Coherently Sub-Grouped µDC-Pod and -Interconnect with Analogue EML Transceivers Operated in TDMA

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We exploit an IM/DD transmitter as coherent receiver for filterless micro-datacenter pods and their interconnect. A transistor-outline EML performs coherent homodyne reception under a 240kHz TDMA frame with 139ns guard interval between free-running transmitters.

1. Introduction

Soaring traffic demand in datacenter networks (DCNs) at cloud datacenter warehouses is stimulating the development of ever-faster DCN switches. Equipment manufacturers aim to double the capacity of their switches every two years; however, the slowdown of Moore's law is raising concerns as per the possibility to keep pace with such rigorous scaling cycles. The situation is exacerbated considering the diminishing improvements in energy efficiency of switch silicon, which is bringing DCN's closer to the "energy wall". In this milieu optical switching is gaining traction as a promising path for gracefully scaling DCNs. A multitude of optical switching architectures have been proposed, building upon the advantages and limitations of currently available switches. The most notable hardware constraint is the trade-off between reconfiguration speed and switch size [1]. On top of this, excessive fiber-to-fiber loss is plaguing most integrated solutions. Optical switched architectures based on coherent optics can overcome these shortcomings by leveraging their inherent amplification gain and their wavelength selectivity [2]. Given that existing coherent links rely on computationally-demanding digital signal processing (DSP), efforts focus on DCN-optimized coherent links that alleviate the need for DSP, especially as micro-datacenters move closer to the edge. DSP-free coherent reception was demonstrated in [3] using envelope detection within a high-speed electronic rectifier. Alternative approaches rely on optical or electrical phase-locked-loops [4]. However, both schemes necessitate custom electronics which directly impact the cost, size and power consumption.

In this work we demonstrate a coherent TDMA architecture for intra- and inter- micro-DC networking, which builds on direct-detection transceiver technology. We show coherent homodyne 10 Gb/s transmission, sourced by multiple EMLs with fully analogue transmitting and receiving sub-systems, over an end-to-end budget of 61.7 dB.

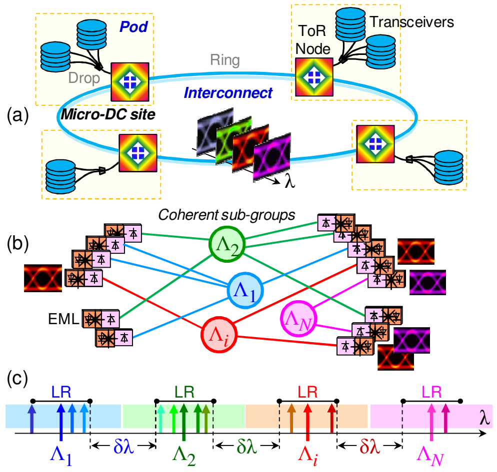

Fig. 1. (a) Coherent intra/inter micro-DC architecture. (b) Coherent TDMA groups. (c) Ultra-dense spectral allocation.

2. Coherent Homodyne Micro-Datacenter Network

Figure 1(a) shows the architecture investigated in this work. Multiple micro-DC are interconnected in a ring topology. Each micro-DC is administered by a Top-of-Rack node, arranged in a pod with a group of transceivers. The ToR unit serves to connect to multiple end-hosts installed on the micro-DC (e.g. servers, storage) and interconnects to other micro-DCs. Although the physical topology for this interconnect is a ring -by virtue of its simple implementation- the logical topology is a mesh enabling all-to-all communication within the end-hosts of all micro-DCs. Coherent sub-groups can be collapsed over the entire network as virtual point-to-multipoint links (Fig. 1(b)). Provided that an agile coherent receiver is available, multiple transmitters in the interconnect domain can share a single wavelength by means of TDMA. This ensures a resource-friendly allocation of short-lived data flows without spectral exhaustion. However, the cost-ineffectiveness of coherent optics is the most significant barrier which currently impedes a coherent intra- or inter- micro-DC approach. As a graceful migration from IM/DD technology we propose to adopt the same transceiver technology for coherent transmission as found in IM/DD pluggables: the EML. This low-cost laser device consists of all required elements that shape a coherent receiver [5]. Its distributed feedback (DFB) laser serves as local oscillator (LO) with a high optical launch power of ~10 dBm. The electro-absorption modulator (EAM) is equivalent to a fast in-line PIN photodiode with typical bandwidths exceeding 10 GHz. The position of the EAM between optical input and LO allows to injection-lock the local source, which in turn results in homodyne detection provided that the incident optical signal falls within the locking range (LR) of the LO. As a consequence there is no need for DSP due to the frequency-preserving and phase-agnostic translation of the optical signal to the electrical domain. Moreover, there is no need for DSP-assisted signal demodulation as in previous demonstrations with advanced passband modulation formats [5], which renders the proposed coherent receiver as fully analogue through its end-to-end signal chain.

