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Speed-Optimized Soft-Decision Demodulation of Multilevel DAPSK

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Abstract--**We propose a speed-optimized noncoherent soft-decision demodulation of multilevel differential amplitude and phase shift keying (DAPSK) signals as part of a generic transmission system for multimedia indoor communications.**
The computation of soft-decision bit metric increments as input to a Viterbi decoder is quite time-consuming for higher DAPSK levels, as the total number of constellation points increases exponentially. To effectively reduce this computational cost at the receiver, we quantize the received signals at an early stage of the demodulation process. From this point on, the remaining soft-decision DAPSK demodulation can be reduced to a single table look-up per symbol. We show that the proposed preprocessing allows for fast soft-decision demodulation and that for all investigated DAPSK levels the signal-to-noise ratio (SNR) penalty is less than 0.25 dB compared to the unquantized case.

I. INTRODUCTION

To make use of both, wired and wireless indoor transmission, we applied orthogonal frequency division multiplexing (OFDM) with adaptive tone ordering to our generic transmission system. The subcarriers are modulated using DAPSK with up to 4096 levels. Due to differential modulation and demodulation no time-consuming channel estimation and equalization as described in [1] is necessary. The channel coding scheme includes convolutional encoding with constraint length $l_c = 7$ and code rate $R_c = 1/2$. Soft-decision Viterbi decoding is applied at the receiver in order to achieve good performance compared to hard-decision decoding [2].

Especially for high-level modulations the calculation of soft-decision bit metric increments as input to a Viterbi decoder is very time consuming. Therefore, we investigate an early stage signal quantization at the receiver, which allows for a fast computation of bit metric increments in real-time.

II. DAPSK

A. Modulation

The generic transmission system comprises DAPSK modulation in time direction [3] for each subcarrier separately. To this end, the bit sequence of subcarrier k is grouped by Gray labeling into a sequence of independent symbol pairs $(\Delta a_{n,k} \in \{0, 1, \ldots, N_a - 1\}, \Delta b_{n,k} \in \{0, 1, \ldots, N_p - 1\})$ according to the M-DAPSK level with $N_a = 2^{m_a}$ amplitude circles and $N_p = 2^{m_p}$ phases per amplitude circle. The total number of constellation points for the M-DAPSK is given by $M = N_a \cdot N_p$. These symbol pairs are used to modulate the quotient $t_{n,k}$ of two successively transmitted symbols $X_{n-1,k}$ and $X_{n,k}$ at discrete time $n-1$ and n according to

$$t_{n,k} = \mu^{\Delta a_{n,k}} \cdot e^{j(2\pi/N_p)\Delta b_{n,k}}, \tag{1}$$

where $\mu > 1$ is the ring ratio of the DAPSK. The differential encoding in time direction can be described analytically by

$$\begin{aligned} X_{n,k} &= X_{n-1,k} \cdot t_{n,k} \\ &= \lambda \cdot \mu^{[a_{n-1,k} + \Delta a_{n,k}] \bmod N_a} \cdot e^{j(2\pi/N_p)[b_{n-1,k} + \Delta b_{n,k}] \bmod N_p} \end{aligned} , \tag{2}$$

where parameter $\lambda = \sqrt{N_a(\mu^2 - 1)/(\mu^{2N_a} - 1)}$ normalizes the mean signal power of the M-DAPSK signal to unity.

B. Noncoherent Hard-Decision Demodulation

With noncoherent demodulation the decision is based on the quotient $r_{n,k}$ of two successive received symbols [4]

$$r_{n,k} = \frac{Y_{n,k}}{Y_{n-1,k}} = \frac{X_{n,k} \cdot H_{n,k} + N_{n,k}}{X_{n-1,k} \cdot H_{n-1,k} + N_{n-1,k}}, \tag{3}$$

where $H_{n,k}$ is the transfer function of subcarrier k at discrete time n, and $N_{n,k}$ represents additive white Gaussian noise (AWGN). Since the bits are independently mapped to amplitude and phase the hard-decision demodulation can be carried out by corresponding amplitude and phase thresholds.

C. Optimized Parameters for M-DAPSK

Using the thresholds given in [5], we obtained optimal modulation parameters for noncoherent demodulation of different M-DAPSK levels by simulation. The parameters given in Fig. 1 correspond to a target bit error rate (BER) of 10^{-2}. To our knowledge no optimized modulation parameters for $M-$DAPSK levels with $M \geq 256$ have been published so far.

