# Frequency Stabilized Lasers for Coherent Fiber Interconnects in the Datacenter

(Invited Talk)

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***Abstract*— As data center ethernet switches scale towards 100Tbps, the fiber interconnect will face significant cost, power and engineering barriers. We describe FRESCO, a fiber data center interconnect (DCI) that brings highly coherent WDM Terabit links inside the data center without the need for DSPs and other power consuming technologies. FRESCO is based on integrated ultra-stable, ultra-low linewidth laser, frequency comb and silicon photonic transceiver technologies.**

### Introduction

As Hyperscale data centers become prevalent, switch ASIC chips, the engines of the Data Center Interconnect (DCI), will grow from 12.8 Tbps today to next generation 25.6 Tbps with continued capacity demands and strain on energy resources [1] [2]. However, continued scaling of these switches using today's approaches is difficult, due to power envelope and energy consumption and heat dissipation engineering limits. Scaling the switch ASIC to 100 Tbps is equivalent to integrating the electronic functions of architectures like the 92 Tbps Cisco CRS-1, consisting of 8 racks of switches and 72 racks of buffers and other electrical functions [3], to the scale of a single switch package as illustrated in Fig. 1.

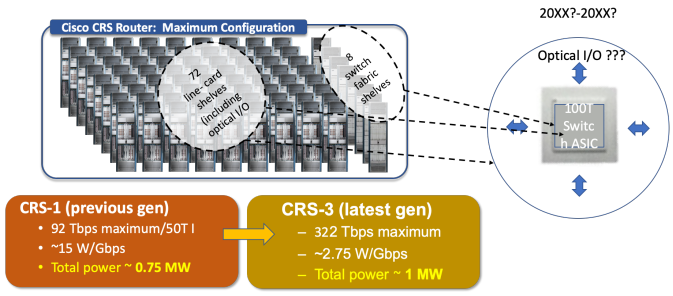


*Fig. 1. Future integration of prior generation multi-rack 92 Tbps switches to a single switch chip package will face challenges using today's optical I/O solutions to scale with the switch ASIC.*

This level of integration of the switching, buffering and other electronic functions pushes the limits of Moore's law. However, the ability to integrate the equivalent of 72 racks of optical I/O pushes beyond the capabilities of today's optical interface technology. Historically, the optical I/O capacity and power envelope lags behind the switch technology, and with switch ASIC scaling to 100 Tbps there will be a divergence of optical I/O capacity to track switch capacity. An illustration of number of modules and fiber count for 50 G NRZ, next generation 50G PAM-4 and possible 100G PAM-4 is shown in Fig. 2.

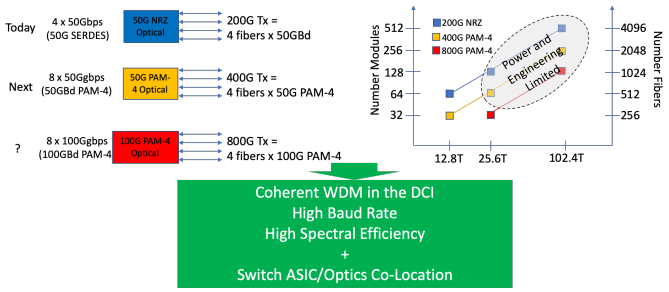


*Fig. 2. Module count and fiber count for various switch ASIC capacities using today's and emerging optical I/O technology, will be power and engineerable solution limited. New coherent WDM solutions that are DSP-free and free of high power, high speed electronics, will be needed.*

To scale fiber capacity while maintaining the power envelope and cost while closing the gap with switch integration, high capacity coherent WDM will need to be brought into the DCI. However, today, these links rely on power consuming technologies like digital signal processors (DSPs) and large-bandwidth phase locked loops [4]. New solutions are needed to enable high-capacity coherent WDM without power and cost consuming DSPs and other high power analog or digital electronics .

