Viterbi Equalizer for Chromatic Dispersion and PMD Mitigation in DPSK and DQPSK Systems at 10 Gb/s

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Abstract *We study the Viterbi equalizers for chromatic dispersion and PMD mitigation in 10 Gb/s NRZ-DPSK and NRZ-DQPSK systems. Monte Carlo simulations are used to assess the performance of the Viterbi equalizers.*

Introduction

In high bit rate fiber optical systems operating at 10 Gb/s or beyond, chromatic dispersion (CD) and polarization mode dispersion (PMD) in the fiber can become troublesome [1]. In recent years, more interest has been brought to electronic equalization for the mitigation of optical impairments, because electronic signal processing techniques offer great potential in reducing the cost. Analog equalizers have been investigated by both simulations and integrated chip realizations [2]. Digital equalizers for the mitigation of CD and PMD based on maximum likelihood sequence estimation (MLSE) for on-off keying (OOK) systems have been simulated and the results indicate good performance [3]. In [4], MLSE was applied in simulation to improve the CD tolerance for data with differential phase modulation formats (DPSK and DQPSK). In [5], the performance of feed-forward equalizers (FFEs) and decision-feedback equalizers (DFEs) was studied in compensating chromatic dispersion and the 1st order PMD in optically amplified nonreturn-to-zero (NRZ) OOK and NRZ-DPSK systems at 10 Gb/s. In this paper, we report on Monte Carlo simulations for CD and PMD mitigation in NRZ-DPSK and NRZ-DQPSK optical transmission systems at 10 Gb/s using Viterbi equalizers.

Equalization techniques

The Viterbi algorithm [6] as a realization of MLSE is commonly used to decode convolutional codes. The signal distortion within an optical channel can be treated as a kind of coding of the signal, which is very similar to convolutional codes. Thus, using an estimation of the channel model by the Viterbi equalizer, the true transmitted bit stream can be recovered. In a simple receiver, the decision on each bit is immediate. In a MLSE, the decision is performed by searching through a whole sequence of bits and selecting the “most likely” sequence, which means that the probability of all bit combinations for the whole sequence is considered and the combination with the highest probability is assumed as the transmitted bit combination [3]. This paper will focus on how to apply Viterbi equalizers to DPSK and DQPSK systems.

Fig. 1 shows the receiver structure for DPSK data. In DPSK receiver with a Viterbi equalizer, the distorted optical DPSK signal and amplified spontaneous emission (ASE) noise pass through an interferometer, a pair of balanced photodiodes (PD) followed by an electrical low pass filter (LPF), electrical sampler and A/D converters (ADC). Then a Viterbi equalizer is used to decode the data.

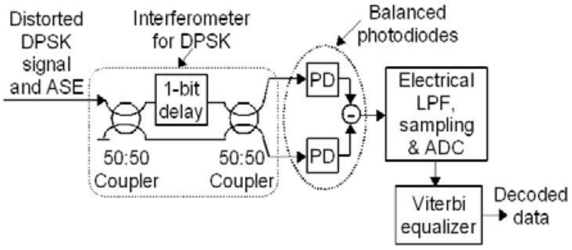

Fig. 1 Viterbi receiver structure for NRZ-DPSK data

Fig. 2 shows the Viterbi receiver structure for DQPSK signals. The DQPSK data has two independent channels (channel I and channel Q), therefore the receiver consists two interferometers and two pairs of balanced photodiodes. To the output of each balanced photodiodes, we apply a separate Viterbi equalizer, which process the I data and Q data separately.

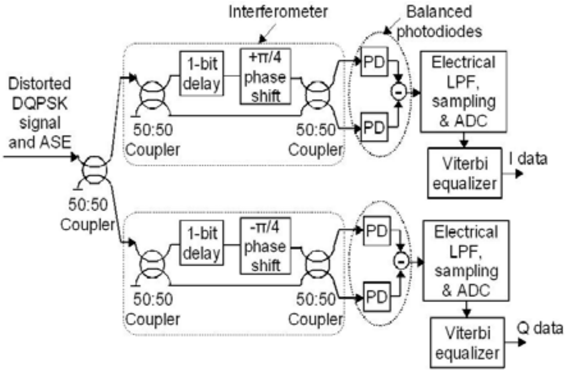

Fig. 2 Viterbi receiver structure for NRZ-DQPSK data

Simulation results

We have carried out Monte Carlo simulations to assess the performance of the Viterbi equalizer in DPSK and DQPSK systems. Fig. 3 shows the optical transmission system for the simulations. The transmitter generates 10 Gb/s NRZ DPSK signal or 5

GBaud DQPSK signal. A CD/PMD simulator generates variable chromatic dispersions and the 1st order PMD. Then the Gaussian noise is added to simulate the ASE noise. After optical band pass filtering (BPF), the Viterbi receiver structures in Fig. 1 and Fig. 2 are applied to equalize the DPSK and DQPSK signals. A DPSK or DQPSK receiver performs opto-electronic conversion. Then electrical 5th order Bessel low pass filters (LPF) are applied with a 3 dB bandwidth of about 5 GHz for DPSK and 2.5 GHz for DQPSK, which are the optimum electrical bandwidths we find through optimizing the receivers. The data signal is sampled at the center of eye with 1 sample/bit. In order to determine the ultimate performance of Viterbi equalizer, we calculated with infinite ADC resolution and it has been shown that for the case of NRZ signal the application of 3 or 4 bit analog to digital conversion will lead to a low additional penalty of 0.2 dB [3]. The data signal is fed into the Viterbi equalizer and the 1st 20480 bits are used to calculate the probability density functions of each symbol.

