Quasi-coherent Technology for Cost Efficient High Loss Budget Transmission

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Abstract: In this paper, we present results achieved with real-time quasi-coherent receivers in context with challenges for next generation access networks. -35 dBm receiver sensitivity at 10 Gbps for NG-PON2 applications and 32.5 km 25 Gbps C-band transmission over an uncompensated SSMF link for 5G front/mid-haul is presented.

1. Introduction

The Gigabit race is on. As global IP traffic is forecasted to hit 3.3 zettabytes by 2021 [1] network operators around the world are taking stock of their existing networks and working out which technologies they need in order to ensure their competitive positioning moving forward. Next-generation optical access technologies will be required to deliver much higher speeds than that of existing fiber-to-the-premises service offerings, while also providing an agile physical layer for on-demand services creation and cloud-based services delivery.

As the massive deployment of optical access networks continues worldwide, operators expect more from fiber-based technologies and are converting their traditional copper or microwave-based access networks to a fiber-based access network. At present, the main driver for increased fiber-access capacity is front- and mid-haul 5G mobile network. Although different ISPs have different strategies for this roll-out based on their individual customer base, there are a few main trends:

1. NG-PON2 is a passive optical network (PON) standard specifically developed for integrating mobile, business and residential networks into one network with software control [2,3]. It is a dense wavelength division multiplexed (DWDM) C-band architecture employing 4-8 10 Gbps channels with a 100 GHz channel spacing. In addition, there is a point-to-point (P2P) DWDM L-band overlay included in the standard. The main challenges here is related to the upstream transmitter. It is very challenging to cost-effectively built burst mode transmitters with a burst mode spectral excursion that complies with NG-PON2 requirements of 40 GHz channel width while having enough launch power to deliver the required optical power budget.

2. Coarse (CDWM) employing six 25 Gbps channels in the low dispersion O-band [4,5]. This approach is favored by leading Chinese ISPs and provides an attractive solution when the total 150 Gbps capacity suffices.

3. For the cases where the 40-150 Gbps capacity offered by NG-PON2 or O-band CWDM is insufficient, DWDM systems employing 16-32 25 Gbps channels in the C-band can be the solution [6]. The main challenge here is chromatic dispersion limiting transmission distance over uncompensated links to 10-13 km [7]. There is a great desire to increase this reach to 20-40 km

2. Bifrost Communications Quasi-Coherent detection

The quasi-coherent (QC) detection scheme based on optical heterodyning with analog signal processing has the potential to overcome the main challenges in options 1. and 3. above.

For NG-PON2, when placed at the optical line terminal (OLT), the improved receiver sensitivity of -35.2 dBm (BER = 10^{-3}) [8] provided by QC detection can be used to lower the required launch power of the optical network unit (ONU) transmitters, thereby reducing overall system cost.

For 25 Gbps line rate DWDM C-band systems, the optical heterodyning process employed in QC receivers allow for radiofrequency (RF) - domain compensation of chromatic dispersion. In this paper, we demonstrate 32.5 km C-band transmission over an uncompensated link. This result is achieved by RF-domain single-sideband (SSB) filtering in the QC receiver.

As illustrated in Fig. 1, the quasi-coherent Bifrost receiver can be realized with as little as 1 polarizing beam splitter (PBS), 1 coupler and 2 conventional single-ended photodetectors (PDs) compared to the 2 PBS, 2 90º hybrid and 4 pairs of balanced PDs (8 PDs in total) needed for the "full" homodyne receiver. In addition, the complex and power-hungry digital signal processing (DSP) required for phase locking the local oscillator (LO) to the signal can be avoided.

