photonic Reservoir Computing based on Optical Filters in a Loop as a High Performance and Low-Power Consumption Equalizer for 100 Gbaud Direct Detection Systems, ECOC 2021
K. Sozos et al., High-Speed Photonic Neuromorphic Computing Using Recurrent Optical Spectrum Slicing Neural Networks, **Nature Comm. Engineering**,



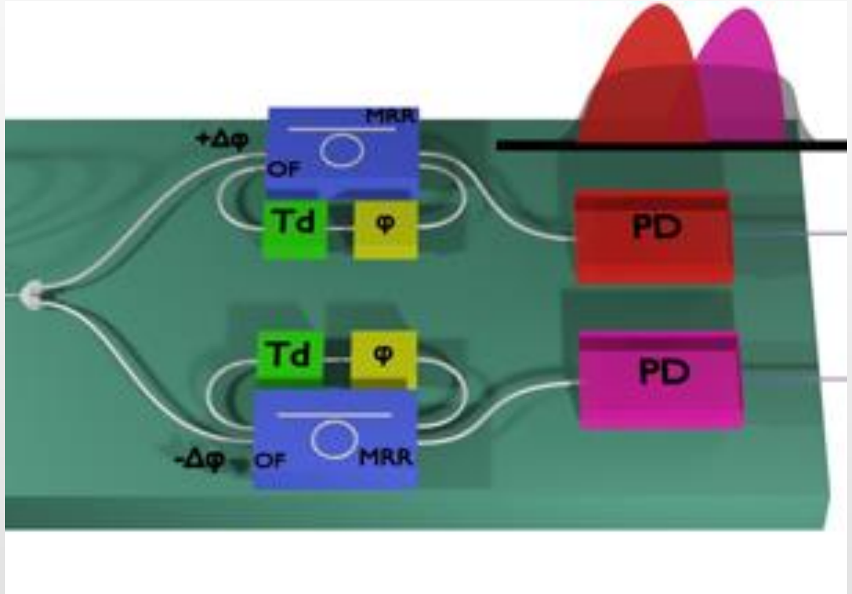
- Coherent processing in the spectral domain
- Almost zero consumption (phase shifters)
- Compatible to programmable photonic platforms
- Recursive operation adds memory to the receiver
- Optical frequency diversity
- Capable of 100 Gbaud and beyond with 50 GHz opto-electronic components thanks to slicing!

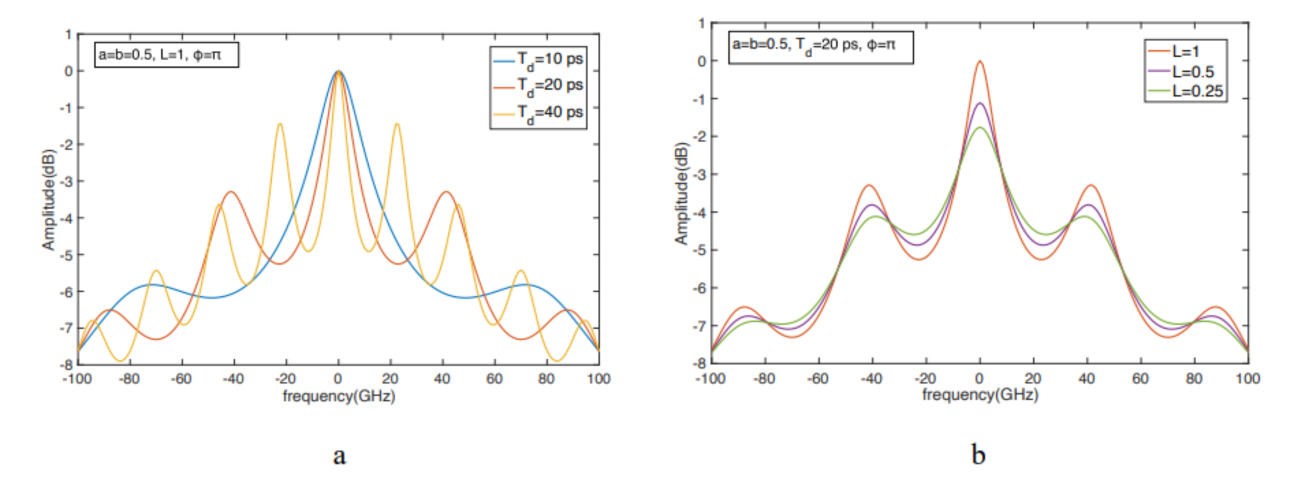
- **Trade-off between complexity and efficiency**

