Low-Complexity Digital Signal Processing Techniques to Enable Coherent Optical Systems for Metro and Access networks

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Abstract
We summarize our recent research works on enabling coherent optical transmission systems for metro and access networks with low-complexity digital signal processing techniques, focusing on reduction of laser linewidth requirement with efficient carrier phase recovery.

I. INTRODUCTION
To date, the metro and access networks are constantly being extended to reach base stations for mobile applications, data centers, local exchanges and new enterprises, resulting in a continuous growth of data traffic at a significant increasing rate during the past five years [1]. All this traffic is eventually routed through the metro and regional core networks, creating challenges to keep quality of services while maintaining a low-cost target for service providers. As a response, cost effective coherent technologies with reduced complexity and form factors are being introduced and developed. Currently, thousands of 100G+ coherent optical equipment ports are being deployed for the metro and access applications, thanks to the development of large-scale photonics integrated circuits (PICs) technologies [2][3].

One of the significant design aspects for PIC-based coherent transceivers to be suitable for metro and access applications is the laser, the linewidth of which correspondingly impacts the complexity of digital signal processing (DSP) module and the employed modulation formats. Monolithically integrated semiconductor lasers are generally more cost-effective, energy-efficient and easy to integrate, comparing to the external cavity lasers (ECLs) commonly used in coherent transceivers for long-haul networks. However, one drawback of using such semiconductor lasers is the higher linewidths, requiring potentially more complex DSP for carrier phase recovery (CPR) and coding/decoding, increasing ASIC power consumption and size, therefore the cost. Such a trade-off imposes challenges on the design and development of low-complexity and high-performance DSP algorithms.

In this abstract, we aim to take the initiative to discuss potential solutions to lower the complexity of the DSP algorithms for coherent transceivers, particularly targeting to lower the laser and CPR requirements. Mainly three approaches will be discussed: 1) lower the complexity of feedforward CPR structure for conventional square shaped QAM signals; 2) adapt the constellation shape of the QAM signals for low-complexity CPR algorithms that have difficulties to be applied to square QAM constellations; and 3) use self-homodyne implementation to achieve a stable carrier phase performance.

II. POTENTIAL COHERENT TECHNOLOGIES FOR METRO AND ACCESS NETWORKS
From the perspective of DSP on conventional coherent system architecture, blind feedforward CPR methods including blind phase search (BPS) and, Viterbi & Viterbi (V&V) algorithms can be potentially applied on QAM signals, directly or indirectly. Furthermore, from a system architecture perspective, self-homodyne coherent system together with spatial division multiplexing (SDM) technologies may open a new way to address future metro and access applications and demand.

A. Low complexity CPR for square QAM
For square shaped QAM signals, BPS based CPR methods are preferred owning to its scalability for any constellation shapes and modulation orders. However,
complexity induced with high phase search resolution should be considered and reduced for practical use. We have proposed to use a sliding average filter to mitigate the intrinsic high frequency noise enhancement induced by the limited discrete phase resolutions of the BPS algorithms [4][5]. The performance enhancement and complexity reduction can be observed in Fig. 1.

**B. Circular shaped QAM constellation**

The non-uniform phase distribution of square shaped QAM constellations limits the direct application of the low-complexity V&V algorithm and/or its multi-stage CPR implementations. We propose to use a circular shaped QAM constellation which transparently accommodates to the operational requirements of the algorithms [6][7]. This is in line with the current trend of using flexible constellations with geometrical constellation shaping. Figure 2 shows the example of a multi-stage CPR structure for circular 64QAM. Such combination can greatly enhance phase noise tolerance comparing to that of the square QAM.

**C. Self-homodyne implementation and its synergy with SDM technology**

Self-homodyne coherent detection (SHCD) technique can offer stable carrier phase performance, thus reducing the requirements on both the DSP and the laser. A straightforward approach is to couple the SHCD with SDM technologies, in such a way the local oscillator (LO) can be forwarded with a separate spatial channel and shared by multiple data channels. Our recent experimental demonstration (Fig. 3) shows that this approach can potentially support high data rate with multilevel modulation formats, e.g. 64QAM [8].

We summarized our recent research initiatives on investigating possibilities of using low-cost coherent transceivers with low DSP complexity. The main effort up to now focuses on the carrier phase recovery for large linewidth integrated semiconductor lasers. Considering both the signal and the system architecture, different approaches can be utilized to achieve improved performance with lower transceiver complexity. Additionally, the envisioned target should also include future efforts on lowering the complexity of equalizer and forward error correction coding schemes, etc.

**ACKNOWLEDGMENT**

This work was supported by the EU H2020-MSCA-IF Project NEWMAN (no. 752826), the EU Project ICONE (no. 608099), the Swedish ICT TNG project SCENE, the Swedish Research Council (Vetenskapsrådet) and VINNOVA funded Celtic Plus sub-project C2015/3-5 SENDATE-FICUS. The equipment was funded by Knut and Alice Wallenberg foundation.

**REFERENCES**

[1] Cisco Global Cloud Index: Forecast and Methodology, 2016–2021, *White Paper*, Cisco, updated 2018.
[2] 100G+ Coherent Optical Equipment Ports. *Tech. rep.* IHS Infonetics, 2015.
[3] W. Forysiak, D. S. Govan. “Progress toward 100-G digital coherent pluggables using InP-based photonics”. *J. of Lightwave Technology*, vol. 32, pp. 2925–2934, 2014.
[4] J. Rodrigo Navarro et al., “High performance and low complexity carrier phase recovery schemes for 64-QAM coherent optical systems,” in Proc. OFC 2017, Los Angeles, CA, 2017, paper W2A.53.
[5] J. Rodrigo Navarro et al., “Blind Phase Search with Angular Quantization Noise Mitigation for Efficient Carrier Phase Recovery,” *MDPI Photonics*, vol. 4, no. 2, 37, 2017.
[6] J. Rodrigo Navarro et al., “Adaptive Boundaries Scheme for Cycle-Slip Mitigation in C-mQAM Coherent Systems,” *IEEE Photonics Technology Letters*, vol. 27, no. 20, pp. 2154-2157, 2015.
[7] J. Rodrigo Navarro et al., “High Phase Noise Tolerant Circular-64QAM with Efficient Phase Recovery for Coherent Optical Systems,” in Proc. ACP 2017, Sa3B.7.
[8] A. Udalcovs et al., “MCF-Enabled Self-Homodyne 16/64QAM Transmission for SDM Optical Access Networks,” in CLEO 2018, San Jose, CA, 2018.

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**Fig. 2. Block diagram of the proposed F-BPS+F-BPS CPR scheme for circular shaped 64QAM signal at 28 Gbd. [7]**

**Fig. 3. Block diagram of the proposed 28-Gbaud 16/64QAM transmission link utilizing a SHCD enabled by a multicore fiber: (a) transmitter configuration; (b) 33.6 km long fiber-link based on a 7-core multicore fiber; (c) receiver configuration; (d) constellations after optical back-to-back (OB2B) transmission at high OSNR values [8]**