Dispersion Compensation of DQPSK Signal Using Multi-Chip Joint Maximum-Likelihood Sequence Estimation

Jian Zhao*, Lian-Kuan Chen
Department of Information Engineering, Chinese University of Hong Kong, Shatin, N.T., Hong Kong
Phone: +(852) 26098479, Fax: +(852) 26035032, Email: jian.zhao@tyndall.ie
(*now with Tyndall National Institute, University College Cork, Cork, Ireland)

Abstract
Multi-chip joint maximum likelihood sequence estimation (MLSE) is proposed and shown to outperform joint MLSE, achieving 330km optically-uncompensated 10GS/s DQPSK signal transmission and less than 3dB OSNR penalty for 100ps DGD.

Introduction
Recently, the advance of high-speed microelectronics, such as 30GSamples/s analogue-to-digital converter, has enabled the application of electronic dispersion compensation (EDC) in optical communication systems at 10Gbit/s. Four-state maximum likelihood sequence estimation (MLSE) for on-off keying (OOK) format has been commercially available and can achieve optically-uncompensated 10Gbit/s OOK signal transmission up to 250km [1]. Such distance was further extended by 50% by using full optical-field MLSE [2]. On the other hand, differential quaternary phase shift keying (DQPSK) has attracted much attention for high-speed optical transmission due to its higher spectral efficiency and better tolerance to chromatic dispersion (CD) and polarization mode dispersion (PMD) [3]. Joint MLSE was proposed to enhance the transmission reach of the DQPSK signal [4]. This technique exploits the samples of the in-phase and quadrature tributaries simultaneously, and exhibits better compensation performance than conventional MLSE.

In this paper, we will propose a multi-chip joint MLSE for CD and PMD compensation in DQPSK format. This method exploits the phase difference between not only the adjacent symbols but also the symbols with one symbol slot apart for data sequence estimation. We will show that multi-chip joint MLSE significantly outperforms joint MLSE in CD and PMD compensation for the DQPSK signal while maintaining the same electronic computation complexity.

Simulation setup
Fig. 1 shows the simulation setup. Continuous wave light with 5MHz laser line width was modulated by a 10GS/s DQPSK data train. The DQPSK data train consisted of two 2^{11}-1 pseudo-random binary sequences (PRBS) repeated nine times (18,423 bits) for in-phase and quadrature tributaries. Delays were applied to the tributaries so that their bit sequences were uncorrelated. The electrical '1' bits were raised-cosine shaped with a roll-off coefficient of 0.4 and 40 samples per bit.

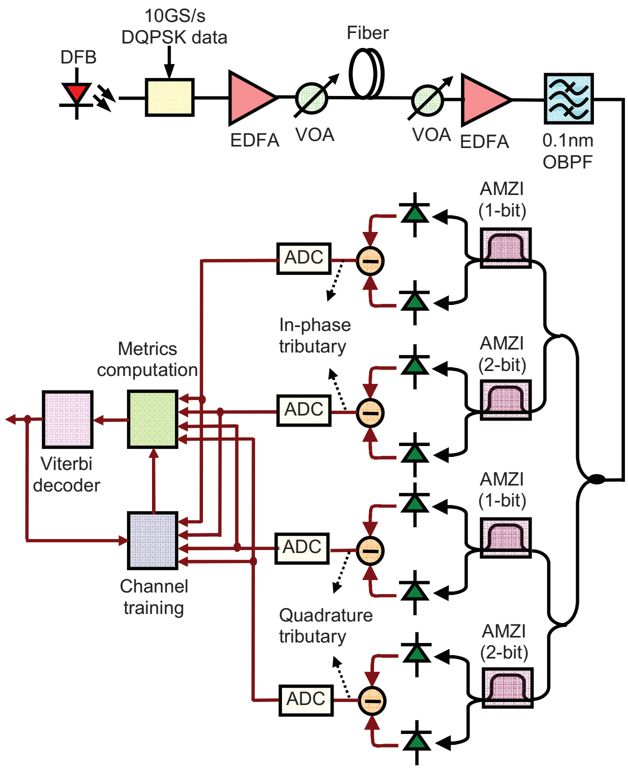

Fig. 1. Simulation setup

The signal was launched into the transmission link of single-mode fiber (SMF) with 0dBm. The SMF was assumed to have CD of 16ps/km/nm and a loss of 0.2dB/km. The signal power was split equally between the fast and slow orthogonal polarization modes to simulate the worst PMD case.

The noise of the optical preamplifier was modelled as additive white Gaussian noise with equal noise spectral power density for each polarization. The launch power into the preamplifier was adjusted to control the OSNR. The amplified signal was filtered by a 0.1nm Gaussian-shaped optical bandpass filter (OBPF). The in-phase and quadrature tributaries of the DQPSK signal were demodulated by using asymmetric Mach-Zehnder interferometers (AMZIs) with $\pi/4$ and $-\pi/4$ phase shift. For multi-chip detection, two AMZIs with one- and two-bit delay were employed to exploit the phase difference between both the adjacent optical symbols and the

