Iterative Detection of Differentially Modulated APSK Signals in an OFDM Transmission System

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***Abstract*— In this paper an iterative detection technique for DPSK and its extension to higher level DAPSK modulation schemes is presented. We consider the well-known OFDM transmission technique that requires, in combination with noncoherent detection, no channel state information. By simulation it is shown that the proposed algorithm leads to a significant performance gain in terms of bit error rate.**

I. Introduction

The combination of differential modulation and the well-known OFDM multi-carrier technique yields a transmission system that is robust against time variant, frequency-selective channels. Since no channel state information is used for noncoherent detection, receiver structures with low complexity are possible. However, in terms of bit error rate (BER), conventional noncoherent differential detection (DD) shows inferior performance compared to coherent detection (CD) [8].

System performance can be improved if multiple symbol differential detection (MSDD) techniques are applied in the receiver [4]. By increasing the length N of the observation interval and applying maximum likelihood sequence estimation (MLSE), BER is significantly improved and finally, as $N \to \infty$, the gap between conventional DD and CD is filled. However, for large interval lengths the amount of computational complexity is exorbitantly high. Therefore, a MSDD scheme has been proposed that employs the Viterbi algorithm (VA) to reduce computational complexity [1]. This so-called ML-DD [1] scheme yields a remarkably good performance in terms of BER while the computational complexity is kept moderate.

The approach presented in this paper extends the VA in ML-DD to the soft output VA (SOVA) [5] and applies the well-known turbo decoding scheme [3] to the cascade of ML-DD and convolutional channel decoding [6]. This *turbo differential detection* (TDD) yields an even more efficient DD scheme that approximates (with finite computational complexity) the theoretical limit for MSDD given in [4]. Whereas [6] focuses on lower level DPSK modulation schemes, here we propose an extension of TDD to differential amplitude and phase shift keying (DAPSK).

II. Trellis Diagram for DPSK Modulated Signals

Conventional incoherent detection of DPSK modulated signals is based on the ratio between two successive received symbols r_k and r_{k-1}:

$$\Delta\theta_k = \arg\left(\frac{r_k}{r_{k-1}}\right). \tag{1}$$

Using log-likelihood values the soft output estimation for an assumed transmitted phase difference $\Delta\phi_k$ is given by

$$\lambda(\Delta\phi_k, \Delta\theta_k) = -\frac{(\Delta\theta_k - \Delta\phi_k)^2}{|1/r_k|^2 + |1/r_{k-1}|^2}. \tag{2}$$

In order to extend the observation interval from $N = 2$ for conventional DD to $N = 3$ for MSDD, the metric used for TDD does not only consider $\Delta\phi_k$ but also $\Delta_2\phi_k$ which is defined as the phase difference between the transmitted symbols s_k and s_{k-2}:

$$\Delta_2\phi_k = \Delta\phi_k + \Delta\phi_{k-1} = \arg\left(\frac{s_k}{s_{k-2}}\right). \tag{3}$$

Using Equation (3) a *joint-decision* metric is defined by:

$$\begin{aligned}\lambda_j(\Delta\phi_k, \Delta\phi_{k-1}, \Delta\theta_k, \Delta_2\theta_k) &= \lambda(\Delta\phi_k, \Delta\theta_k) \\ &\quad + \lambda(\Delta_2\phi_k, \Delta_2\theta_k) \\ &= -\frac{(\Delta\theta_k - \Delta\phi_k)^2}{|1/r_k|^2 + |1/r_{k-1}|^2} - \frac{(\Delta_2\theta_k - \Delta_2\phi_k)^2}{|1/r_k|^2 + |1/r_{k-2}|^2}.\end{aligned} \tag{4}$$

The corresponding trellis diagram for MSDD is shown in Figure 1 by an example of binary DPSK. The starting state of a particular branch indicates the previous estimation $\Delta\phi_{k-1}$, while the ending state depends on the current estimation $\Delta\phi_k$. With $\Delta_2\phi_k = \Delta\phi_k + \Delta\phi_{k-1}$ a metric value can be computed for each branch that depends on these assumed phase differences $\Delta\phi_k$ and $\Delta\phi_{k-1}$:

$$\begin{aligned}&\lambda_j(\Delta\phi_k, \Delta\phi_{k-1}, \Delta\theta_k, \Delta_2\theta_k) \\ &\quad = -\frac{(\Delta\theta_k - \Delta\phi_k)^2}{|1/r_k|^2 + |1/r_{k-1}|^2} - \frac{(\Delta_2\theta_k - \Delta\phi_k - \Delta\phi_{k-1})^2}{|1/r_k|^2 + |1/r_{k-2}|^2}.\end{aligned} \tag{5}$$

Since the starting state of a branch in the trellis diagram is determined by the previous estimated phase difference, a DPSK modulation scheme with M phases yields a trellis with M states.