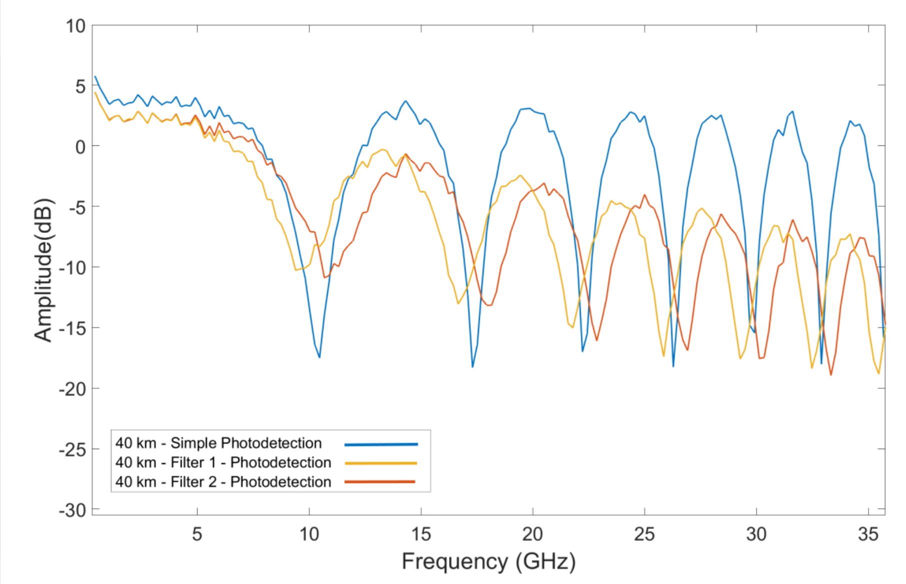
Basic Concept

Tunable recurrent filter transfer functions process the input signal in the frequency domain

- Power fading can be vastly reduced
- Phase information can be efficiently translated in the amplitude domain (self-coherent detection for M-QAM signals)







Photonic Accelerator based on Recurrent spectrum slicing : Self—Coherent approach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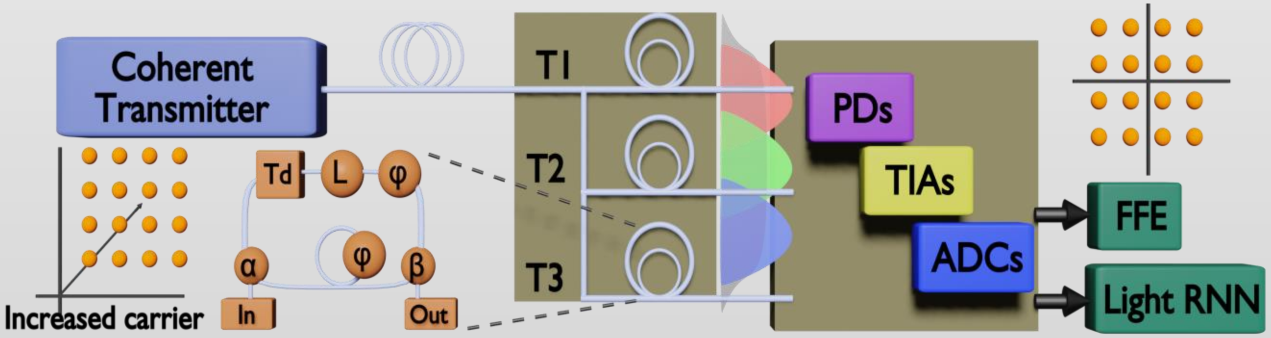
Self-Coherent Receiver Based on a Recurrent Optical Spectrum Slicing Neuromorphic Accelerator

Kostas Sozos, Stavros Deligiannidis, Charis Mesaritakis, and Adonis Bogris, *Senior Member, Optica*