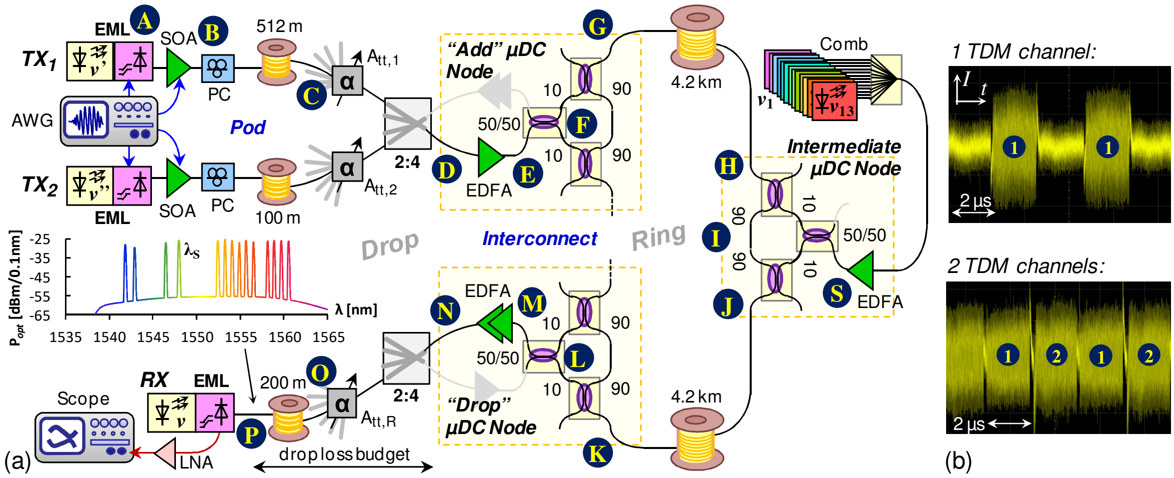

Fig. 2. (a) Experimental setup of the coherent pod network. (b) Received signal for one and two present TDM channels.

This work will demonstrate that this greatly simplified coherent homodyne broadband receiver can operate in TDMA mode. Precise optical synchronization among multiple TDM channels with free-running source lasers is overcome through the receiver's fast injection-locking property, which eliminates any frequency offset between the source laser and the LO. This process is supported by the stability of a transistor-outline (TO) packaged EML with co-integrated micro-Peltier element, which guarantees that the wavelength stability is much smaller than the LR.

The flexibility offered through a filterless, coherent architecture eventually enables ultra-dense channel packing. Figure 1(c) shows the seamlessly utilized spectrum. Coherent homodyne detection dictates that transmit channels are to be placed within the LR of the receiver-side LO at Λ_i, which is ~200 MHz for an injected power of -30 dBm [5]. The spacing $\delta\lambda \approx 2\ R_{sym} >> \text{LR}$ between the receiver wavelengths Λ_i, and therefore between the coherent sub-groups, is mainly given by the dual-sideband modulation setting at the symbol rate R_{sym}. Wider tuning ranges for the EML with fast wavelength switching at the same time would require to incorporate additional tuning structures [6].

3. Experimental Setup and Signal Evolution

The experimental setup is presented in Fig. 2(a). Two EML-based transmitters ($TX_{1,2}$) are sharing a wavelength λ_T of 1546.92 nm within a coherent sub-group by means of TDM. The EAMs are driven by 10 Gb/s burst-mode data (A) at a TDMA frame rate of 240 kHz and a guard interval of 139 ns between the bursts of both transmitters (Fig. 2(b)). Gated semiconductor optical amplifiers (SOA) are used to ensure a good extinction before and after the data burst. Both TDM data signals are combined at a 2:32 drop splitter that serves as a passive branching device, emulated through variable attenuators ($A_{tt1,2}$) and a 2:4 splitter (C). The compound signal is then added to the collector ring. EDFA-based add- (D) and drop-amplification (M) stages are employed at the ring nodes (RN) to account for a high end-to-end loss budget. Colorless ring insertion / drop is made through 10/90 couplers (G,M) to ensure a low pass-through loss (H-J) for each ring node. Resiliency is provided through a 50/50 feed at all nodes. The node-to-node span was 4.2 km.

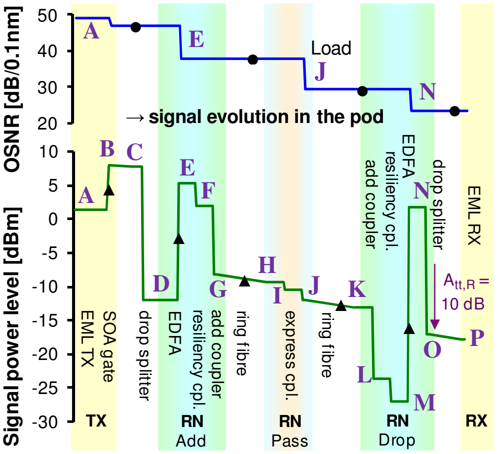

Fig. 3. Signal power and OSNR along the pod network.

