Polarization coupled carrier phase estimation for coherent polarization multiplexed QPSK with OOK-neighbours

Citation for published version (APA):
Piyawanno, K., Kuschnerov, M., Hauske, F. N., Al Fiad, M. S. A. S., Spinnler, B., Napoli, A., Waardt, de, H., & Lankl, B. (2009). Polarization coupled carrier phase estimation for coherent polarization multiplexed QPSK with OOK-neighbours. In *Proceedings of the 2009 Optical Fiber Communication Conference / National Fiber Optic Engineers Conference (OFC 2009 / NFOEC 2009) 24 - 26 March 2009, San Diego, California* (pp. OMT6-1/3). Institute of Electrical and Electronics Engineers.

Document status and date:
Published: 01/01/2009

Document Version:
Publisher’s PDF, also known as Version of Record (includes final page, issue and volume numbers)

Please check the document version of this publication:

• A submitted manuscript is the version of the article upon submission and before peer-review. There can be important differences between the submitted version and the official published version of record. People interested in the research are advised to contact the author for the final version of the publication, or visit the DOI to the publisher's website.
• The final author version and the galley proof are versions of the publication after peer review.
• The final published version features the final layout of the paper including the volume, issue and page numbers.

Link to publication

General rights
Copyright and moral rights for the publications made accessible in the public portal are retained by the authors and/or other copyright owners and it is a condition of accessing publications that users recognise and abide by the legal requirements associated with these rights.

- Users may download and print one copy of any publication from the public portal for the purpose of private study or research.
- You may not further distribute the material or use it for any profit-making activity or commercial gain
- You may freely distribute the URL identifying the publication in the public portal.

If the publication is distributed under the terms of Article 25fa of the Dutch Copyright Act, indicated by the “Taverne” license above, please follow below link for the End User Agreement:

www.tue.nl/taverne

Take down policy
If you believe that this document breaches copyright please contact us at:

openaccess@tue.nl

providing details and we will investigate your claim.

Download date: 16. Nov. 2023

Polarization Coupled Carrier Phase Estimation for Coherent Polarization Multiplexed QPSK with OOK-neighbours

K. Piyawanno[1]**, M. Kuschnerov**[1]**, F.N. Hauske**[1]**, M.S. Alfiad**[2]**,**
B. Spinnler[3]**, A. Napoli**[3]**, H. de Waardt**[2] **and B. Lankl**[1]
[1]*Federal Armed Forces University Munich, Institute for Communications Engineering,*
D-85577 Neubiberg, Germany, e-mail: kittipong.piyawanno@unibw.de
[2]*COBRA institute, Eindhoven University of Technology, The Netherlands*
[3]*Nokia Siemens Networks GmbH Co. KG, Hofmannstr. 51, D-81379, Munich, Germany*

Abstract: We propose a novel algorithm for carrier phase estimation with differential demodulation, phase coupling between both polarizations and non-redundant error correction. The algorithm is demonstrated on measured 111Gb/s polarization-multiplexed QPSK with 10x10.7Gb/s OOK neighbours.

OCIS codes: (060.4510) Optical communications; (060.1660) Coherent communication

1. Introduction

Due to the growth of the bandwidth requirements, existing 10.7Gb/s on-off keying (OOK) wavelength-division multiplexing (WDM) optical transmission systems will be partially upgraded to a 111Gb/s line rate in the near future [1]. With the increased receiver sensitivity and the feasibility for linear equalisation, coherent polarization-multiplexed quadrature phase shift keying (CP-QPSK) attracts a lot of attention for the gradual replacement of existing direct detection systems. In particular, the non-linearity induced cross-phase modulation (XPM) is one of the main impairments, which becomes the limiting effect on the transmission distance and performance in multi-rate WDM systems [2, 3]. The phase variation caused by non-linearity can be suppressed by a carrier phase recovery. Hence, the carrier phase recovery becomes a major problem for those XPM limited WDM systems.