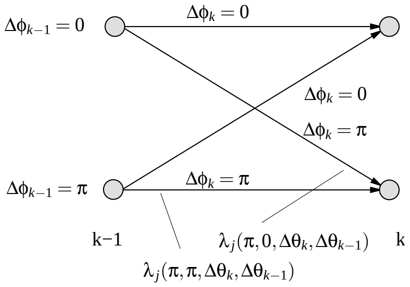
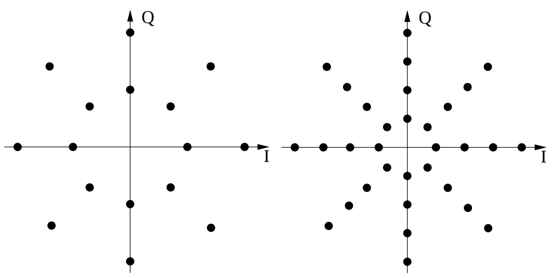


Fig. 1. Trellis diagram for MSDD of binary DPSK

III. Trellis Diagram for DAPSK Modulated Signals

At first glance it seems to be possible to apply the above analysis (based on phase differences in a DPSK modulation scheme) to amplitude ratios in a DAPSK modulation scheme (see Figure III). In that case, $\Delta\theta_k = \arg(r_k/r_{k-1})$ and $\Delta\phi_k = \arg(s_k/s_{k-1})$ have to be replaced by the amplitude ratios $\alpha_k = |r_k/r_{k-1}|$ and $\beta_k = |s_k/s_{k-1}|$, respectively. However, M_a amplitude states of the considered modulation scheme result in $(M_a-1)2+1$ different amplitude ratios [9]. Analogous to the above analysis, the states of the trellis are related to the transmitted amplitude ratios, and hence the number of states in the trellis equals $(M_a-1)2+1$. For example, a 32-DAPSK modulation with four amplitude states results in a trellis with 7 states (Table I).



(a) $M = 16$ (b) $M = 32$

Fig. 2. Signal space diagram for DAPSK

Information Symbol	$\mathcal{A}^1 = 0$	$\mathcal{A}^2 = 1$	$\mathcal{A}^3 = 2$	$\mathcal{A}^4 = 3$
Amplitude Ratios	1	a a^{-3}	a^2 a^{-2}	a^3 a^{-1}

TABLE I

Mapping between amplitude ratios and information symbols in a 32-DAPSK modulation scheme

To reduce the number of states and hence computational complexity, a different branch metric has to be applied for DAPSK modulation. Instead of using the amplitude ratios β_k, the information symbols $A_k \in \{\mathcal{A}^1, \ldots, \mathcal{A}^M\}$ related to the respective ratios are employed to compute the branch metrics:

$$\lambda(\beta_k, \alpha_k) \quad \rightarrow \quad \lambda'(A_k, \alpha_k) \tag{6}$$

$$\lambda(\beta_{2,k}, \alpha_{2,k}) \quad \rightarrow \quad \lambda'(A_{2,k}, \alpha_{2,k}), \tag{7}$$

where

$$\alpha_{2,k} = \left|\frac{r_k}{r_{k-2}}\right| \text{ and } \beta_{2,k} = \left|\frac{s_k}{s_{k-2}}\right|. \tag{8}$$

The metrics $\lambda'(A_k, \alpha_k)$ and $\lambda'(A_{2,k}, \alpha_{2,k})$ are simply the soft output (for amplitude bits) of a conventional DAPSK-Demodulator with input α_k and $\alpha_{2,k}$, respectively [7]. $A_{2,k}$ is the information symbol that leads from the estimated amplitude state $|s_{k-2}|$ to the estimated amplitude state $|s_k|$. In order to compute $A_{2,k}$ by A_k and A_{k-1} we define the *concatenation* function c that is simply the modulo M_a addition:

$$A_{2,k} = c(A_{k-1}, A_k) = (A_{k-1} + A_k) \bmod M_a. \tag{9}$$

Hence, if A_{k-1} leads from $|s_{k-2}|$ to $|s_{k-1}|$ and A_k leads from $|s_{k-1}|$ to $|s_k|$ then $c(A_{k-1}, A_k)$ leads from $|s_{k-2}|$ to $|s_k|$.

