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Next Generation FEC for High-Capacity Communication in Optical Transport Networks

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***Abstract*—Codes on graphs of interest for next generation forward error correction (FEC) in high-speed optical networks, namely turbo codes and low-density parity-check (LDPC) codes, are described in this invited paper. We describe both binary and nonbinary LDPC codes, their design, and decoding. We also discuss an FPGA implementation of decoders for binary LDPC codes. We then explain how to combine multilevel modulation and channel coding optimally by using coded modulation. Also, we describe an LDPC-coded turbo-equalizer as a candidate for dealing simultaneously with fiber nonlinearities, PMD, and residual chromatic dispersion.**

***Index Terms*—Coded modulation, codes on graphs, fiber-optics communications, low-density parity-check (LDPC) codes, turbo equalization.**

I. Introduction

THE transport capabilities of fiber-optic communication systems have increased tremendously in the past two decades, primarily due to advances in optical devices and technologies, and have enabled the Internet as we know it today with all its impacts on the modern society. In particular, dense wavelength division multiplexing (DWDM) became a viable, flexible, and cost-effective transport technology. Net- work operators already consider 100 Gb/s per DWDM channel transmission, yet the performance of fiber-optic communication systems operating at those data rates is degraded significantly due to several transmission impairments including intra- and interchannel nonlinearities, the nonlinear phase noise, and polarization-mode dispersion (PMD) [1], [2]. These effects constitute the current limiting factors in efforts to accommodate demands for higher capacities/speeds, longer link lengths, and more flexible wavelength switching and routing capabilities in optical networks. To deal with those channel impairments, novel advanced techniques in modulation and detection, coding and signal processing

Codes on graphs [3], such as turbo codes [4]–[9] and low-den- sity parity-check (LDPC) codes [10]–[15] have revolutionized communications, and are becoming standard in many applica- tions. LDPC codes, invented by Gallager [10] in 1960s, are linear block codes for which the parity check matrix has low density of ones. LDPC codes have generated great interests in the coding community recently, and this has resulted in a great deal of understanding of the different aspects of LDPC codes and their decoding process. An iterative LDPC decoder based on the *sum-product algorithm* (SPA) has been shown to achieve a performance as close as 0.0045 dB to the Shannon limit [13]. The inherent low-complexity [10]–[15] of this decoder opens up avenues for its use in different high-speed applications, in- cluding optical communications.

column weight, respectively, and where d stands for the min- imum distance of the code], it follows that large girth leads to an exponential increase in the minimum distance, provided that the column weight is at least 3. ($\lfloor\rfloor$ denotes the largest integer less than or equal to the enclosed quantity.) For example, the min- imum distance of girth-10 codes with column weight is at least 10. The parity-check matrix of regular QC LDPC codes [14], [16] can be represented by