A comb with 12 side-channels from 1539.77 to 1560.61 nm (see inset in Fig. 2(a)) has been added at the intermediate node (S) in order to load the inter-DC network before coherent broadcast-and-select reception at λ_T is performed. A coherent EML receiver with an electrical low-noise amplifier (LNA) is locked to λ_T (P). Its sensitivity was evaluated as function of the loss budget at the receiver-side drop segment (O). Due to the unavailability of a fourth EML, polarization diversity reception [7] was not implemented and manual polarization control (PC) has been applied at the transmitter side (B). The BER was estimated off-line since no burst-mode tester was available.

The electro-optic response of the EML transmitter and EML receiver is presented in Fig. 4(a). The transmitter bandwidth of the TO-can EML is 7.3 GHz. The receiving EML shows a similar value if the ripple is ignored.

A detailed evolution of signal power (▲) and OSNR (●) along the three nodes of the micro-DC interconnect is shown in Fig. 3. A high passive end-to-end loss budget (B-P) is supported through add-/drop EDFAs (D-E, M-N), which contribute with a gain of 46 dB in total. The erosion of this optical budget enables split ratios of 2:32 at the drop segment. The delivered OSNR of 23.5 dB is determined by the received power at the drop amplifier (M).

4. Coherent TDMA Reception

The BER performance for the receiver-side drop loss budget (N-P in Fig. 2(a)) is presented in Fig. 4(b) for continuous- and in Fig. 4(c) for burst-mode coherent reception. For the worse TX2 channel under single-channel (□, λ_T), continuous-mode transmission a drop loss budget of 20 dB is compatible at the hard-decision forward error correction (FEC) threshold of $3.8 \cdot 10^{-3}$. The mere fact that a BER well below the FEC level is obtained proves the correct coherent homodyne reception without DSP. Addition of the DWDM comb (■) leads to a 0.8 dB penalty in achievable budget, which is attributed to the reduced EDFA gain for the loaded micro-DC interconnect.

The burst-mode BER is shown in Fig. 4(c) for a single TDM-channel (△,○) and for both TDM channels in co-existence (▲,●). There is no penalty between single-channel and dual-channel TDM transmission after omitting the preamble that blanks out the transient that is induced by the low-frequency cut-off at the transmitting and receiving EMLs. The compatible drop budget is 18.6 dB for the worst channel (●). This corresponds to a 0.6 dB penalty with respect to continuous-mode transmission, which is associated to the residual ripple in the waveform arising from the AC-coupling in the RF chain of the data path. Nevertheless, the obtained drop loss budget leads to a compatible split of 1:32 for the pod network while leaving a comfortable power margin of 2.6 dB. Together with the EDFA amplification in the ToR nodes, the obtained results enable a passive end-to-end lightpath budget of 61.7 dB (B-P in Fig. 2(a)), as a sum of several passive losses traversed along the micro-DC interconnect.

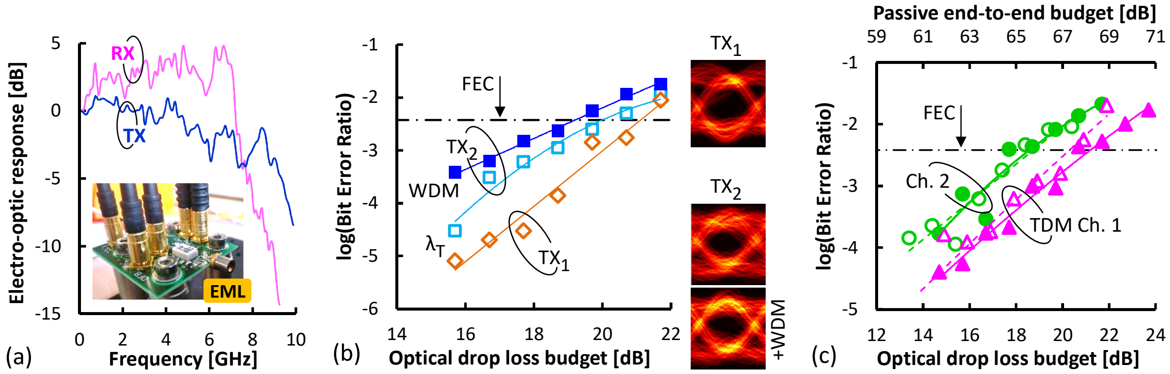

Fig. 4. (a) Electro-optic response of EML transmitter and receiver. BER performance in (b) continuous and (c) burst mode.

5. Conclusions

We have demonstrated an EML-based coherent receiver. All-optical locking enables homodyne detection, which allows for a fully-analogue broadband design that does not require DSP functions for neither signal recovery nor demodulation. Coherent TDMA reception over a filterless 1:32 split, 9 km reach ring interconnect with two free-running transmitters at a frame rate of 240 kHz and a guard interval of 139 ns between the data bursts has been validated. We believe that this conceptually simple transceiver concept, together with a transimpedance-amplifier based front-end for a higher sensitivity and bandwidth, can improve the spectral- and energy-efficiency in DCN.

6. Acknowledgement

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7. References

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