On the Difficulty of Bit–Interleaved Coded Modulation for Differentially Encoded Transmission over Fading Channels

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Abstract — The application of bit–interleaved coded modulation (BICM) in combination with differential encoding and non-coherent reception over flat fading channels is assessed. Since the labeling plays a central role for BICM we propose a suitable definition of Gray labeling for differentially encoded transmission. We show that for multiple symbol detection such a Gray labeling does not exist. Finally, we illustrate the consequences on the capacity by comparing BICM and an optimum coded modulation scheme.

I. INTRODUCTION

We consider the application of the simple but suboptimum bit–interleaved coded modulation (BICM) [1] to transmission over slowly time-varying, frequency non-selective Rician fading channels, where neither channel state information is available nor reliable coherent reception is possible. Channel state and carrier phase offset are expected to be constant over a block of N consecutive symbols. In these situations, differential decoding of N − 1 dimensional vector symbols a at the transmitter and multiple symbol detection of the last N received channel symbols at the receiver are convenient. We employ signal constellations for mixed amplitude/phase modulation, consisting of α · β points arranged in α concentric rings with radii ri, i = 0, . . . , α − 1, and β uniformly spaced phases (αβPSK) for both the differential symbols and the transmit symbols.

We propose a suitable definition of Gray labeling and we study its implementation. As a measure of performance the capacity achievable by the BICM transmission scheme is compared to the capacity of an optimal coded modulation scheme.

II. GRAY LABELING

Generally, a mapping of binary address vectors to symbols in the signal space is Gray labeled, if the most likely error event results in the wrong decision of a single binary digit. A suitable criterion is the pairwise error probability PEP(a → ²a). The (differential) signal point ²a will be called a nearest neighbor of a if PEP(a → ²a) is maximum.

For the AWGN and Rayleigh fading channels the results of [2] indicate that the PEP is maximum when ²d(a, a) := Nβ² − [r0, ²a] [r0, a]² is minimum. Using ²d(a, a) as an approximated noncoherent distance for Rician fading channels in general, we can prove the following

Theorem: A DPSK constellation can be Gray labeled iff N = 2. The maximum number of pairs of nearest neighbors is Gray labeled when the usual Gray labeling, based on the Euclidean distance of the signal point pair a, ²a is employed.

For DAPSK, since the subset of nearest neighbors corresponding only to phase transitions coincides with the set of nearest neighbors of a DPSK constellation, we conclude that no Gray labeling is possible when N > 2.

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III. NUMERICAL RESULTS AND DISCUSSION

Numerical results for the capacity over the average signal-to-noise ratio $\bar{E}_s/N_0$ ($\bar{E}_s$: average energy per symbol, $N_0$: one-sided noise power spectral density) and the case of Rayleigh fading are presented. For BICM, N = 2, we employ a perfect Gray labeling; for N > 2 we resort to usual Gray labeling based on Euclidean distance of differential vectors a.

In Figure 1 the capacity achievable by BICM and the capacity achievable by an optimal coded modulation (CM) scheme are compared for D2A8PSK with ring ratio r1/r0 = 2.0. Optimal CM is obtained via multilevel coding and multistage decoding [3] (details are given in [4]). When N = 2 the capacity loss due to the use of BICM instead of optimal CM is negligible. But, whereas enlarging the block size N increases the capacity of the optimal CM scheme, the capacity of BICM and N = 4 is almost the same as for N = 2. Additionally, as upper bound, the capacity $C_{CSI}$ for coherent reception and channel state information is shown. The CM capacity converges (rather slowly) to $C_{CSI}$ as N goes to infinity.

Fig. 1: Capacity for D2A8PSK over Rayleigh fading channel. Solid lines: CM capacity, N = 2, 3, 4. Dashed-dotted lines: BICM capacity, N = 2, 4. Dashed Line: Capacity $C_{CSI}$.

REFERENCES