Feasibility Study on Baud-Rate Sampling and Equalization (BRSE) for 800G-LR1

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Power saving for 800LR1

- ADC/DAC and equalization account for a large proportion of power consumption of coherent receiver ASIC [1]
- A O-Band with baud-rate sampling ADC/DAC and DSP will be a good candidate to significantly reduce the DSP power
- In this contribution, we conducted an initial feasibility study of BRSE-based 800G-LR1

TED: timing error detection; CPR: carrier phase recovery; VCO: Voltage controlled oscillator

[1] Presenter: Hongbin Zhang, Cisco Systems Inc, United States “Power Efficient Coherent Detection for Short-Reach System”, OFC 2023, invited talk: M1E.1
BRSE has been used in IMDD receivers [2]

- Independent clock tracking digital timing recovery (TR) loop for each lane with low enough latency.
- Analog based clock recovery schemes with sample at the center of each signal pulse (eye open)

Why BRSE hasn’t been used in coherent yet

- BRSE is **sensitive to ADC sampling phase**, that results:
  - **Firstly, the timing recovery (TR) is more risk to a distorted coherent receiver**
    - The incoming signal is temporally varying due to LOFO, SOP, and so on. The analog TR with eye open cannot work.
    - The digital TR before the MIMO may fail due to the strong inter-symbol-interference (ISI) caused by CD and PMD.
    - **However, the ISI is much smaller for 800LR (especially in O band), timing error detection (TED) methods have the chance to work**
  - **Secondly, the BRSE technique is sensitive to delays or skews between the XY and IQ**
    - Coherent receiver ADCs are challenge to sample at the center of each signal pulse (with delays or skews between the XY and IQ)
    - The skews cannot be compensated by traditional coherent DSP with interpolation based digital methods under baud-rate sampling.
    - **However, a real-value 4X4 MIMO can enhance the tolerance to the skews, while implementation complexity can be simplified when the fiber CD is negligible.**
    - **What’s more, the required timing delay for each of four ADC clocks could be individually or jointly optimized [3]**
  - **Thirdly, it is has a limited tolerance to fiber CD and PMD**
    - Traditional coherent is for metro and long-haul transmission in the C-band, where CD and PMD can be too high for BRSE.
    - **However, for 800LR the fiber CD and PMD are much smaller**

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Simulation for BRSE

- Simulation model and DSP flow

<table>
<thead>
<tr>
<th>Simulation Parameters</th>
<th>value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baud-Rate</td>
<td>123.6GBaud</td>
</tr>
<tr>
<td>Modulation format</td>
<td>16QAM</td>
</tr>
<tr>
<td>FEC threshold</td>
<td>1.1e-2 (Based on KP4+BCH)</td>
</tr>
</tbody>
</table>

TED: timing error detection; TD-MIMO: time domain MIMO; CPR: carrier phase recovery; ABSPD: abs timing phase detector [4]

# CD tolerance to TR of ADC under Baud-Rate Sampling

<table>
<thead>
<tr>
<th>TED Algorithm Example</th>
<th>Note</th>
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| Gardner/Godard [5]    | • Normally used, can suffer uncompensated CD and PMD  
                          • Cannot work under baud-rate sampling (without distinct spectral line at the baud-rate) |

                                              • But sensitive to the CD and PMD  
                                              • Expected CD tolerance smaller than 40ps/nm |

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CD Influence to Baud-Rate Sampling Equalizer

- The CD tolerance can be improved to >150 ps/nm.

Note: An extra CD compensation before TR has been done for those cases.

- Why CD brings extra penalty to BRSE?
  - Out-of-band spectral components are mixed in-band under baud-rate sampling, causing colored noise.
  - The effect of aliasing could be enhanced by CD [9,10].

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Improve Tolerance to IQ Skew and PMD

• Normal 2x2MIMO cannot work with Skew > 1 ps.
• DGD/PMD distortion may one of the top problems of BRSE, and four ADC clocks with individually optimizing may help to future increase the tolerance.
• A real-value 4X4 MIMO, can enhance the tolerance to both IQ skew and DGD (to 3 ps).
• BRSE is relatively sensitive to local oscillator frequency offset (LOFO), with ~3GHz tolerance.
• Thus, the LOFO should have a proper constraint.
Summary

- We have conducted an initial feasibility study on the use of baud-rate sampling and equalization (BRSE) to achieve low power consumption in 800G-LR1.
- The simulation results show that BRSE is feasible to achieve for 800G-LR1 (123GBd DP16QAM) without a CDC module
  - Non-decision aided TR is expected to tolerate <40ps/nm dispersion.
  - The 4x4 MIMO based Baud rate equalizer is expected to tolerate, 3.5ps IQ skew, 3.5ps DGD, and ±3GHz Laser frequency accuracy, respectively.
- With a CDC module prior to TR, >150ps/nm CD can be tolerated.
- Due to its multiple benefits, BRSE is a promising coherent-lite approach for further evaluation, especially for O-band 800G-LR1 (even for O-band 800G-ER1).

Thank you!