Coherent Co-Packaged Optical Interfaces Enabling Next-Generation Data Center Switching

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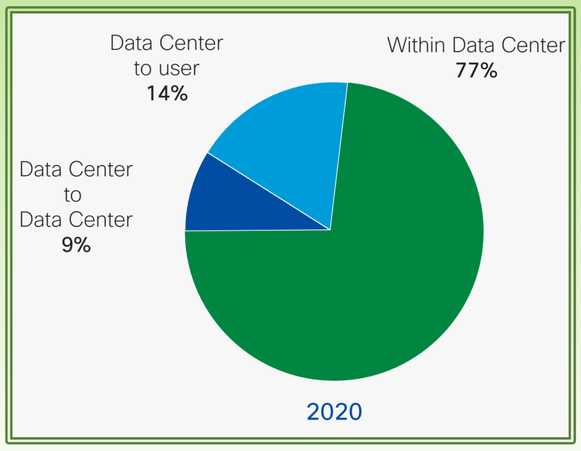
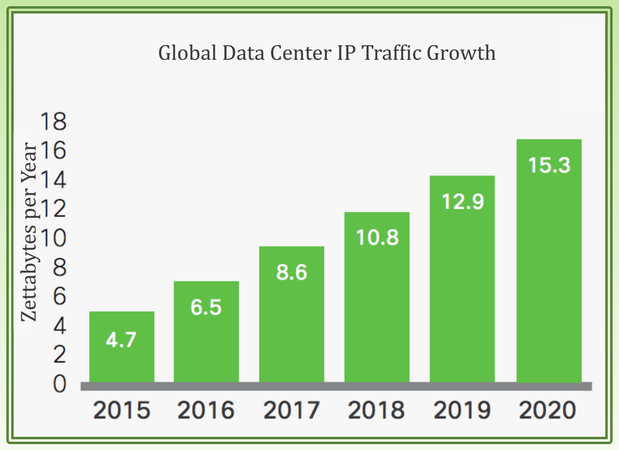
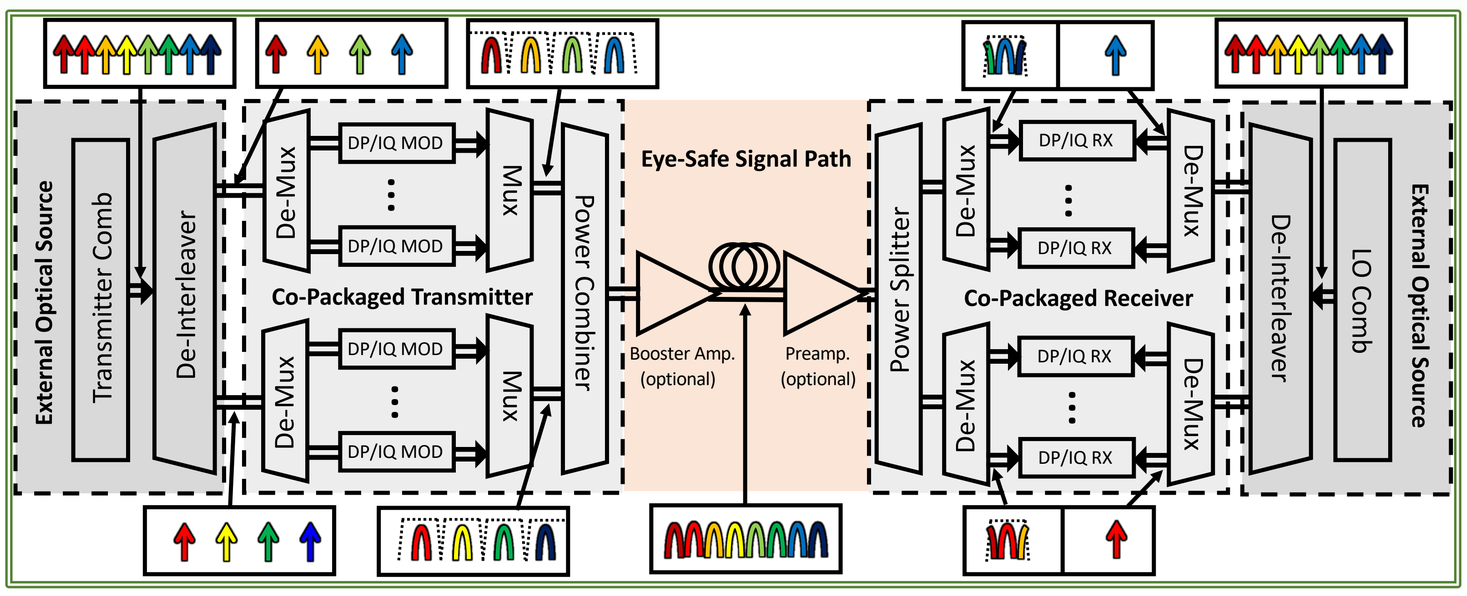
Introduction

