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Efficient splitting of multidimensional alphabets for modulation codes

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Summary—We propose a new combined coded modulation construction which gives a reduced decoding complexity. It is a generalization of the constructions of Ginzburg [1] and Ungerboeck [2] and is based on splitting a multidimensional alphabet with $2^k, k \geq 2$, symbols into k binary alphabets. The encoder consists of a set of k binary convolutional encoders, *elementary encoders*, operating at code rates $R_1, R_2, \ldots, R_k$, where $R_1 < R_2 < \ldots < R_k$. The data bits are split into k streams, each encoded by one of the elementary encoders. The set of k elementary encoder outputs is mapped onto the set of 2^k-ary modulator symbols. The decoder consists of k *elementary decoders*. The decoding is performed step by step beginning with the first elementary decoder, then the second etc. Each elementary decoder uses information from the outputs of the previous decoders. The code rate and memory of each elementary encoder is chosen such that the elementary decoders have approximately the same complexity and reliability.

We describe this method in more detail for the Gaussian channel and 4-PSK with soft decisions. Our rate R encoder consists of two (elementary) parallel binary rates R_1 and R_2 convolutional encoders, where $R = R_1 + R_2$. Each encoder generates one binary code symbol per time unit; $v_t^{(1)}$ for the first encoder and $v_t^{(2)}$ for the second encoder. The pairs of code symbols are represented as numbers $j = (v_t^{(2)}, v_t^{(1)})$ written in binary representation.

These numbers are mapped into modulation signals

$$s_j(t) = \cos(wt + \varphi_j),$$

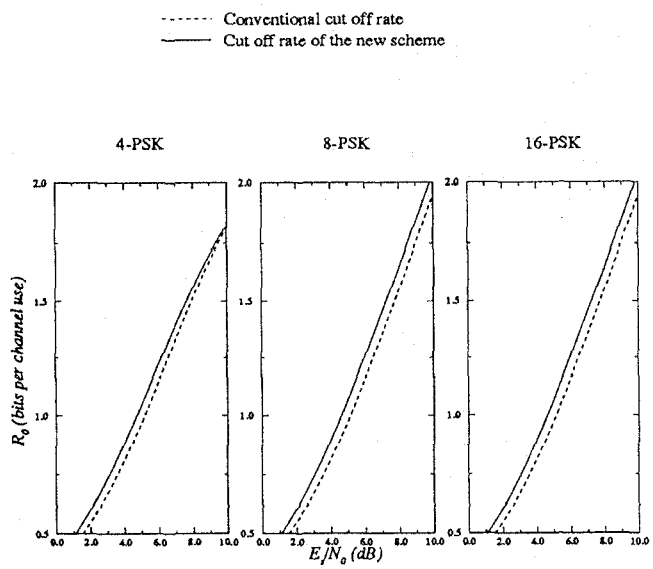
where $\varphi_j = j\pi/2$.

The decoder consists of two Viterbi decoders. The first one, corresponding to the first encoder, operates without taking the output sequence of the second encoder into account, i.e., it makes its estimates based on the conditional probability distribution for the received signal given that the code sequence $\underline{v}^{(1)} = (v_1^{(1)}, v_2^{(1)} \ldots)$ was transmitted.

The second Viterbi decoder estimates the second code sequence based not only on the second received sequence but also on the estimated code sequence from the first Viterbi decoder.

If the first decoder output is error free, then the second decoder knows exactly which of the signal pairs $(s_0(t), s_2(t))$ and $(s_1(t), s_3(t))$ that corresponds to each code symbol. Hence, the decoding process is reduced to decoding of BPSK signals.

In this paper we prove that we can choose the design parameters of the encoders and decoders such that for given reliability and complexity the transmission rate R for our scheme is greater than that for the conventional coded modulation scheme. Estimations of the systems performance for 4-PSK, 8-PSK, and 16-PSK (see fig.) with soft decisions show coding gains of about 0.5 dB compared to the conventional constructions.



References

[1] V.V. Ginzburg, "Multidimensional signals for a continuous channel", *Probl. of Inform. Transm.*, Vol. 23, No. 4, pp. 20–34, 1984.

[2] G. Ungerboeck, "Channel coding with multilevel/phase signals", *IEEE Trans. on Inform. Theory*, Vol. IT-28, pp. 55–67, 1982.

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