Random-Coding-Exponent-Based Design of Coded Modulation for Multiple-Symbol Differential Detection

Lutz H.-J. Lampe, Robert F.H. Fischer

Lehrstuhl für Nachrichtentechnik II, Universität Erlangen-Nürnberg, Cauerstr. 7/NT, D–91058 Erlangen, Germany
Email: {LLampe,fischer}@LNT.de WWW: http://www.LNT.de/LNT2/

I. Introduction and Coded Modulation

Coded modulation (CM) matched to M-ary differential phase-shift keying (MDPSK) modulation over Rayleigh block fading channels [1] with multiple-symbol differential detection (MSDD) [2] is discussed. Different coding techniques are assessed by evaluating the associated random coding exponent (RCE), i.e., taking decoding delay into account.

Let the channel coherence time be N samples. At the transmitter, $N-1$ uniform i.i.d. (differential) PSK data symbols (phase increments, i.e., prior to differential encoding) are combined into a vector $\boldsymbol{a}$. At the receiver, a vector $\boldsymbol{y}$ comprises the N corresponding received signal samples. Between $\boldsymbol{a}$ and $\boldsymbol{y}$ a *vector channel* is established, which is assumed to be memoryless, even when imposing delay constraints. Channel coding and decoding is done with respect to vectors $\boldsymbol{a}$ and $\boldsymbol{y}$, respectively, containing $\ell = (N-1)\log_2(M)$ coded binary digits.

A. Multilevel coding (MLC)/multistage decoding (MSD) [3]: The ℓ binary digits b^i, $i=0,\dots,\ell-1$, which result from independent encoding (rates R^i, total rate $R=\sum_{i=0}^{\ell-1} R^i$) of the data symbols, are mapped to vector symbols $\boldsymbol{a}$. Using MSD, the word error rate (WER) of level i is bounded by

$$p_w^i \le 2^{n\cdot E_r^i(R^i,N)}\,, \qquad (1)$$

where $E_r^i(R^i,N)$ is the RCE [4]

$$E_r^i(R^i,N) = \max_{0\le\rho\le1}\{E_0^i(\rho,N)-\rho R^i\} \qquad (2)$$

and $E_0^i(\rho,N)$ is Gallager's function (for details see [5]) of the *equivalent* binary channel i [3, 6]. Noteworthy, for usually desired (low) error rates and well-designed MLC, the effect of error propagation over levels can be neglected, and WER's of levels are almost equal.

B. Bit-interleaved coded modulation (BICM) [7]: Only one binary code is applied and ℓ encoded bits are grouped to select the vector $\boldsymbol{a}$. The coding exponent of BICM reads

$$E_{r,\mathrm{BICM}}(R,N) = \max_{0\le\rho\le1}\{E_{0,\mathrm{BICM}}(\rho,N)/\ell-\rho R/\ell\}\,, \qquad (3)$$

where $E_{0,\mathrm{BICM}}(\rho,N)$ is Gallager's function of BICM over block fading, i.e., the effect of non-ideally bit-interleaving is taken into account.

C. Hybrid coded modulation (HCM) [5]: MLC and BICM are the two extreme cases with respect to encoding. An obvious modification is to combine levels in the MLC approach and to perform BICM within these "hyper levels". Strategies for merging of levels can be found in [5]. Again, for calculation of RCE the effect of non-ideally bit-interleaving is considered.

If, for a fair comparison, the code length of the binary (component) codes are chosen such that the over-all delay is fixed, BICM uses codes with ℓ times the length of the component codes in MLC. HCM allows a trade-off between optimality of MLC/MSD and increased code length of BICM, and is able to combine the specific advantages of both MLC and BICM.

II. Results and Discussion

The proposed CM schemes are assessed regarding the minimum required $\bar{E}_b/N_0$ ($\bar{E}_b$: average received energy per information bit, N_0: one-sided noise power spectral density) resulting a RCE, which leads to WER p_w lower than a given threshold. 8DPSK with target rate of 2 bit/(ch. use) is considered. For MLC/BICM, separate Ungerboeck/Gray labeling (UL/GL) of the constituent PSK constellation is advantageous (cf. [5]). Based on GL, for HCM all levels, which correspond to a single PSK symbol of $\boldsymbol{a}$, are merged. Hence, instead of $\ell=(N-1)\cdot\log_2(M)$ (MLC), now, $\ell=N-1$ levels remain.

In Fig. 1 the curves for the required $\bar{E}_b/N_0$ over decoding delay for p_w=10^{-3} and MSDD with N=2, 3, 4 are depicted. As performance limit, the curves for overall maximum-likelihood decoding (MLD) are also plotted. Although the performance of noncoherent transmission is expected to improve with N, for short delay curves for different N intersect. This is due to reduced fading diversity (MLD, BICM) and code length (MLC), respectively, for fixed delay and increased N. For delay ≤ 400 symbols, BICM and $N=2$ performs best. For increasing delay MLC/MSD becomes superior to BICM. In contrast to BICM, noncoherent MLC/MSD benefits from an extended observation interval N. Remarkably, in a wide range of medium decoding delay, the proposed HCM offers improvements. The advantages of both MLC and BICM are combined.

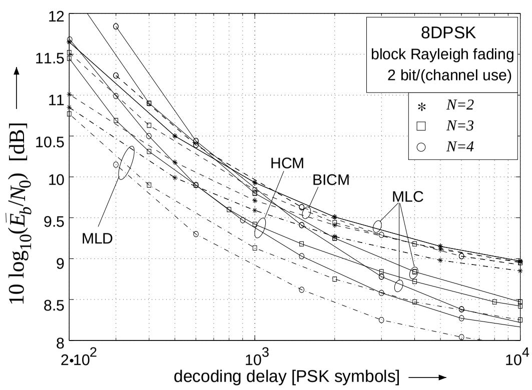

Figure 1: Required $\bar{E}_b/N_0$ over decoding delay for $p_w=10^{-3}$.

References

[1] T. Ericson. A Gaussian Channel with Slow Fading. *IEEE Tr-IT*, 353–355, May 1970.

[2] S.G. Wilson, J. Freebersyser, and C. Marshall. Multi-Symbol Detection of M-DPSK. *Proc. GLOBECOM*, Dallas, Nov. 1989.

[3] H. Imai and S. Hirakawa. A New Multilevel Coding Method Using Error Correcting Codes. *IEEE Tr-IT*, 371–377, 1977.

[4] R.G. Gallager. *Information Theory and Reliable Communication.* John Wiley & Sons, Inc., New York, 1968.

[5] L. Lampe and R. Fischer. Noncoherent Coded Modulation for Fading Channels. *AEÜ(Int.J.Electr.)*, 399–411, Dec. 2000.

[6] U. Wachsmann et al. Multilevel Codes: Theoretical Concepts and Practical Design Rules. *IEEE Tr-IT*, 1361–1391, July 1999.

[7] E. Zehavi. 8-PSK Trellis Codes for a Rayleigh Channel. *IEEE Tr-COM*, 873–884, May 1992.