- Intra-data center traffic consumes 77% of global IP traffic with a compound annual growth rate of 27% (>90% including intra-rack interconnects)[1].
- Data center switches will scale to throughputs of 51.2 Tb/s or higher over the next 5 years [2].
- Co-packaged optics may reduce system power by eliminating lossy electrical interconnects and alleviating front panel bottlenecks [3] [4].
- However, co-locating optics and electronics increases optical loss, system complexity, and thermal fluctuations (particularly important for integrated lasers and multiplexers).
- We propose a co-packaged optical interface for next-generation electrical switches that uses wideband (de)multiplexers, external optical sources, and coherent detection [5].
- Coherent links utilizing the proposed architecture can scale to over 12.8 Tb/s per fiber while links based on direct detection scale to less than 1.3 Tb/s per fiber.





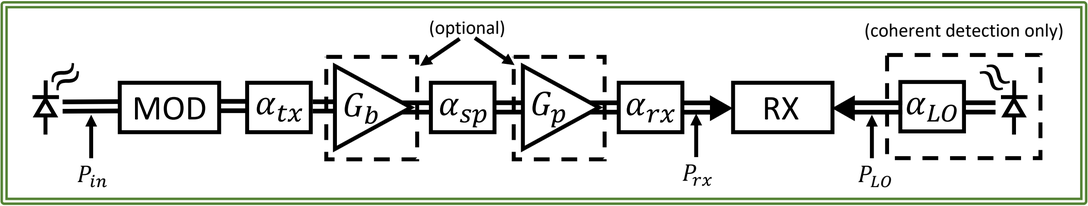


Proposed Link Architecture

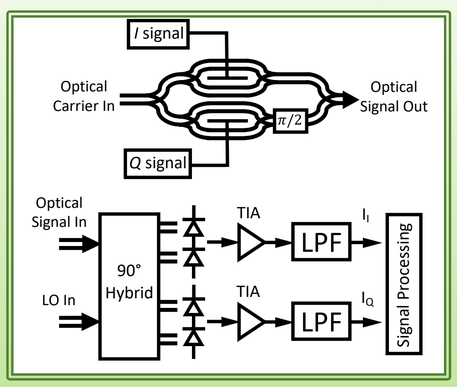
- An external multi-wavelength carrier (MWC), de-interleaved to prevent crosstalk, is coupled onto a photonic integrated circuit (PIC), where it is demultiplexed with temperature-sensitive wideband arrayed waveguide gratings (AWGs).
- The carriers are modulated, multiplexed into, and output-coupled to the signal path, which may include amplifiers to enable lossy optical switching.
- The signal is input-coupled to the receiver PIC, where it is demultiplexed and coherently detected. Neighboring channels can be filtered out electronically after down-conversion by the local oscillator (LO).

Receiver Statistics Modeling

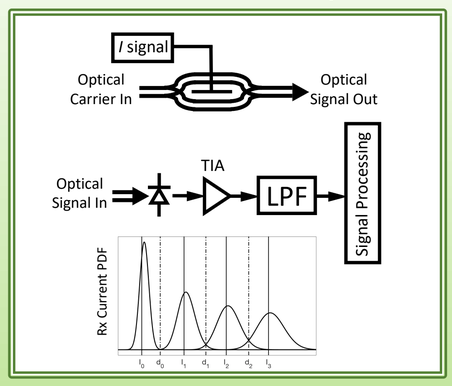
- The link design shown above can be simplified to the link model below.
- We model shot, thermal, and ASE noise as well as finite extinction ratio.
- While noise in the coherent links is approximately Gaussian, direct detection links can operate with significant thermal and ASE noise, which is modeled by computing the PDF of the received signal.



