Adaptive LDPC-Coded Polarization Multiplexed Coherent Optical OFDM in Optically-Routed Networks

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Abstract: We present a power-variable rate-adaptive LDPC-coded polarization multiplexed coherent OFDM scheme, suitable for use in optically-routed networks in which different lightwave paths experience different penalties due to deployment of ROADMs and WXCs. We demonstrate that channel capacity can be closely approached with proposed scheme.

OCIS codes: (060.0060) Fiber optics and optical communications; (060.1660) Coherent communications; (060.4080) Modulation; (060.4230) Multiplexing; (999.9999) Coding

1. Introduction

Current limitations of photonics-enabled networks result from the heterogeneity of the infrastructure and consequential bottlenecks at different boundaries and interfaces [1,2]. In optically-routed networks, neighboring WDM channels can have random traffic patterns, in which different lightwave paths experience different penalties due to deployment of reconfigurable optical add-drop multiplexers (ROADMs) and wavelength cross-connects (WXCs).

In order to have seamless integrated transport platforms, which can support heterogeneous networking, in this paper, we propose the use of power-variable rate-adaptive low-density parity-check (LDPC)-coded polarization multiplexed OFDM. We describe the optimum power loading algorithm suitable to deal with bandwidth reduction due to concatenation of ROADMs and WXCs, propose the rate adaptation scheme, determine the channel capacity and show that the proposed scheme can closely approach the channel capacity.

2. Power-Variable Rate-Adaptive LDPC-Coded Polarization-Multiplexed Coherent OFDM

In an optically-routed network, different signal transmission paths have different number of optical amplifiers, WXCs, and ROADMs. Different wavelength channels carrying the traffic to different destinations can have quite different signal-to-noise ratios (SNRs) and signal is differently impacted by various channel impairments including PMD, chromatic dispersion, fiber nonlinearities, and filtering effects due to concatenation of optical filters/ROADMs/WXCs. The optical networks should provide a target bit-error ratio (BER) performance regardless of the data destination. To address all these issues, we propose the use of power-variable rate-adaptive LDPC-coded polarization-multiplexed optical OFDM system with coherent detection, which is shown in Fig. 1. To deal with concatenated ROADMs/WXCs and bandwidth limitation problems, and imperfections of various devices, we employ the adaptive water-filling algorithm to determine the optimum power to be allocated to ith subcarrier P_i as follows

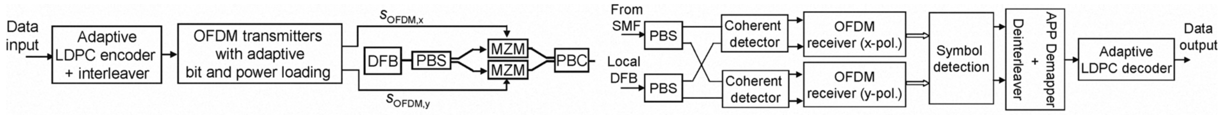
$$P_i/P=\begin{cases}1/\gamma_{\mathrm{tsh}}-1/\gamma_i, \gamma_i\geq\gamma_{\mathrm{tsh}}\\ 0,\ \text{otherwise}\end{cases} \tag{1}$$

where P is the total available power, γ_i is the SNR in ith subcarrier, and the optimum threshold SNR is determined from condition that total power in all subcarriers cannot be larger than available power, $\sum_i P_i \leq P$. The variable-rate adaptation is achieved by choosing the maximum product $m_i R_i \leq C_i$, where m_i is the number of bits per ith subcarrier, R_i is the code rate and C_i is the channel capacity of the ith subcarrier. The signal constellation size $M_i=2^{m_i}$ per ith subcarrier and the corresponding code rate R_i of component LDPC code are chosen in accordance with the channel conditions. When the channel conditions are favorable (large SNR) the larger constellation sizes and higher code rate LDPC codes are employed. Among several candidate LDPC codes we employ one (based on subcarrier γ_i) which provides the largest product $m_i R_i$ closest to the subcarrier channel capacity (but lower than C_i). The use of different channel codes for different destinations would be costly to implement due to increased hardware complexity, unless a unified encoding and decoding architectures can be used for all destinations. The structured quasi-cyclic (QC) LDPC codes [2], provide us with this unique feature.

The channel capacity of polarization-multiplexed optical coherent OFDM scheme (derived based on theory due to Bölcskei *et al.*[3], with N subcarriers can be evaluated as follows

$$C=\mathrm{E}_H\left\{\frac{1}{N}\max_{\mathrm{Tr}(\boldsymbol{\Sigma})\leq P}B_N\log_2\left[\det\left(\boldsymbol{I}_{2N}+\frac{1}{\sigma_n^2}\boldsymbol{H\Sigma H}^\dagger\right)\right]\right\},\ \boldsymbol{\Sigma}=\mathrm{diag}\{\boldsymbol{\Sigma}_i\}_{i=0}^{N-1},\ \boldsymbol{\Sigma}_i=\frac{P}{2N}I_2;\ \boldsymbol{H}=\mathrm{diag}\{\boldsymbol{H}(i)\}_{i=0}^{N-1},\ \boldsymbol{H}(i)=\begin{bmatrix}H_{xx}(i) & H_{xy}(i)\\ H_{yx}(i) & H_{yy}(i)\end{bmatrix}, \tag{2}$$