With Equation (6), (7) and (9) a joint-decision metric is defined as follows:

$$\lambda'_j(A_k, A_{k-1}, \alpha_k, \alpha_{2,k}) = \lambda'(A_k, \alpha_k) + \lambda'\left(c(A_{k-1}, A_k), \alpha_{2,k}\right). \tag{10}$$

The resulting amplitude trellis for a DAPSK modulation scheme with two amplitude states is shown in Figure 3. Hence, TDD for M-DAPSK yields an M_a-state amplitude trellis and an M_p-state phase trellis with $M_a + M_p = M$. Since M-DPSK yields one M-state trellis, TDD for M-DAPSK requires less computational complexity than TDD for M-DPSK.

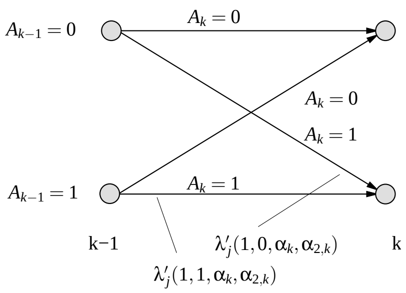


Fig. 3. Amplitude Trellis for TDD of 16-DAPSK

IV. Joint Optimization of ML-DD and Convolutional Decoding

Employing the SOVA to the phase and amplitude trellis introduced above, soft output information is provided. This *soft output ML-DD* (SOML-DD) can be used for a joint optimization of differential detection and convolutional decoding. The TDD algorithm, that performs this joint optimization, is similar to the iterative decoding algorithm for serial concatenated codes [2], where the place of the inner decoder is taken by SOML-DD. For DAPSK modulation this SOML-DD is

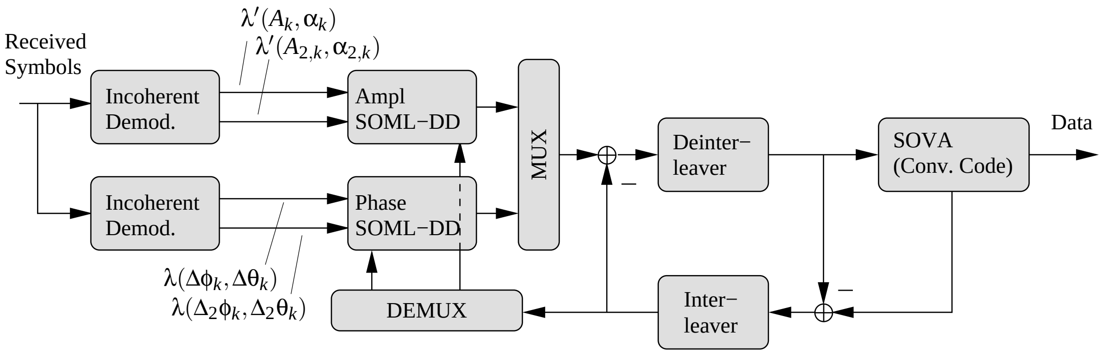


Fig. 4. Block diagram of iterative detection algorithm

split into an amplitude and a phase part (see Figure 4). The extrinsic information of both amplitude and phase SOML-DD is multiplexed, deinterleaved and then fed to the soft output convolutional decoder, which performs an SOVA itself. The provided extrinsic information is interleaved, demultiplexed and then fed back to the amplitude and phase SOML-DD to repeat this procedure iteratively.

V. Simulation Results

To evaluate the TDD performance, simulation results were performed for different modulation valencies and channel characteristics.

Figure 5 depicts simulation results for an OFDM transmission with 16-DAPSK in a non line of sight (NLOS) wide sense stationary uncorrelated scattering (WSSUS) channel. As a reference, simulation results are given for 16-DPSK with incoherent demodulation and a 16-QAM with realistic channel estimation[1]. For higher signal to noise ratios (SNR), TDD yields an SNR gain of 2 dB in comparison to conventional incoherent demodulation (DD). This result is already achieved with one iteration, i.e. further iterations yield no improvement for this system.

In higher level modulation schemes with line of sight transmission (LOS), this is different. Figure 6 depicts the influence of the iteration depth for 64-DAPSK modulation. As it can be seen, after the first iteration, the BER-Performance of TDD is worse than the BER of DD. Achieving a BER improvement in the next two iteration steps, TDD outperforms DD even for higher modulation levels.

In many systems not the BER, but the packet error rate (PER) is important for the overall performance. For that reason, Figure 7 shows the PER over SNR. Whereas the performance gain in terms of BER for 64-DAPSK is 1 dB in comparison to DD, the performance gain in terms of PER is 2 dB.