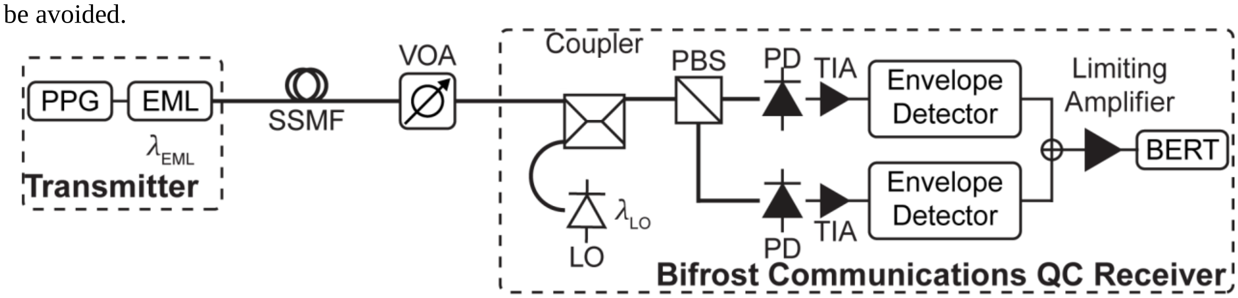

Fig. 1. Block diagram of the quasi-coherent Bifrost receiver

3. QC-based OLT receivers enabling all classes of NG-PON2

Fig. 2.a shows BER vs. received power (PRX) for the NG-PON2 QC receiver. The sensitivity at a BER of 10^{-3} is obtained at -35.2 dBm back to back (B2B) as well as after transmission through 40 km standard single mode fiber (SSMF), potentially enabling even the most demanding Class E2 [9] with only +2 dBm ONU launch power – an achievement which is impossible even with the best state-of-the-art APD direct detection receivers available today. Fig. 2.b shows the dynamic range of the QC receiver, i.e. the BER vs. PRX for the sensitivity and the overload region. The overload PRX of the QC receiver is -12.3 dBm, which leads to a dynamic range of 22.9 dB comfortably exceeding the 15 dB required by the NG-PON2 standard [9].

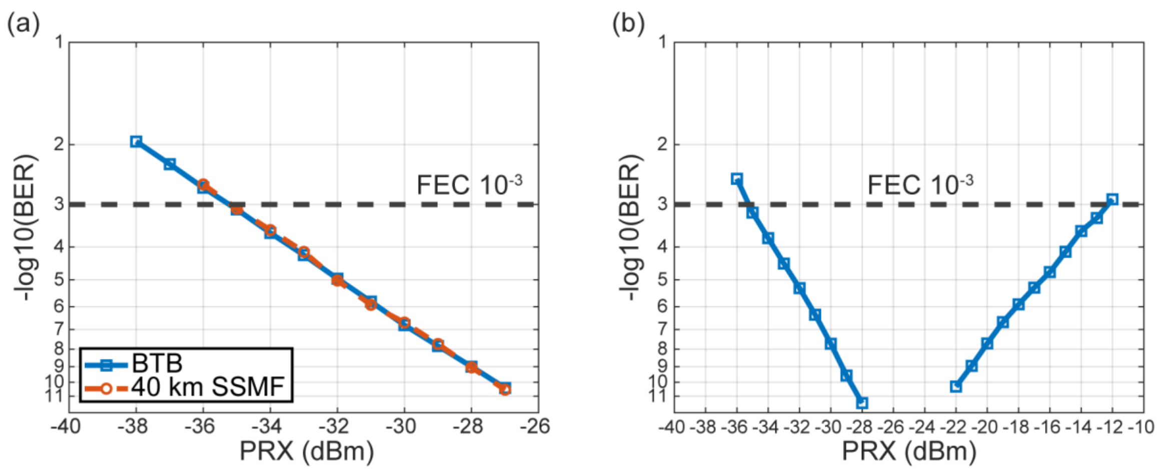

Fig. 2. BER vs. PRX for NG-PON2 QC receiver: a) BTB and 40 km SSMF transmission, b) Dynamic range

4. RF-domain single sideband (SSB) filtering for +30 km 25 Gbps C-band links

The SSB QC receiver performs a low pass filtering of the signal at the intermediate frequency (IF) using either a dedicated filter or the bandwidth limitation of the PD and transimpedance amplifier (PD+TIA). The SSB filtering eliminates the chromatic dispersion induced frequency selective fading [10] that appear for intensity modulated double side band (DSB) signals due to the different phase rotation of the frequency components in the upper and the lower side band. For the SSB QC receiver, this fading simply does not occur as the upper sideband has been removed by tuning the LO laser wavelength such that the upper sideband of the intermediate frequency (IF) signal is removed by RF low-pass filtering.