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## I. FRESCO Architecture

In this talk we describe a new WDM coherent link architecture for the DCI, based on highly-integrated, ultra-stable, narrow-linewidth laser and transceiver technology. Our approach, the FREquency Stabilized Coherent Optical (FRESCO) WDM link, supports coherent Tbps transmission per wavelength and scaling to support future 100 Tbps switch ASICs with order several pJ per bit efficiency. FRESCO brings narrow linewidth and laser stabilization technology developed for frequency standards [5] and atomic clocks [6] to the coherent fiber DCI.

The FRESCO architecture is based on a shared ultra-stable, spectrally-pure laser, that drives a ultra-stable, spectrally pure, shared optical comb (Tx and LO), and is modulated with highly-integrated silicon photonic coherent transceiver. The integrated FRESCO transceiver is shown in Fig. 3.

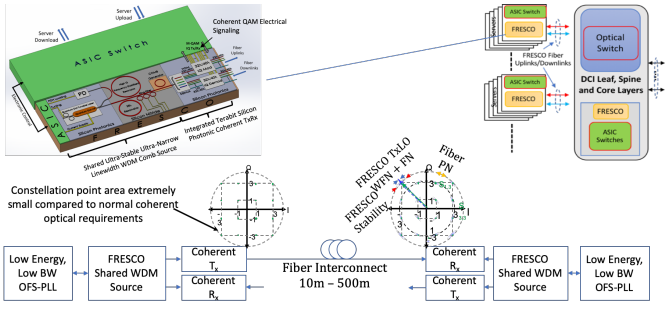


*Fig. 3. FRESCO integrated transceiver based on a shared sub-Hz ultra-stable frequency WDM comb source and integrated Terabit per wavelength coherent WDM modulators and receivers. Connection of switches in a DCI using FRESCO technology. Independent mutually coherent source fractional frequency stability. Fresco link with DSP-free coherent QAM modulation and shared low energy, low speed PLL for fiber WDM.*

Spectrally-pure, ultra-stable lasers, the workhorse of precision scientific experiments like atomic clocks and metrology, offer a new approach to realizing low-energy coherent links for the DCI that are free of power consuming DSPs and high bandwidth electronics. FRESCO integrates low linewidth lasers with extremely high stability and frequency noise reduction (low close-to-carrier frequency noise) to transfer techniques developed for precision frequency stability and transfer into the WDM coherent link. These techniques utilize low power, low-bandwidth, Pound-Drever-Hall (PDH) [5] loops to lock a laser to an ultra-high Q optical resonator, providing Hz-level laser linewidth with phase coherence that is stable to better than 1E-12 over periods of greater than 100ms. This approach creates mutually coherent lasers at the transmitter and local oscillator (LO) that are able to stay aligned open loop for billions of bits of coherent data transmission. The impact is that this level of carrier and phase stability eliminates the need for DSPs and high bandwidth PLLs that scale with bit-rate. The feedback circuits needed for the FRESCO kHz loop bandwidths are able to maintain flat power consumption and scale to Tbps links using less than 1 mW power mixed CMOS. Other aspects of FRESCO eliminate the clock and data recovery (CDR) and other power consuming elements. The ultra-narrow linewidth significantly reduces analog to digital converter (ADC) requirements and energy. This new design allows a Tbps coherent link to be operated with only several mW circuits with the potential of using the same circuits for all or a subset of wavelengths on a single WDM DCI fiber, leading to an unprecedented low energy consumption for a WDM Tbps coherent link.

## II. Frequency Stabilized Lasers

A FRESCO shared optical source consists of a silicon photonic tunable laser [7], a micro-scale ultra-stable optical reference cavity, and a silicon nitride Brillouin laser [8] that pump a nonlinear optical frequency comb (OFC) source [9]. The ultra-stable, spectrally pure, shared WDM source serves as the Tx and LO carriers for a silicon photonic integrated coherent modulator and receiver [10]. All chip sets are implemented using foundry compatible silicon photonic and silicon nitride processes. Coherent QAM modulation will operate at 64 and 72 GBd and 64- and 256-QAM, and support out to 1.6 Tbps and 3.2 Tbps per wavelength on a frequency stabilized link.


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