Dispersion Compensation Using Decision-Feedback MLSE for Spectrally-Efficient Optical Transmission

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Abstract *We propose a novel decision-feedback maximum likelihood sequence estimation, and numerically demonstrate its use in 10GS/s 8-ASK-DQPSK (8-ASK-QPSK) systems to significantly improve the dispersion tolerance, without increasing the computation complexity exponentially with the format-level number.*

Introduction

The advance of high-speed microelectronics, such as 30GSamples/s analogue-to-digital converter (ADC), has enabled the application of electronic dispersion compensation (EDC) in optical communications at 10GS/s. On-off keyed (OOK) direct-detection based maximum likelihood sequence estimation (MLSE) is commercially available[1]. Full-field MLSE with 50% performance improvement with the same electronic computation complexity has been proposed[2]. However, when extending the concept of MLSE to multi-level formats, the complexity scales exponentially with format level number. For example, joint MLSE was used for differential quaternary phase shift keying (DQPSK) signal[3]. This technique exhibits significant performance improvement but at the expense of increased complexity from 2^{m+1} to 2^{2m+2} compared to conventional MLSE, where *m* is the memory length. This increased complexity severely hinders the practicality of scaling of joint MLSE for formats with more level number.

In this paper, we propose a novel decision-feedback MLSE and numerically demonstrate its use for great performance improvement in a 10GS/s 8-ASK-DQPSK (8-ASK-QPSK) system. The method is used in a system with asymmetric impairment tolerance for different tributaries. By independently decoding the tributaries with greater impairment tolerance to crosstalk from other tributaries and feeding the decoded information for equalization of the remaining tributaries, EDC for a complicated system without exponentially increased complexity can be achieved.

Principle and simulation model

Fig. 1 shows the simulation model. Continuous wave light was phase modulated by a 10GS/s DQPSK (QPSK) data train, followed by a Mach-Zehnder intensity modulator driven by 10Gbit/s OOK data with temporally aligned eye crossings. The distributed feedback (DFB) laser has 5-MHz and 200-kHz linewidth for direct and coherent detection respectively. The DQPSK (QPSK) and ASK data trains were uncorrelated 2^{11}-1 pseudo-random binary sequences repeated nine times (18,423 bits). The electrical '1' bits were raised-cosine shaped with a roll-off coefficient of 0.4 and were simulated with 40 samples per bit. The extinction ratio (ER) of the signal was controlled by adjusting the bias and the amplitude of the electrical data. The modulated signal was launched into single-mode fiber with CD of 16ps/km/nm at 0dBm.

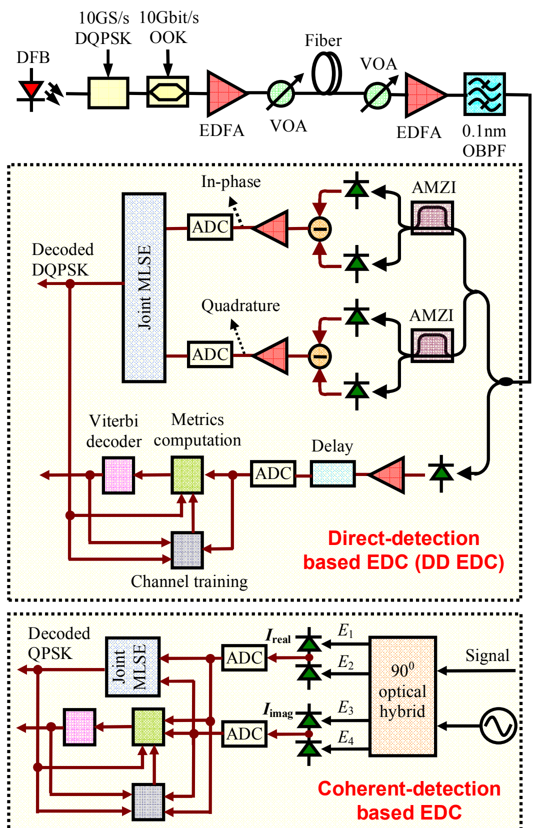

Fig.1. Simulation model

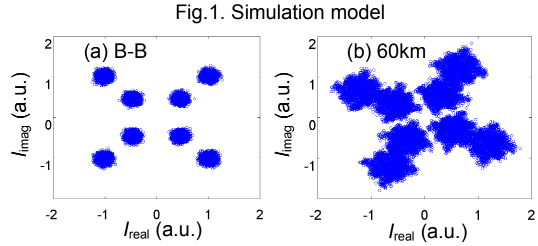

Fig. 2. Constellation of 8-ASK-QPSK signal at 6.84dB ER

The amplified spontaneous emission (ASE) noise, modelled as additive white Gaussian noise with random polarization, was loaded at the receiver. The

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pre-amplified signal was filtered by a 0.1nm Gaussian-shaped optical bandpass filter (OBPF) and detected using either direct or coherent detection. The received optical power was -3dBm, and thermal noise spectral power densities of the direct and balanced detectors were $18pA/Hz^{1/2}$ and $100pA/Hz^{1/2}$ respectively. The power of local oscillator was 10dBm. After photo detection, the signals were amplified with 7GHz cut-off frequency, sampled at two samples per bit. The ADCs had 6-bit resolution.

