8.4 dB Net Coding Gain Achieved with a Serially Concatenated Coding Scheme for Differential Quadrature Phase Shift Keyed Optical Systems

Patrick Faraj, Stefan Schöllmann, Jochen Leibrich, and Werner Rosenkranz
pf@tf.uni-kiel.de University of Kiel, Chair for Communications, Kaiserstr. 2, 24143 Kiel, Germany.

Abstract We improve the system performance using Differential Quadrature Phase Shift Keying modulation format combined with a 100% overhead Convolutional Code concatenated with the standard Reed-Solomon code RS(255,239).

Introduction

Differential Quadrature Phase Shift Keying (DQPSK) is of increasing interest for optical communication systems mainly due to its ability to increase the capacity of optical links while preserving a high spectral efficiency, and a high tolerance towards fibre non-linear effects [1]. In addition to advanced modulation formats, Forward Error Correction (FEC) techniques are widely considered as a promising way to improve the performance of existing optical systems.

DQPSK's main characteristic is doubling the information rate (using 4 symbols in the complex plane) while retaining the same bandwidth of a conventional On/Off keying modulation format. Benefiting from this important property, we allocated the parity bits generated by the convolutional encoder to the increase of the modulation levels (two to four), and thus, we used the same bandwidth to transmit both information and parity bits.

Combining convolutional encoding with RZ-DQPSK modulation was previously proposed by [2] and [3]. Moreover, code concatenation has been widely used in wireless communications as well as recently in optical communications to improve the error correction capability in comparison to single schemes at a cost of slightly increasing the overhead.

The idea in this paper is to further enhance the coding performance by using an improved coding scheme. Therefore, we included a concatenated scheme (Convolutional code + Reed-Solomon block code) to improve the performance of DQPSK by increasing the Net Coding Gain (NCG) of the system.

System Setup and Codes in Use

To determine the Bit Error Ratio (BER) performance, we performed several Monte-Carlo simulations. The investigated system consisted of a back-to-back single channel transmission which corresponds to an optically preamplified system with dominating ASE noise. The modulation format was fixed to DQPSK, while the FEC encoding schemes were varied and compared. The Reed-Solomon code RS(255,239) was chosen as the first standard for submarine optical systems due to its low overhead (OH) of 6.67%, and its simple encoding and decoding implementation. Therefore, it was used here to be investigated as an FEC code for DQPSK. Moreover, a simple non-recursive R=1/2, convolutional code with two delay elements as described in [2], with an OH of 100% was also combined with DQPSK. In general, concatenated codes involve two different error-correcting codes, an inner code and an outer code that could constitute of different coding schemes, giving the ability of correcting different types of errors [4]. Therefore, we finally investigated the serial concatenation of the previous two types of FEC codes.

Interleaving and deinterleaving were omitted since burst errors are not present in our back-to-back ASE noise limited system [5]. The transmission setup for this serially concatenated scheme is shown below in fig. 1.

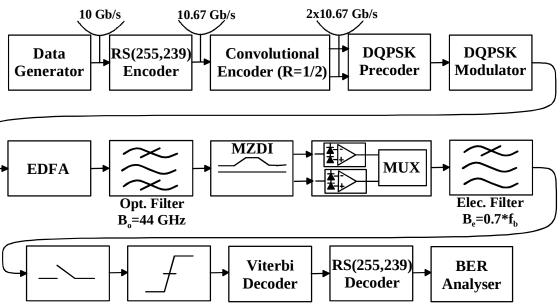

Figure1: Transmission Setup

At the transmitter, the 10 Gb/s data sequence is encoded into a 10.67 Gb/s sequence using an outer Reed-Solomon block code RS(255,239) with 6.7% OH. The output sequence is then encoded with an inner convolutional code which has 100% OH, to generate two parallel data streams of 10.67 Gb/s each. In this case, doubling the data rate as previously described in DQPSK does not correspond to doubling the information rate, because of the additional encoding overhead transmitted on one of the two in-phase and quadrature arms of the DQPSK transmission system.

The generated parallel sequences are fed to a differential precoder implemented according to [6], modulated according to an RZ-DQPSK serial modulator setup [1], and then transmitted through the channel. At the receiver end, after optical filtering (Gaussian, 44 GHz), a Mach-Zehnder Delay

Interferometer (MZDI) was used as a differential receiver to detect the real and imaginary parts of the DQPSK signal, whereas two balanced detectors were used to demodulate both parts. After combining the parallel sequences using a multiplexer (MUX), the electrical signal is also filtered prior to data recovery through the sampler and the slicer. Hard-decision error correction is performed using an inner hard-input hard-output Viterbi decoder and an outer Reed-Solomon decoder.