Recently two novel algorithms for digital carrier phase recovery with significant performance improvements have been proposed. The joint-polarization carrier phase estimation (JPC) [4] applies Viterbi-Viterbi feed forward carrier phase estimation (VV) [5] in each polarization and mutually cross-couples phase information between both polarizations to enhance the feedback adjusting phase corrections. An alternative approach has been introduced in [6], where the correlation of both polarizations is employed in a similar principle as in JPC. However, the algorithm requires a precise parameter adjustment and involves a relatively high implementation complexity. In this work, we present the polarization coupled carrier phase estimation (PCC) for WDM CP-QPSK systems. The algorithm employs polarization coupled information from the JPC structure in combination with differential decoding and non-redundant error correction. This combines the positive properties of JPC to mitigate XPM induced phase shifts, differential decoding to mitigate cycle slips and NEC to compensate for the performance loss due to differential decoding. Furthermore, the complexity is strongly decreased compared to the algorithm described in [6]. The performance is evaluated based on measured 111Gb/s CP-QPSK with 10x10.7Gb/s OOK neighbours.

2. Algorithm Principle

At the receiver, coherent demodulation transfers the electrical field from the optical into the electrical domain, where linear channel impairments like chromatic dispersion and polarisation mode dispersion can be equalised with a linear FIR filter. After equalisation, the remaining phase variation caused by the frequency offset of the free running local oscillator (LO), including deviations caused by the laser line width, and the XPM phase noise can be reduced by frequency offset compensation and carrier phase estimation. Since the signal in the x- and y-polarization is mixed down by the same LO, the phase variation caused by the frequency offset and laser line width is identical in the x- and y-polarization. As shown in [4] and [7], the XPM phase noise is correlated in the x- and y-polarization. Thus, phase coupling between both polarizations can improve the performance of the carrier phase estimation [4, 6].

The JPC algorithm is the first carrier phase estimation, which employs the correlation between polarizations. The block diagram of JPC is show in Fig. 1. After phase recovery by the VV algorithm, the phase variation in the x- and y-polarisation is coupled and weighted by a factor X_x and X_y, with $0 \leq X_x = X_y \leq 1$.

The proposed PCC algorithm combines combines JPC with differential decoding, which avoids cycle-slips at the cost of error propagation. This error propagation can be compensated by NEC [9], which provides error detection and correction. Additionally, a block with differential digital demodulation (DDD) provides necessary information

978-1-55752-865-0/09/$25.00 ©2009 IEEE

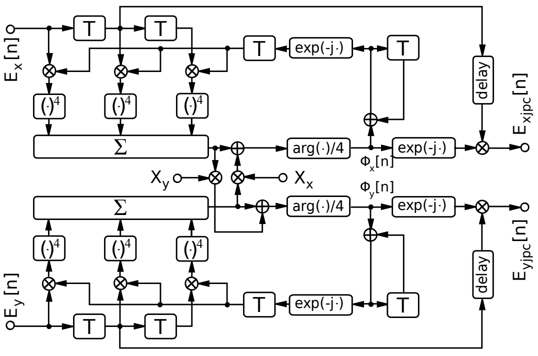

Fig. 1. Block diagram of JPC algorithm

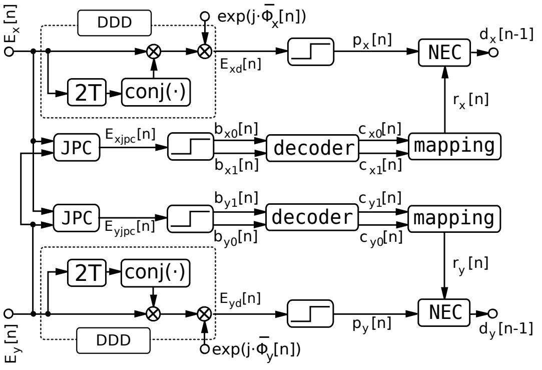

Fig. 2. Block diagram of PCC algorithm

for NEC. According to Fig. 2, the complex valued signal for both polarizations $E_x[n]$ and $E_y[n]$ is fed into the carrier recovery block after equalisation. In the x-polarization, the complex signal $E_{xjpc}[n]$ from JPC is mapped to bit sequences $b_{x0}[n]$ and $b_{x1}[n]$, which are differentially decoded to bit sequences $c_{x0}[n]$ and $c_{x1}[n]$. Then, $c_{x0}[n]$ and $c_{x1}[n]$ are mapped to $r_x[n]$ to provide information symbols for NEC. The parity symbols $p_x[n]$ for NEC can be retrieved using DDD, a phase rotation with the constant phase $\bar{\Phi}_x$ and a mapping pattern as described in [6]. The same applies for the y-polarization vice versa.