Fig. 2 depicts that at 60km and 20dB OSNR, the QPSK data can be correctly identified whereas the ASK tributary is severely distorted due to intersymbol interference (ISI). Here, ISI comes from not only its own tributary but also the QPSK tributaries. Consequently, the knowledge of data information of other tributaries is beneficial for CD compensation of the targeted tributary. The proposed EDC uses a joint MLSE for DQPSK (QPSK) data decoding and feeds the decoded information to decision feedback MLSE for CD compensation of the ASK tributary. Such structure, compared to joint processing of all tributaries, reduces the complexity from 2^{3m+3} to $2^{2m+2}+2^{m+1}$ (reduction by a factor of 8 for *m*=2).

The simulation was iterated 10 times with different random number seeds to give a total of 184,230 simulated bits. The performance was evaluated in terms of the required optical-signal-to-noise ratio (OSNR) to achieve a bit error rate (BER) of 5×10^{-4}.

Results and discussions

Fig. 3 shows performance variation of the ASK and DQPSK tributaries as a function of the signal ER. *m* was 2 for both DD and coherent EDC. It is clearly seen that the optimum ER depends on the detection method and fibre length, with optimum value of 6.8dB for hard decision. This value is reduced to 5.3dB for DD EDC at 100km. A lower ER ensures improved performance of the DQPSK tributary by reducing the crosstalk from the ASK tributary, and the crosstalk from the DQPSK tributary to the ASK tributary is compensated by the decision-feedback MLSE. Fig. 4 verifies that by using the proposed EDC, approximately three and seven times CD tolerance improvements are exhibited at 18dB OSNR for DD (triangles) and coherent-detection (circles) EDC respectively. A higher ER of 6.84dB using coherent-detection EDC (pluses), compared to 5.3dB ER, degrades the transmission performance of the QPSK tributary, which in turn limits the performance of the ASK tributary by error feedback. We also find that the ADC resolution is crucial for the 8-ASK-QPSK format and 6-bit ADC is required to limit the quantization penalty less than 1dB, as shown in Fig. 5.

Conclusions

We have proposed a novel decision-feedback MLSE and demonstrated its use at 4 states for effective CD compensation in 10GS/s 8-ASK-DQPSK (8-ASK-QPSK) systems. This method exploits asymmetric CD tolerances for the ASK and DQPSK (QPSK) tributaries, controlled by tuning of the signal ER. The proposed technique enables EDC of a multi-level format without exponentially increased computation complexity with respect to the format level number. Whilst the investigation was based on 8-ASK-DQPSK format, the technique can also be used in other systems, e.g. 16-ASK-DQPSK format or a 50GHz spaced hybrid DWDM system with interleaved 10Gbit/s OOK and 40Gbit/s DQPSK channels. This work was supported by HKSAR RGC 4110/07 and Science Foundation Ireland 06/IN/I969.

References

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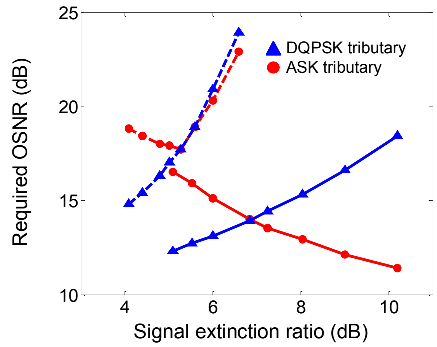

Fig. 3. Required OSNR versus ER for 8-ASK-DQPSK signal using hard decision at back-to-back (solid), and using DD EDC at 100km (dashed).

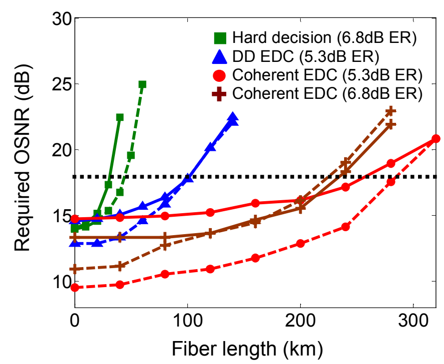

Fig. 4. Required OSNR versus fiber length for the ASK (solid) and DQPSK (or QPSK) (dashed) tributaries.

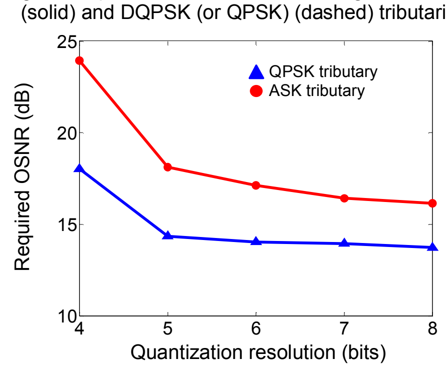

Fig. 5. Required OSNR versus quantization resolution for coherent detection based EDC at 5.3dB ER and 240km

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