Coherent Detection Tx/Rx



Direct Detect. Tx/Rx

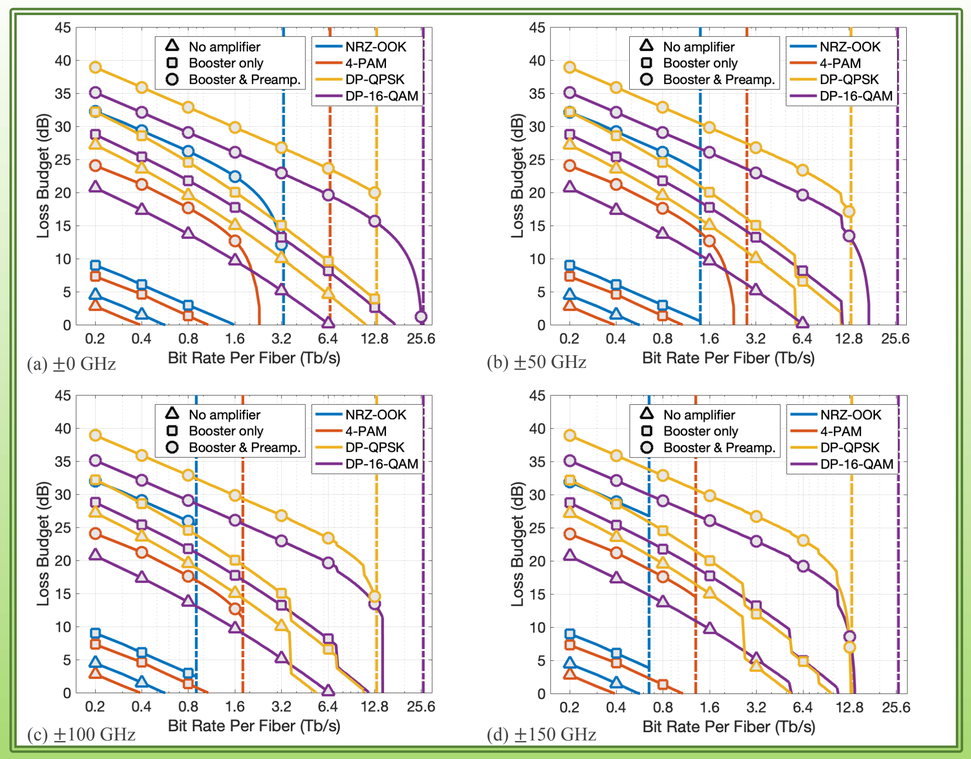


Performance Comparison

- Coherent links utilizing co-packaged optical interfaces can scale to >12.8 Tb/s per fiber in the presence of temperature-induced AWG center frequency shifts of up to 150 GHz.
- Comparable direct detection links can scale to less than 1.3 Tb/s per fiber.
- Both coherent and direct detection links, limited by eye-safety, experience a sharp roll-off in loss budget due to dominance of thermal noise in the receiver.
- The optical bandwidth-limited per-fiber bit rate (vertical dashed lines) decrease for direct detection because the channel spacing is large.
- Coherent links can utilize densely packed channels due to the thermally insensitive design, increasing per-fiber bit rates.

Component	Insertion Loss
Input/Output Coupler	−1.5 dB
Power Splitter and Combiner	−1 dB
Waveguide (several cm)	−2 dB
AWG (De)Multiplexer	−3 dB
Modulator	−5 dB

Symbol Rate	56 Gbaud
Channel Width	75 GHz
MWS Output Power	25 dBm
Transmitter Insertion Loss (α_{tx})	−20 dB
Modulator Extinction Ratio (r_{ex})	−10 dB
Center Wavelength	1550 nm
Available Bandwidth (C Band)	5 THz
Signal Path Loss (α_{sp})	−3.5 dB
Eye Safety Limit (Class 1)	10.1 dBm [40]
Amplifier Noise Figure	5 dB
Maximum Amplifier Gain	30 dB
AWG Center Frequency Shift	±0-150 GHz
Receiver Insertion Loss (α_{rx})	−7 dB
Local Oscillator Insertion Loss (α_{LO})	−7 dB
PIN Photodiode Sensitivity	1 A/W
TIA Input-referred Noise	30 pA/$\sqrt{\text{Hz}}$



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