3. Experimental Setup

The measured data from a loop experiment as described in [3] is analysed to evaluate the performance of the algorithm. The 111Gb/s CP-QPSK signal with 10x10.7Gb/s OOK neighbours was transmitted over 760km and 1140km SSMF on a dispersion managed link as shown in Fig.3. The signal spacing between the central channel and the nearest OOK neighbours is set to 50GHz, 100GHz and 200GHz. Neighbour channels are placed 50GHz away from each other for all experiments. At the receiver the signal is fed into the 90°-optical hybrid and mixed down by a free running LO. The signal blocks of $2 \cdot 10^7$ samples (2 samples/bit) are saved by a digital storage oscilloscope. The offline signal post processing is applied on a PC to evaluate the algorithm performance as shown in Fig. 4.

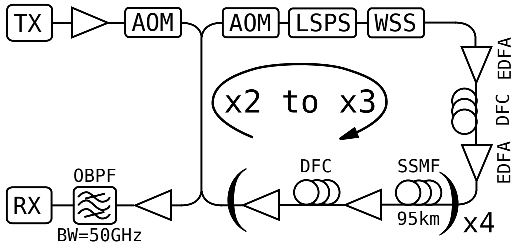

Fig. 3. Loop experiment setup

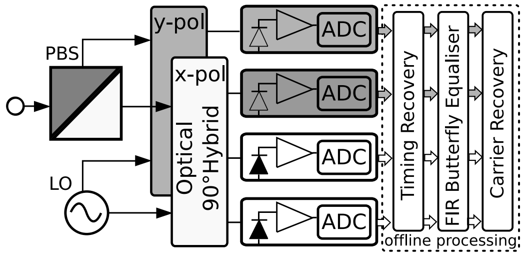

Fig. 4. Receiver setup with post-processing

4. Algorithm Performance

For each measurement point, the BER is calculated over 5 sets of the measured data to enhance the statistical reliability. The channel spacing is adjusted to 50GHz between all channels. The factors X_x and X_y depends on the channel parameters, which is slowly time-varying. Hence, we initially optimised $X_x = X_y = 0.6$ for all evaluations.

Fig. 5 and 6 show the BER performance vs. launch power of PCC in comparison with VV and differential decoding with NEC. It can be seen, that the BER performance is best around the launch power of -3 and -2dBm, decreasing towards lower and higher powers. This represents a trade-off between the OSNR value and the non-linearity. The PCC algorithm outperforms the conventional VV algorithm for all measurement points. The performance improvements depend on the launch power and the transmission distance. Due to the ASE-noise by the lower launch powers, the PCC algorithm considerably improves the performance both at transmission distances of 760km and 1140km. Since the XPM phase variation is accumulated with transmission distance, the performance improvements of PCC at 1140km are clearly decreased in comparison to 760km due to non-linearities.

The optimisation of N can minimize the BER of PCC and VV [2, 8]. With the ASE-noise impairment, the correlation length of the phase variation is large. Therefore, the BER of PCC and VV with $N = 5$ for lower launch powers is better than $N = 2$. The correlation length of the phase variation is decreased with the increasing non-linearity caused for higher launch powers. In this case, $N = 2$ is the optimal estimation block length, where the performance of VV

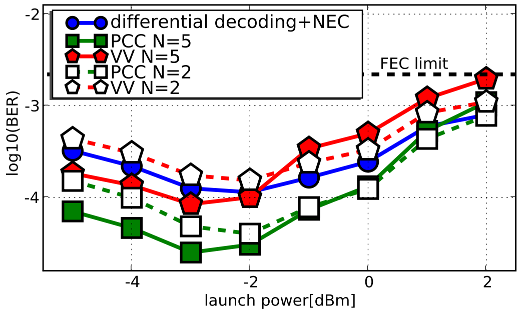

Fig. 5. BER vs. launch power over 760km

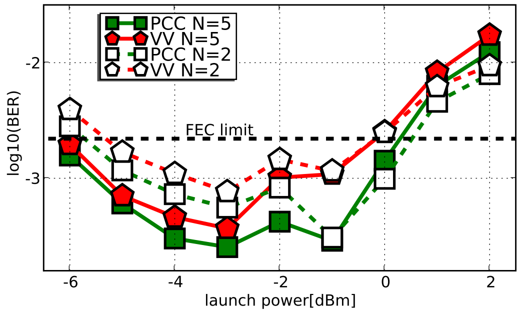

Fig. 6. BER vs. launch power over 1140km

algorithm is related to differential decoding [2]. Hence, the advantage of the NEC can be confirmed by the comparison of differential decoding with NEC to the VV with $N = 2$. It should be noted, that the BER of the PCC with $N = 2$ is similar to $N = 5$ by higher launch powers. The reason for that is the coupling with the differential decoded signal from the DDD. Fig. 7 shows the performance of the proposed algorithm for various averaging block lengths N, where the best performance is reached for $N = 5$.