with P being the maximum overall transmit power, and σ_n being the standard deviation of ASE noise process, and B_N being the bandwidth of subcarrier channel. $\mathrm{Tr}(\boldsymbol{\Sigma})$ denotes the trace of matrix $\boldsymbol{\Sigma}$, $E_{\boldsymbol{H}}$ denotes the expectation operator with respect to channel matrix $\boldsymbol{H}$, and $\boldsymbol{I}_{2\mathrm{N}}$ is $2N$x$2N$ identity matrix. The channel matrix in (2) is a block diagonal matrix with ith block diagonal element corresponding to the 2x2 Jones matrix $\boldsymbol{H}(i)$ of ith subcarrier. The chromatic dispersion effect and reduced bandwidth effect due to concatenation of ROADMs, as well as different linear channel imperfections, are all incorporated in $\boldsymbol{H}(i)$.

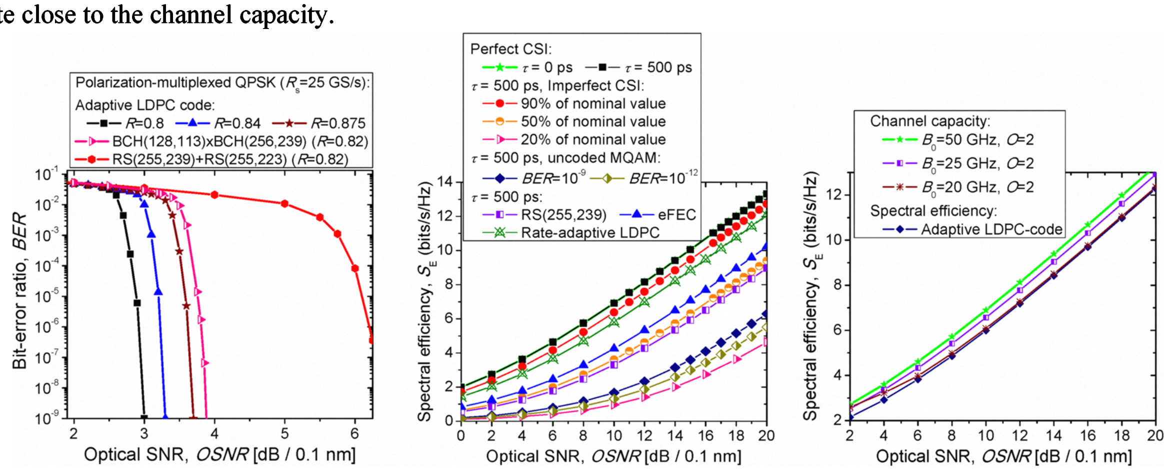


(a) (b)

Fig. 1 Block diagram of proposed adaptive LDPC-coded OFDM scheme: (a) transmitter, and (b) receiver configurations. DFB: distributed feedback laser, PBS/C: polarization-beam splitter/combiner, MZM: dual-drive Mach-Zehnder modulator, APP: *a posteriori* probability.

3. Evaluation of Proposed Scheme and Conclusions

We designed rate-adaptive QC LDPC code of codeword length 28800 (that is shorter than turbo-product code proposed by Mizuochi *et al.* [5]), with possible rates {0.875, 0.84, and 0.8}, whose BER performance is shown in Fig. 2(a). Even highest rate code (0.875) outperforms the turbo-product code of rate 0.82, and significantly outperforms the concatenated RS code. In Figs. 2(b,c) we show the channel capacity calculated based on (2) for polarization-multiplexed OFDM system when all order PMD with average DGD τ of 500 ps is observed, for 2000 km of SMF, 128 subcarriers, and OFDM signal bandwidth BW of 25 GHz. We see that when channel matrix (the channel state information, CSI) is perfectly known we can completely compensate for different linear channel impairments, which was expected because the Jones matrix is unitary. However, when the CSI is not ideal (the channel estimation is not perfect) we can have significant channel capacity degradation (see Fig. 2(b)). We see when channel coefficients are estimated to be 90% of nominal values we have small performance degradation. However, when the channel estimates are 50% of nominal value we have found significant channel capacity degradation. We also have found that for target BERs below 10^{-9} M-ary QAM (MQAM) is far away from the channel capacity. However, with adaptive LDPC coding we can closely approach the channel capacity. To reach the channel capacity we have to invent better modulation formats and use them in combination with adaptive LDPC coding. In Fig. 2(c) we study the efficiency of the optimum power-adaptation (1) in dealing with concatenation filtering problem (that is modeled as super-Gaussian filter of order O=2 and bandwidth B_0=20, 25, and 50 GHz). We see that channel capacity is getting worse as the bandwidth of optical filter is getting smaller than OFDM signal bandwidth, but we are still quite close to the channel capacity.



(a) (b) (c)

Fig. 2 BER and spectral efficiency performances of proposed scheme: (a) BERs for polarization-multiplexed QPSK for aggregate rate of 100 Gb/s, (b) spectral efficiencies of polarization multiplexed OFDM (BW=25 GHz), and (c) effect of concatenation filtering problem.

In conclusion, we present a power-variable rate-adaptive LDPC-coded polarization-multiplexed coherent OFDM scheme, which is suitable for use in optically-routed networks. We determine the channel capacity and demonstrate that it can be closely approached with proposed scheme.

References

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