One regression unit (FFE) per quadrature

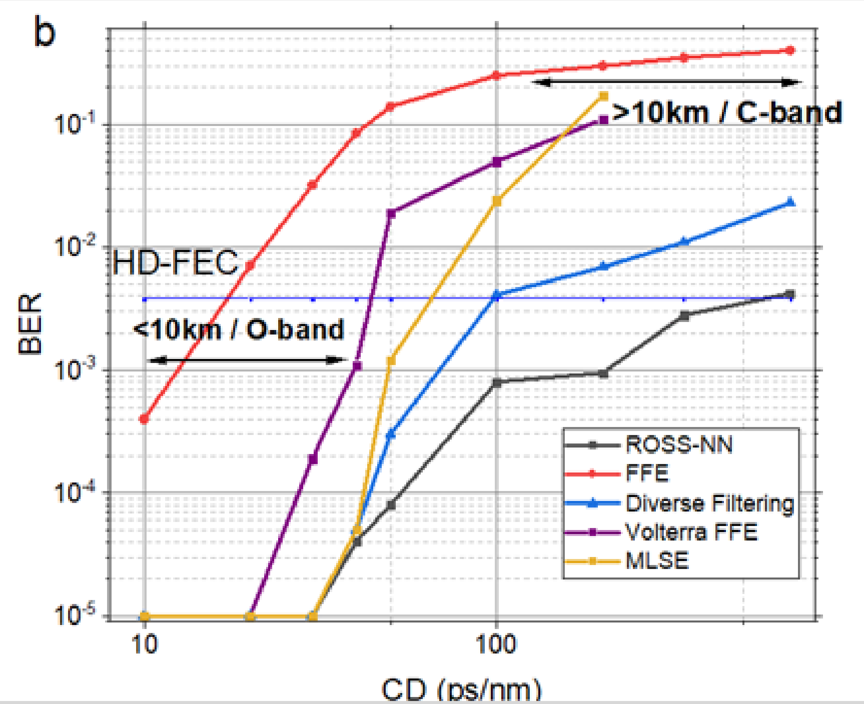


Critical Optimization Parameters for a given baud-rate and link

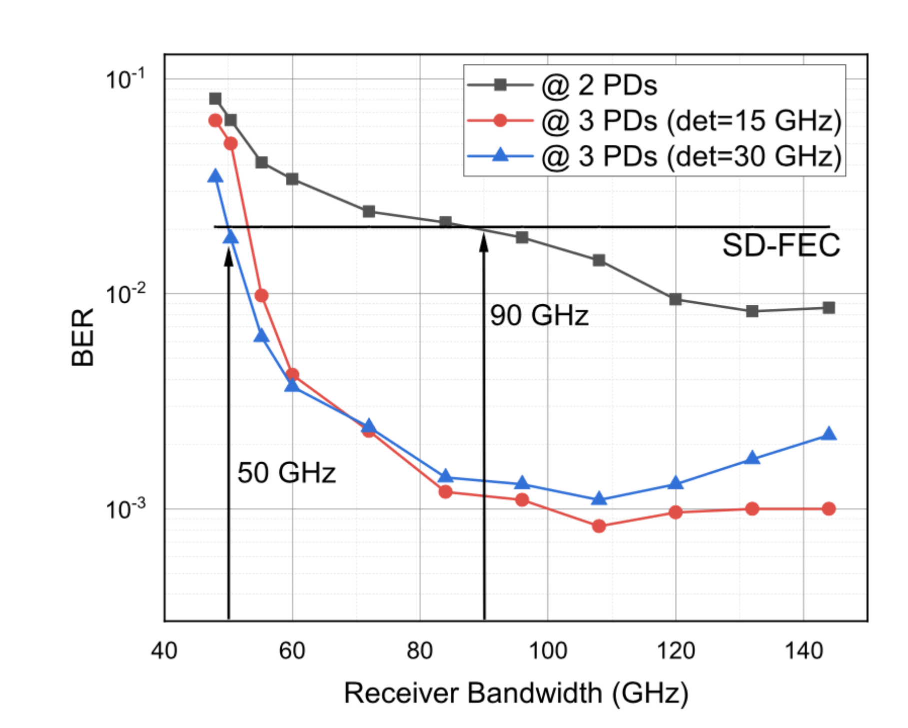
1. Carrier-to-signal noise ratio (CSPR)
2. Recurrent filter properties
3. Number of receivers and their bandwidth
4. Constellation Shape (Not examined yet)