The performance of coherent receivers and of PCC are limited by non-linearities, which can be mitigated by changing the signal spacing between the central channel and the nearest OOK neighbours. In our experiments, we configured this to 50GHz, 100GHz and 200GHz. Fig. 8 depicts, that the non-linearity impairments induced XPM can be reduced with the expanded channel spacing.

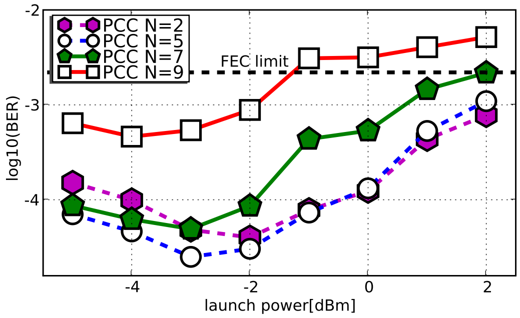

Fig. 7. BER vs. launch power over 760km for different N

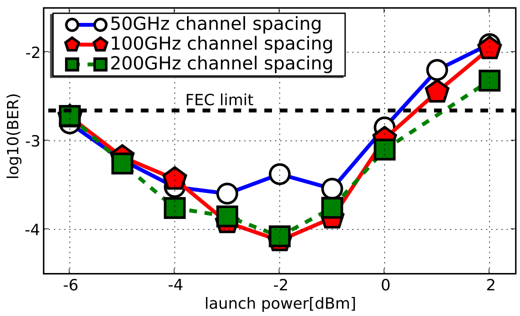

Fig. 8. BER vs. launch power with different channel spacing

5. Conclusions

We have proposed the PCC carrier phase estimation algorithm for coherent receivers of CP-QPSK in a XPM limited multi-rate WDM transmission system. The algorithm outperforms the conventional Viterbi-Viterbi feed forward carrier phase estimation with slightly increased implementation complexity. The algorithm performance is analysed for measurements of 111Gb/s CP-QPSK with 10x10.7Gb/s OOK neighbours.

References

[1] T.J. Xia et al., "Multi-Rate (111-Gb/s, 2x43-Gb/s, and 8x10.7-Gb/s) Transmission at 50-GHz Channel Spacing over 1040-km Field-Deployed Fiber", ECOC 2008 Th.2.E.2
[2] D. van den Borne et al., "Carrier phase estimation for coherent equalisation of 43-Gb/s POLMUX-NRZ-DQPSK transmission with 10.7-Gb/s NRZ neighbours", ECOC 2007 We7.2.3
[3] M.S. Alfiad et al., "111-Gb/s POLMUX-RZ-DQPSK Transmission over 1140 km of SSMF with 10.7-Gb/s NRZ-OOK Neighbours", ECOC 2008 Mo.4.E.2
[4] M. Kuschnerov et al., "Joint-Polarization Carrier Phase Estimation for XPM-Limited Coherent Polarization-Multiplexed QPSK transmission with OOK-neighbors", ECOC 2008 Mo.4.D.2
[5] A.J. Viterbi et al., "Nonlinear Estimation of PSK-Modulated Carrier Phase with Application to Burst Digital T ransmission", Trans Inf. Th., Vol. IT-29, N0. 4, July 1983, pp.543
[6] K. Piyawanno et al., "Correlation Based Carrier Phase Estimation for WDM DP-QPSK Transmission", accepted PTL 2008
[7] G. P. Agrawal, *Nonlinear Fiber Optics*, (Academic, 2001), Chap. 6.2
[8] K. Kikuchi, "Phase-Diversity Homodyne Detection of Multilevel Optical Modulation With Digital Carrier Phase Estimation", IEEE Journal of Selected Topics in Quantum Electronics, vol. 12, no. 4, pp. 563-570, Jul./Aug. 2006
[9] H. C. Schroeder and J.R. Sheehan, "Nonredundant error detection and correction system", U.S. Patent 3 529 290, Sep.15, 1970