Differential Phase Shift Keying with Constellation Expansion Diversity

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Abstract — **A new differential encoding strategy is introduced, which is shown to be advantageous for bandwidth efficient transmission over flat Rician fading channels when using multiple symbol differential detection.**

I. System Model and Differential Encoding

Consider a stationary, slowly time–varying, frequency non–selective (flat) Rician fading channel. Channel state and carrier phase offset are expected to be constant over a block of at least N consecutive symbols, but not known at the receiver. For such situations, differential phase encoding at the transmitter and noncoherent demodulation at the receiver are appropriate. To achieve higher spectral efficiencies APSK constellations are attractive, which points are arranged in α distinct concentric rings with radii r_i and β uniformly spaced phases.

Because the received signal amplitude still provides information on the transmitted amplitude, information should be carried in the *actual amplitude*. But then, due to fading, part of the information carried in the amplitude will be lost. One possible approach to overcome this drawback and to exploit the potential of amplitude modulation is to completely map the information onto phase changes, and additionally, to (partly) map the same information onto the amplitude of the transmit symbols. This redundant mapping introduces *diversity*.

The most promising arrangement for the signal points is

$$\mathcal{A} \triangleq \left\{ c = r_{m \bmod \alpha} \mathrm{e}^{\mathrm{j}\frac{2\pi}{\alpha\beta}m} \mid m = 0, \ldots, \alpha\beta - 1 \right\}, \qquad (1)$$

because points whose phases differ by the minimum value $\frac{2\pi}{\alpha\beta}$ have different amplitudes.

Given the data–carrying *differential symbol* $a = r_j \mathrm{e}^{\mathrm{j}\frac{2\pi}{\alpha\beta}m} \in \mathcal{A}$ and the state $s = r_i \mathrm{e}^{\mathrm{j}\phi_n}$ of the differential encoder, the current transmit symbol $x \in \mathcal{X}$ is calculated according to

$$x = r_j \mathrm{e}^{\mathrm{j}\phi_{(n+m) \bmod \alpha\beta}}. \qquad (2)$$

The transmit signal constellation $\mathcal{X}$ now consists of again α amplitudes but $\alpha\beta$ phases. Due to the redundant mapping, $\mathcal{X}$ is *expanded* and the set $\mathcal{A}$ is a proper subset of $\mathcal{X}$. For $\alpha = 4$, $\beta = 4$ the constellations $\mathcal{A}$ and $\mathcal{X}$ are shown in Figure 1.

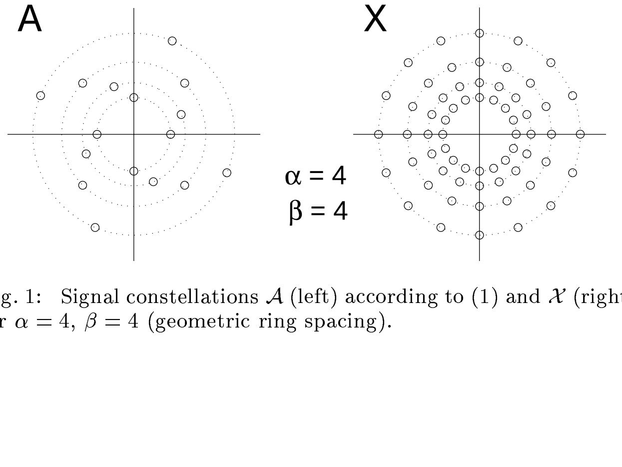

Fig. 1: Signal constellations $\mathcal{A}$ (left) according to (1) and $\mathcal{X}$ (right) for $\alpha = 4$, $\beta = 4$ (geometric ring spacing).

For slow fading channels we apply multiple symbol differential detection [1], where the receiver processes blocks of N consecutive receive symbols. Due to (ideal) interleaving at the transmitter and deinterleaving at the receiver of vector symbols a (virtually) memoryless block fading channel is obtained.

II. Numerical Results

For the AWGN channel and the Rayleigh fading channel the achievable capacity is numerically evaluated as a function of the (average) signal–to–noise ratio $\bar{E}_s/N_0$ ($\bar{E}_s$: average energy per received symbol, N_0: one–sided noise power spectral density). As shown in [2], it is sufficient to fix the differential symbols to be uniformly, independently and identically distributed, and to solely optimize the ring ratio.

Figure 2 shows the capacities of 16–ary modulation schemes using two signaling amplitudes and multiple symbol differential detection of $N = 3$. Clearly, for the AWGN channel, where the amplitude transmit factor is constant, differential encoding of the amplitude is not rewarding. In case of fading channels, absolute amplitude modulation without diversity leads to a flattening of the capacity curve at high SNR. This drawback is overcome by the proposed mapping, which performs best over the whole region of SNR. Hence, the novel scheme incorporates the advantages of the competitors.

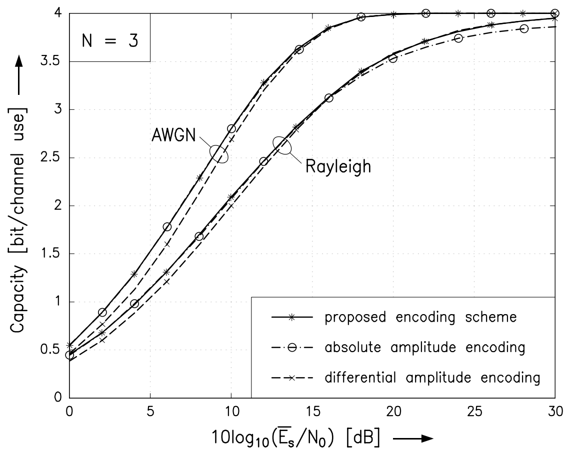

Fig. 2: Capacities for AWGN and Rayleigh fading channel. $N = 3$. Ring ratio $r_1/r_0 = 2$.

Noteworthy, the attainable gain is for free, since it does not require any increment in the coding/decoding complexity when used together with channel coding. The theoretical statements have been verified by simulations, which show a great accordance. For details see [2].

References

[1] D. Divsalar, M.K. Simon. Maximum-Likelihood Differential Detection of Uncoded and Trellis Coded Amplitude Phase Modulation over AWGN and Fading Channels — Metrics and Performance. *IEEE Trans. Commun.*, pp. 76–89, Jan. 1994.

[2] R.F.H. Fischer, L.H.-J. Lampe, S. Calabrò. Differential Encoding Strategies for Transmission over Fading Channels. *International Journal on Elect. and Comm.*, pp. 59–67, Jan. 2000.