The received 10 Gb/s decoded sequence is finally fed to a BER tester. The launched optical power at the input of the EDFA is varied for each simulation and the corresponding BER is depicted. The coding gain is defined as the decrease in the optical power required to maintain the same BER as that achieved without coding.

Results and Discussions

The Bit error ratio (BER) curves of the different formats investigated in this paper are plotted in fig. 2. BER curves of (i) the uncoded DQPSK, (ii) RS(255,239)-encoded DQPSK, (iii) DQPSK encoded with a convolutional code, and (iv) the proposed concatenation with DQPSK are displayed, as well as the respective Net Coding Gains (NCG) achieved at a BER of 10^{-13}.

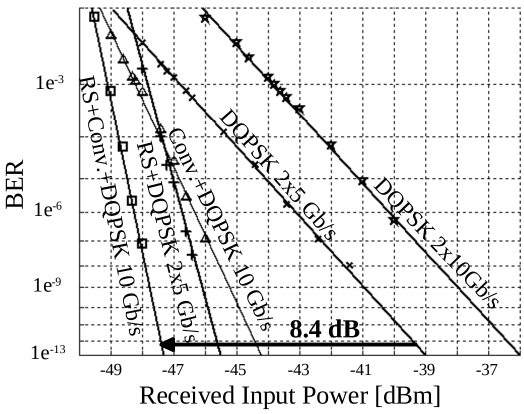

Figure 2: Coded DQPSK schemes (information rates shown) compared to the 10 Gb/s uncoded DQPSK system.

In the case where the schemes involved convolutional encoding, the information rate is reduced by half compared to the uncoded 20 Gb/s (2 x 10 Gb/s). Therefore, it was reasonable to compare the coded schemes to a DQPSK system with the same information rate of 10 Gb/s (2 x 5 Gb/s). This DQPSK system achieved a 3 dB gain over the 20 Gb/s system which was attributed to the reduction of the bandwidth by a factor of 2. Table 1 compares the NCG of all the simulated schemes based on the information bit rate, the symbol rate, and the receiver gain. Additionally, the 10 Gb/s DQPSK system was set as a reference (0dB) and the NCG of other schemes were evaluated.

Table 1

Modulation and Coding Scheme	Information Bit Rate (Gb/s)	Symbol Rate (Gbaud/s)	Receiver NCG @ 10^{-13} (dB)
DQPSK	20	10	- 3
DQPSK	10	5	0 (ref.)
DQPSK+RS	10	5.34	6.5
DQPSK+Conv	10	10	5.2
DQPSK+RS+Conv	10	10.67	8.4

The standard RS(255,239) was used to encode the 10 Gb/s DQPSK. At the cost of increasing the data rate by 6.7%, we achieved a NCG of 6.5 dB at a BER of 10^{-13}. This coding gain is in agreement with what is expected theoretically from a RS(255,239) and with what was specified in the related standard. Using convolutional encoding in conjunction with DQPSK required a 100% increase in the data rate. Compared to the same information rate DQPSK, we obtained a NCG of about 5.2 dB. In the proposed concatenated scheme, the information rate was fixed at 10 Gb/s. The 100 % OH due to convolutional encoding was allocated to the higher modulation level in DQPSK, and the 6.7 % from the standard RS-code slightly increased the bandwidth requirements. Compared to the 20 Gb/s DQPSK system, the proposed scheme has an improvement of 11.4 dB in the receiver sensitivity, but has half of the information rate. In comparison with the 10 Gb/s DQPSK, which has the same information rate, the concatenated scheme improves the sensitivity by about 8.4 dB. Applying soft-decision decoding for our scheme through the modification of the Viterbi decoder is expected to improve the overall performance by up to 2 dB depending on the chosen level of quantization [7], but this would increase the complexity of the decoding system.

Conclusions

We presented in this paper a serial concatenation of a convolutional code with the standard Reed-Solomon RS(255,239) block code for a DQPSK optical system. Using only a hard-decision decoding system, and using a relatively small total OH (6.7%), the concatenated scheme achieved a NCG of 8.4 dB over a DQPSK system with the same information rate.

References

[1] Wree, C. et al., ECOC 2002, paper 9.6.6.
[2] Bülow H. et al., OFC 2004, paper WM5.
[3] Wuth T. et al., OFC 2005, paper OThW4.
[4] Martin Bossert, Wiley, Chichester 1998.
[5] Mello D. et al., OFC 2003, paper ThN3.
[6] Serbay M. et al., IEEE, Electronics Letters, 30 September 2004, Vol 40, No 20.
[7] J. Li, Proc. of IEEE Military Communications Conference (MILCOM), Boston, MA, October 2003.