Short-length Probabilistic Shaping: Improved Methods and Mitigation of Fiber Nonlinearities

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Abstract—Advanced amplitude shapers that improve upon the conventional constant-composition distribution matching in terms of rate loss and computational complexity are reviewed. In a comprehensive comparison, we focus on energy considerations, rate loss, and decoding performance. We further study the mitigating effects of short-length probabilistic shaping on the Kerr nonlinearities occurring during optical fiber transmission and discuss the impact of interleavers on this effect.

In this invited contribution, we discuss probabilistic shaping (PS) in the short-length regime where the block sizes are at most a few hundred symbols. Focusing on probabilistic amplitude shaping (PAS) as underlying coded modulation framework to realize PS [1], we study in detail the amplitude shaping block that maps a block of uniformly distributed data bits into a shaped amplitude sequence. The first amplitude shaper proposed for PAS is constant-composition distribution matching (CCDM) [2], which, as its name suggests, outputs sequences with identical compositions, i.e., they are permutations of each other. While asymptotically lossless, CCDM has suboptimal finite-length performance. Furthermore, the conventional arithmetic coding method used for implementing CCDM is inherently sequential, which introduces latency and limits high-throughput application [3]. It is mainly this combination of requiring long blocks and having a sequential implementation that lead to a great deal of investigation into advanced amplitude shapers. In this contribution, we review such advanced shapers and present a comprehensive comparison. The investigated schemes include multiset-partition distribution matching [4], enumerative sphere shaping [5], [6], and Huffman coded sphere shaping [7]. A numerical analysis of rate loss and performance after forward error correction (FEC) decoding is supported by a study of the signal space occupied by the respective amplitude shaping schemes and the corresponding energy considerations.

In the second part of this contribution, we study the impact that probabilistically shaped signaling has on the Kerr nonlinearities which are present in the optical fiber channel. It has been shown theoretically and demonstrated in simulations that for asymptotically long CCDM block lengths, the effective signal-to-noise ratio (SNR) after fiber transmission and digital signal processing is smaller for shaped signaling than for uniform distributions, which is due to fiber nonlinearities being exacerbated by PS [8]. Surprisingly, the inverse behavior is observed for short CCDM sequences where fiber nonlinearities are mitigated by shaping [9]. This inverse proportionality of SNR with block length can for CCDM be attributed to the fact that certain overall transmit sequences, such as those with long runs of identical amplitudes, cannot occur when several short CCDM blocks are concatenated and combined into a FEC codeword [10]. For long CCDM sequences, on the other hand, this restriction does not apply, and an SNR penalty due to the fiber nonlinearities is observed. We investigate this behavior numerically and show how the utilization of interleavers affects the capability of mitigating fiber nonlinearities by PS.

REFERENCES