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symbols with one symbol slot apart. The demodulated signals were detected by balanced detectors with -3dBm received optical power. The responsivity and equivalent thermal noise spectral power density of the detectors were 0.6A/W and $100\text{pA/Hz}^{1/2}$ respectively. After optical-to-electrical conversion, the signals were electrically amplified, filtered by 7GHz 4^{th}-order Bessel electrical filters (EFs), sampled at two samples per bit, and analogue-to-digital converted with 5-bit resolution. Multi-chip joint MLSE estimates the DQPSK data based on the metric $PM(k)$:

$$PM(k) = PM(k-1) - \sum_{i=1}^{2}\sum_{t_j}\log(p(I_{r,i}(t_j)\,|\,b_{k-m},...,b_k)) - \sum_{i=1}^{2}\sum_{t_j}\log(p(I_{q,i}(t_j)\,|\,b_{k-m},...,b_k)) \quad (1)$$

where t_j is the sampling phase with $j=k$ or $k+1/2$. b_k and $p(I_{r,i}(t_j)\,|\,b_{k-m},\ldots,b_k)$ are the k^{th} DQPSK logical data and the probability of the sampled values of $I_{r,i}(t)$ at time t_j given the logical data $b_{k-m},\ldots,b_k$, respectively. $I_{r,i}(t)$ ($I_{q,i}(t)$) is the demodulated in-phase (quadrature) signal using *i*-bit delay AMZI. *m* is the memory length and is assumed to be 2. The initial metrics were obtained using histogram method. The complexity of Viterbit decoding for multi-chip joint MLSE is the same as that of joint MLSE despite doubled lookup table size.

The simulation was iterated 10 times with different random number seeds to give a total of 184,320 simulated symbols. The performance was evaluated in terms of the required OSNR to achieve a BER of 5×10^{-4} by direct error counting.

Results and discussions

Fig. 2 shows the required OSNR (dB) versus CD using conventional hard decision (circles), joint MLSE (triangles), and multi-chip joint MLSE (squares). From the figure, it is shown that joint MLSE, by exploiting the correlation information between the two tributaries of the DQPSK signal, effectively improves the CD tolerance. At 15dB OSNR, joint MLSE extends the transmission reach of the DQPSK signal from 80km to 250km. Multi-chip joint MLSE further improves the performance, with around 2dB back-to-back sensitivity improvement and optically-uncompensated transmission distance of 330km at 15dB OSNR. This represents more than 30% CD tolerance improvement compared to that using conventional joint MLSE. We attribute this benefit to more exploited signal information of multi-chip joint MLSE using both one- and two-bit delay AMZIs.

The capability of multi-chip joint MLSE to outperform conventional joint MLSE is further verified in first-order PMD compensation. Fig. 3 shows the required OSNR versus DGD using hard decision (circles), joint MLSE (triangles), and multi-chip joint MLSE (squares). From the figure, it is shown that joint MLSE limits the OSNR penalty less than 4dB for DGD up to 100ps, at which point hard-decision fails to detect the signal. Multi-chip joint MLSE performs better than joint MLSE, exhibiting 2dB back-to-back sensitivity improvement and only 2.8dB ONSR penalty for 100-ps DGD.

Conclusions

We have proposed a multi-chip joint MLSE for CD and PMD compensation in DQPSK modulation format. The proposed scheme significantly outperforms conventional joint MLSE while maintaining the same electronic computation complexity. We show that multi-chip joint MLSE can achieve 330km optically-uncompensated transmission distance at 15dB OSNR, representing 30% increased CD tolerance than joint MLSE, and exhibits 2dB back-to-back sensitivity improvement and less than 3dB OSNR penalty for 100ps DGD in a 10Gsym/s DQPSK system. This project is supported by HKSAR RGC grant (CUHK4110/07)

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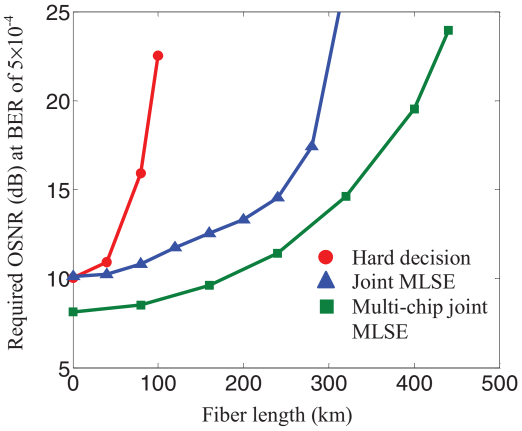

Fig. 2. Required OSNR versus fiber length using different detection methods.

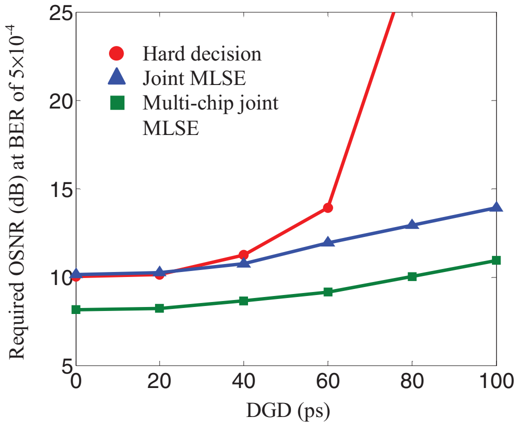

Fig. 3. Required OSNR versus first-order PMD using different detection methods.