Photonic Accelerator based on Recurrent spectrum slicing: Numerical Results

PAM-4 100 Gbaud



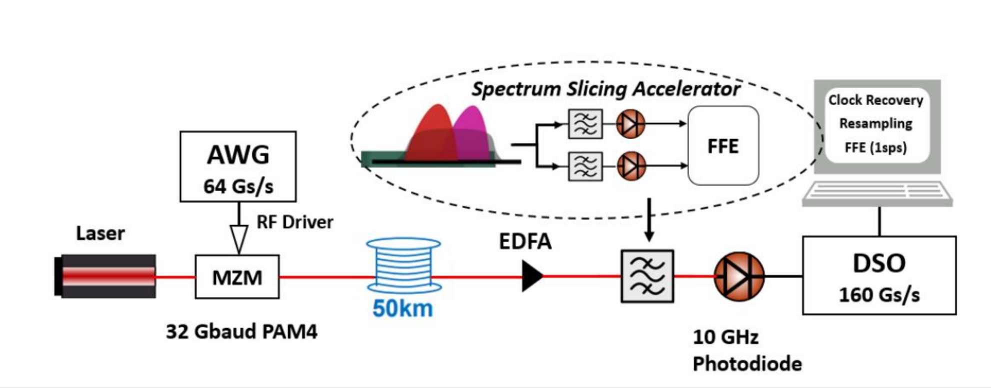
QAM-16 240 Gbaud @ 10 km O-band

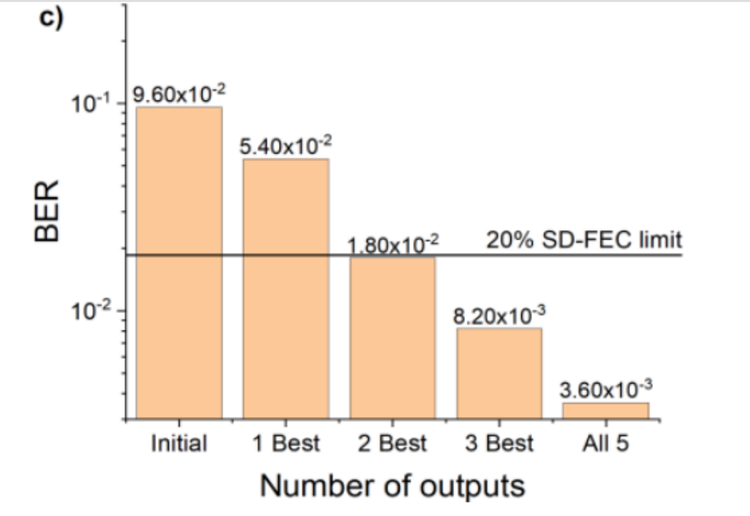


Capabilities: **Up to 960 Gb/s transmission in a single wavelength** – single polarization (16-QAM) with 60 GHz optoelectronic components

Photonic Accelerator based on Recurrent spectrum slicing: Experimental Validation

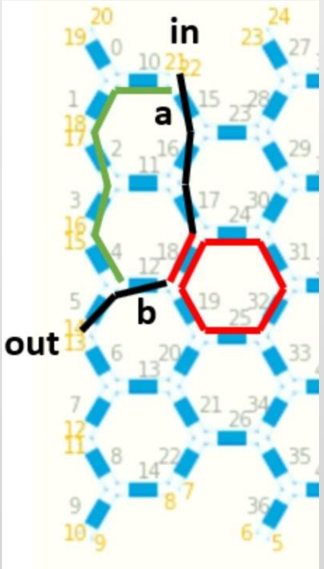
PAM-4 32 Gbaud using off-the-shelf optical filters



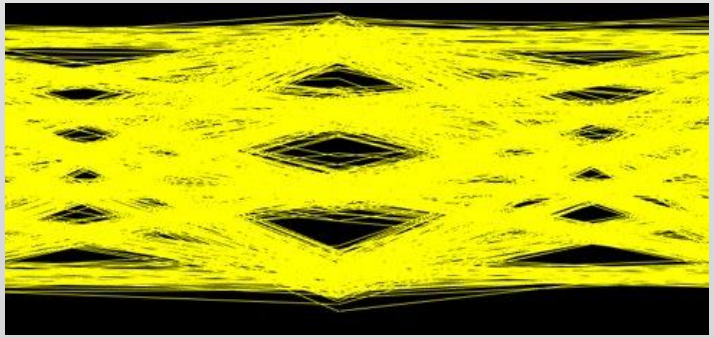


64 Gb/s using no DSP and 10 GHz photoreceivers

QAM-16 and IM-DD on programmable photonic platforms (real-life device emulation)



100 Gb/sec, 60 km, C-band



Techno-economic comparison @ 1.6 Tb/s

	IM/DD	Coherent	Coherent-lite SHD	ROSS IM/DD	ROSS Self-coherent
Symbol Rate/ Format	8x112 Gbaud PAM4	2x120 Gbaud DPQAM16	2x120 Gbaud DPQAM16	8x112 Gbaud PAM4	4x120 Gbaud QAM16
Transmitter	8 semi-cooled EMLs	2 Cooled ECLs	2 semi-cooled moderate power DFBs	8 semi-cooled EMLs	4 semi-cooled low power DFBs
Rx Analog BW	8x Class 60	8x Class 60	8x Class 60	16x Class 30	8x Class 50 or 12x Class 30
DSP	FFE+MLSE	RRC + CD + MIMO + COE + CPE	RRC+MIMO	FFE	FFE
Consumption	~ 20 W	> 30 W	~ 30 W	~ 20 W	~ 20 W
Cost	A	> 5 x A	> 5 x A	~1.5 x A	~ A
Latency	Medium	High	Medium	Low	Low
ER capable	No	Yes	Yes	Yes	Yes

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PROMETHEUS

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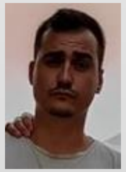
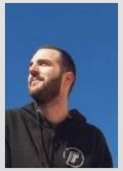


K. Sozos



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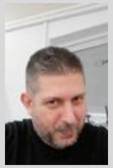

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