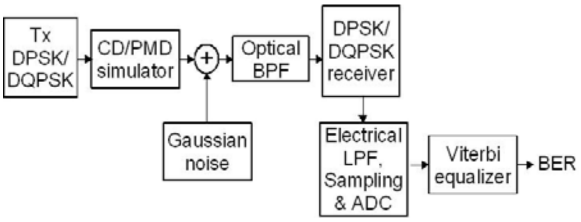

Fig. 3 Optical transmission system for the simulations

Fig. 4 presents the OSNR penalty for a BER of 10-3 vs. chromatic dispersion in NRZ-OOK, NRZ-DPSK and NRZ-DQPSK systems at a bit rate of 10 Gb/s. The OSNR penalty is defined as the OSNR increment that gives the same BER in relation to the back-to-back condition [7]. Fig. 5 shows the OSNR penalty for a BER of 10-3 vs. the 1st order PMD in NRZ-OOK, NRZ-DPSK and NRZ-DQPSK systems at a bit rate of 10 Gb/s. Table 1 exhibits CD and PMD tolerance at 3 dB OSNR penalty for NRZ-OOK, NRZ-DPSK and NRZ-DQPSK systems without VE and with VE. The tolerance numbers are obtained from Fig. 4 and Fig. 5.

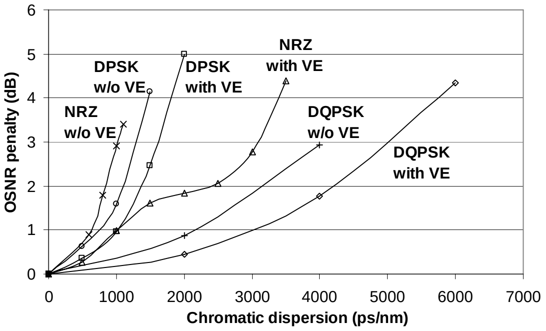

Fig. 4 OSNR penalty for a BER of 10^{-3} vs. chromatic dispersion in 10 Gb/s NRZ-OOK, NRZ-DPSK, and NRZ-DQPSK systems

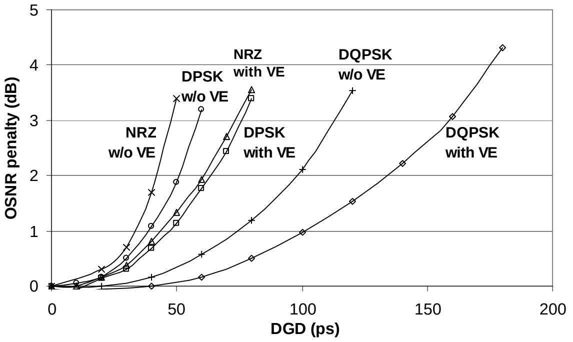

Fig. 5 OSNR penalty for a BER of 10^{-3} vs. the 1st order PMD in 10 Gb/s NRZ-OOK, NRZ-DPSK, and NRZ-DQPSK systems

Table 1: *CD & PMD tolerance at 3 dB OSNR penalty*

	NRZ-OOK		NRZ-DPSK		NRZ-DQPSK	
	w/o VE	with VE	w/o VE	with VE	w/o VE	with VE
CD tolerance (ps/nm)	1000	3111	1318	1635	4063	5048
PMD tolerance (ps)	48	74	59	77	112	160

From table 1, we can see that without a VE, NRZ-DPSK receiver has more CD tolerance than NRZ-OOK receiver. NRZ-DPSK receiver with a VE has less CD tolerance than NRZ-OOK receiver with a VE. For NRZ-DQPSK receiver with a VE, the CD tolerance increases. In terms of the first order PMD tolerance, NRZ-DPSK receiver without a VE has more PMD tolerance than NRZ-OOK receiver without a VE. NRZ-DPSK receiver with a VE has the similar PMD tolerance as NRZ-OOK receiver with a VE. For NRZ-DQPSK receiver with a VE, the PMD tolerance is doubled. Additionally, we showed that the electrical bandwidth typical for 2.5 Gb/s systems may be sufficient for 5 GBaud DQPSK systems.

Conclusions

We show through simulations at 10 Gb/s that using Viterbi equalizers improves the performance of NRZ-OOK, NRZ-DPSK and NRZ-DQPSK receivers. For NRZ-DQPSK receiver with a Viterbi equalizer, the chromatic dispersion tolerance is about 5048 ps/nm and the PMD tolerance is about 160 ps at 3 dB OSNR penalty.

References

1 F. Buchali et al, JLT, 22 (2004), pp. 1116-1126.
2 H. Bülow et al, Elect. Lett., 36 (2000), pp. 163-164.
3 F. Buchali et al, Proc. OFC 2004, paper MF85.
4 M. Cavallari et al, Proc. OFC 2004, paper TuG2.
5 J. WANG et al, PTL, 16 (2004), pp.1397-1399.
6 G. D. Forney, Proc. IEEE, 61 (1973), pp. 268-278.
7 M. Secondini et al, JLT, 21 (2003), pp. 2322-2331.