[1]The channel estimation considered here leads to an SNR loss of 2 dB in comparison to an ideal estimation.

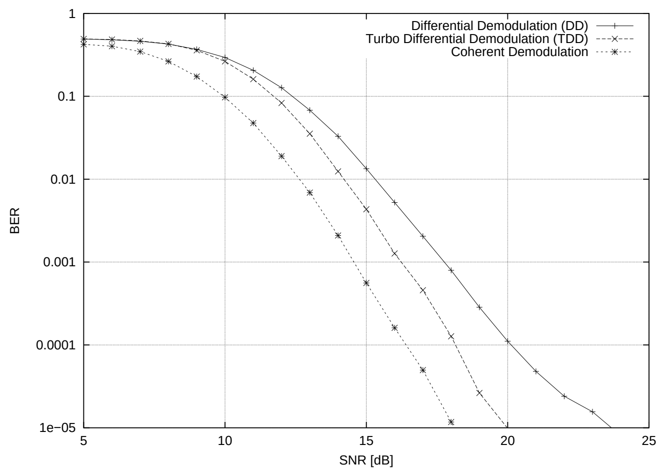


Fig. 5. BER for 16-DAPSK in an OFDM transmission scheme (No. of Subcarriers: 1024, Coh. Bandwidth: 190 kHz, Subcarrier Spacing: 4 Khz, Bit Interleaver Length: 4048, NLOS)

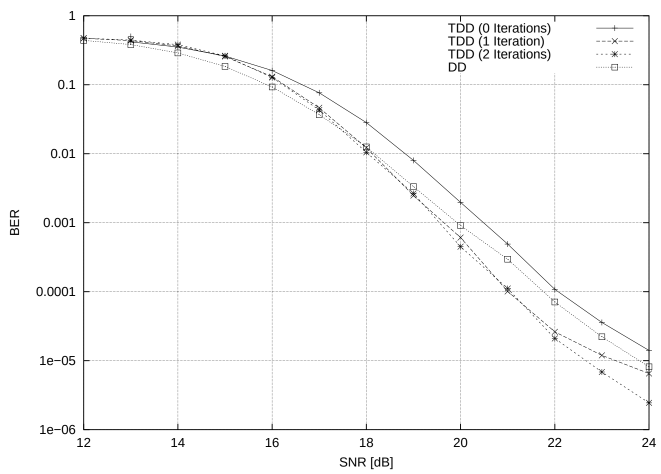


Fig. 6. BER for 64-DAPSK in an OFDM transmission scheme (No. of Subcarriers: 2048, Coh. Bandwidth: 190 kHz, Subcarrier Spacing: 4 Khz, Bit Interleaver Length: 12282, LOS (8 dB))

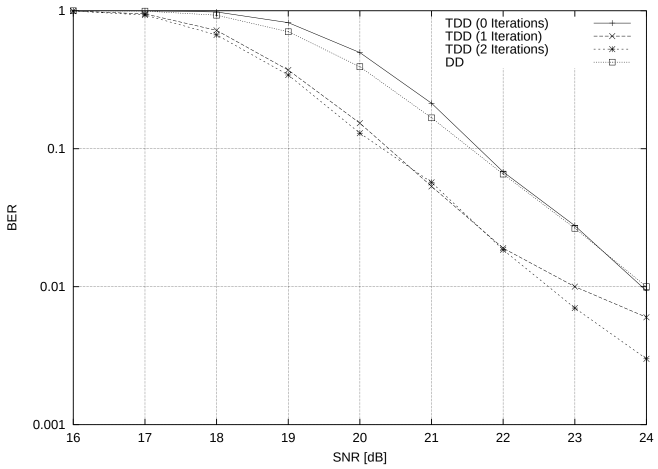


Fig. 7. PER for 64-DAPSK in an OFDM transmission scheme (No. of Subcarriers: 2048, Coh. Bandwidth: 190 kHz, Subcarrier Spacing: 4 Khz, Bit Interleaver Length: 12282, LOS (8 dB))

VI. Conclusion

In this paper, the basic idea of an iterative detection technique for differentially modulated signals in an OFDM transmission system is presented. We described the trellis diagram for MSDD of DPSK and its extension to higher level DAPSK. Splitting the trellis into an amplitude trellis and a phase trellis, computational complexity is reduced.

Simulation results show that by employing the turbo principle to the cascade of the presented SOML-DD and channel decoding, the performance of noncoherent detection of higher level differential modulation schemes can be improved.

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