The received optical eye diagrams, which are equivalent to the electrical eye diagrams after direct detection (DD), are shown in Figure 3.a-d. It is evident, that the signal after 22.5 km and 32.5 km fiber cannot be recovered by conventional direct detection. Already after 22.5 km SSMF, the inter-symbol interference is so severe that the eye diagram has become a 3-level eye. The electrical eye diagrams after SSB QC receiver are depicted in Figure 3.e-h, showing that the QC-SSB receiver is able to recover the NRZ eye even after 32.5 km SSMF transmission.

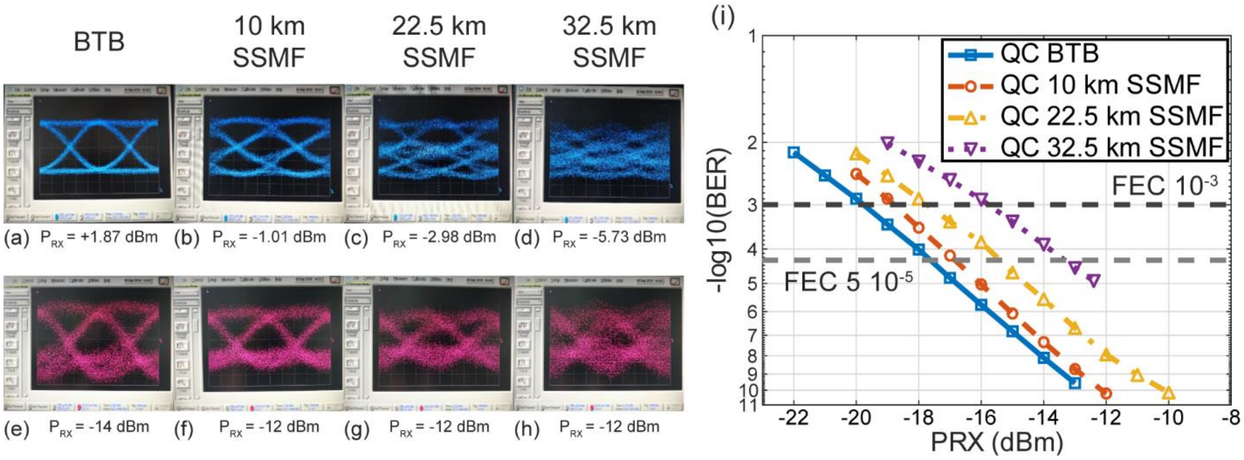

Fig. 3. SSB QC receiver. Optical eye diagram: a) BTB, b) 10 km SSMF, c) 22.5 km SSMF, d) 32.5 km SSMF. Electrical eye diagram: e) BTB, f) 10 km SSMF, g) 22.5 km SSMF, h) 32.5 km SSMF. i) BER vs. PRX

Figure 3.i shows BER vs. PRX for the 25 Gbps SSB QC receiver and for DD. The SSB QC receiver exhibits a sensitivity of -19.8 dBm for a pre-FEC BER limit of 10^{-3} and -17.6 dBm for a pre-FEC BER limit of $5 \cdot 10^{-5}$. The chromatic dispersion penalty for the SSB QC receiver is below 1 dB, 2.2 dB and 4.6 dB for 10 km, 22.5 km and 32.5 km SSMF transmission, respectively.

5. Conclusion

5G fronthaul puts new demands on optical access networks. Demands that different ISPs meets with different strategies among which 10 Gbps line-rate TWDM-PON (NG-PON2) and 25 Gbps point-to-point WDM in either the C-band (DWDM) or the O-band (CWDM) are the most dominant. Quasi-coherent detection has in this paper been shown to aid in meeting these demands by offering increased sensitivity for NG-PON2 and increased reach for C-band 25 Gbps, while maintaining a modest cost- and complexity increase over conventional direct detection. It thereby represents an attractive solution 5 G fronthaul.

6. References

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