Low-Complexity Linewidth-Tolerant Carrier Phase Estimation for 64-QAM Systems Based on Constellation Transformation

S. M. Bilal, G. Bosco, P. Poggiolini
Politecnico di Torino, Italy
gabriella.bosco@polito.it

C. R. S. Fludger
Cisco Optical GmbH, Nürnberg, Germany
cfludger@cisco.com

Abstract - A novel three-stage digital feed-forward carrier recovery algorithm based on the transformation of 64-QAM constellation into QPSK is proposed. For 1 dB penalty at BER = 10^{-2}, it can tolerate a linewidth-times-symbol-rate product of 4.5 \times 10^{-5}, making it possible to operate 32-Gbaud optical 64-QAM systems with current commercial tunable lasers.

Block diagram of the algorithm

QPSK partitioning and MLE stages

64-QAM -> QPSK Constellation Transformation

Simulation Setup and results

Viterbi&Viterbi with QPSK-partitioning

Constellation transformation

Maximum-Likelihood Phase estimation

- Class-1 symbols have modulation angles equal to \pm \pi/4 + m \cdot \pi/2 (m = 0...3).
- 12 out of the 16 symbols lying at the vertices of squares are used in the Viterbi&Viterbi algorithm:

\[ \phi_{\text{est}, \text{class 1}} = \frac{1}{4} \arg \sum_{j=1}^{4} x_j \]

- Performance of the estimators can be further improved by adding an MLE stage:

\[ \phi_{\text{MLE}} = \tan \left( \frac{\text{imag}(z)}{\text{real}(z)} \right) \]

with \( z = \frac{1}{4} \arg \sum_{j=1}^{4} x_j \cdot y_j \)

- The constellation transformations are applied after frequency offset compensation between the LO and transmitter laser and after an initial phase noise correction using a coarse estimate (achieved using the Viterbi&Viterbi algorithm based on QPSK partitioning).

- From 64-QAM to 16-QAM:

\[ Y = Y_r - \text{sgn}(Y_r - 2\cdot\text{sgn}(Y_r)) + j(Y_i - \text{sgn}(Y_i - 2\cdot\text{sgn}(Y_i))) + \]

\[ + Y_r, - \text{sgn}(Y_r - 2\cdot\text{sgn}(Y_r)) + j(Y_i - \text{sgn}(Y_i - 6\cdot\text{sgn}(Y_i))) + \]

\[ + Y_r, - \text{sgn}(Y_r - 6\cdot\text{sgn}(Y_r)) + j(Y_i - \text{sgn}(Y_i - 6\cdot\text{sgn}(Y_i))) + \]

\[ + Y_r, - \text{sgn}(Y_r - 6\cdot\text{sgn}(Y_r)) + j(Y_i - \text{sgn}(Y_i - 2\cdot\text{sgn}(Y_i))) \]

- From 16-QAM to QPSK:

\[ Y = Y_r - \text{sgn}(Y_r - 2\cdot\text{sgn}(Y_r)) + \]

\[ + j(Y_i - \text{sgn}(Y_i - 2\cdot\text{sgn}(Y_i))) \]

Conclusion: A novel low complexity algorithm for carrier phase estimation of 64-QAM has been presented and its performance analyzed through numerical simulations. A linewidth times symbol duration product (\Delta \nu \cdot T_s) equal to 4.5 \times 10^{-5} is tolerated for 1-dB penalty at BER equal to 10^{-2}. Assuming the industry-standard symbol rate of 32 Gbaud, this means that a total combined linewidth of over 1.3 MHz could be tolerated, making it possible to operate optical 64-QAM systems with current commercial tunable lasers.

This work was supported by CISCO Systems within a SRA contract.