III. COMPUTATION OF METRIC INCREMENTS

The speed-optimized differential soft-decision demodulation is based on the suboptimal maximum likelihood sequence estimation (MLSE) derived in [6]. The soft-decision metric increments for the amplitude and phase bits are calculated by evaluating the quotients $t_{n,k}$ and $r_{n,k}$

$$t_{n,k} = \frac{X_{n,k}}{X_{n-1,k}}, \quad r_{n,k} = \frac{Y_{n,k}}{Y_{n-1,k}}. \tag{4}$$

As amplitude and phase bits are dealt with separately, we define the parameters $v_{n,k}$ and $w_{n,k}$ to describe the amplitude ratio of the transmitted and received coefficients

$$v_{n,k} = \ln|X_{n,k}/X_{n-1,k}|, \quad w_{n,k} = \ln|Y_{n,k}/Y_{n-1,k}|. \tag{5}$$

In the same way we define the parameters $\psi_{n,k}$ and $\varphi_{n,k}$ to describe the phase differences of the transmitted and received coefficients

$$\psi_{n,k} = \arg(X_{n,k}/X_{n-1,k}), \quad \varphi_{n,k} = \arg(Y_{n,k}/Y_{n-1,k}). \tag{6}$$

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For the M-DAPSK described in [6], $v_{n,k}$ satisfies $v_{n,k} \in \Omega_v = \{k \cdot \ln\mu \,|\, k \in [-2^{m_a}+1, 2^{m_a}-1]\}$. Similarly $\psi_{n,k}$ satisfies $\psi_{n,k} \in \Omega_\psi = \{q\pi/2^{m_p-1} \,|\, q \in [0, 2^{m_p}-1]\}$.

With this set of parameters, bit metric increments $\lambda^i_{n,k}$ are derived for the suboptimal MLSE

$$\lambda^i_{n,k} = \Gamma_{n,k} \cdot d^i_{n,k}, \tag{7}$$

where factor $\Gamma_{n,k}$ contains an information about the reliability of the kth subcarrier and can be approximated [6] to

$$\Gamma_{n,k} \approx \frac{|Y_{n,k}|^2 \cdot |Y_{n-1,k}|^2}{|Y_{n,k}|^2 + |Y_{n-1,k}|^2}. \tag{8}$$

The variable $d^i_{n,k}$ describes the reliability of the ith bit $b^i_{n,k}$ in the received symbol according to its position in the constellation diagram. According to whether we consider an amplitude or phase bit we define

$$d^{i,a}_{n,k} = \min_{v_{n,k} \in \Omega_v} \left| w_{n,k} - v_{n,k} \big|_{b^i_{n,k}=1} \right|^2 - \min_{v_{n,k} \in \Omega_v} \left| w_{n,k} - v_{n,k} \big|_{b^i_{n,k}=0} \right|^2 \tag{9}$$

as bit reliability information (RI) for the amplitude bits and

$$d^{i,p}_{n,k} = \min_{\psi_{n,k} \in \Omega_\psi} \left| \varphi_{n,k} - \psi_{n,k} \big|_{b^i_{n,k}=1} \right|^2 - \min_{\psi_{n,k} \in \Omega_\psi} \left| \varphi_{n,k} - \psi_{n,k} \big|_{b^i_{n,k}=0} \right|^2 \tag{10}$$

as bit RI for the phase bits, respectively.

IV. SPEED-OPTIMIZED DEMODULATION

The bottleneck of bit RI computation is the minimization criterion in (9) and (10). Since the cardinality of Ω_v and Ω_ψ increases exponentially with m_a and m_p, respectively, the computational complexity becomes tremendous for high-level DAPSK. Therefore, we propose to limit the magnitude of the quotients $r_{n,k}$ and to apply quantization $q_{n,k} = \mathrm{quant}(r_{n,k})$. As the total number of $q_{n,k}$ is finite, this method permits computation of all $d^i_{n,k}$ once at initialization time.

We introduce a uniform quantization of $w_{n,k}$ and $\varphi_{n,k}$

$$\tilde{w}'_{n,k} = \mathrm{round}(S_w \cdot w_{n,k}) \tag{11}$$

$$\tilde{\varphi}_{n,k} = \mathrm{round}(S_\varphi \cdot \varphi_{n,k}) \tag{12}$$

with scale factors $S_w = I/\ln\mu$ and $S_\varphi = I \cdot 2^{m_p-1}/\pi$ for amplitude bits and phase bits, respectively. Parameter I is an interpolation factor which equals one for hard decision.

Furthermore, we limit $\tilde{w}'_{n,k}$ in order to obtain a finite range of $q_{n,k}$

$$\tilde{w}_{n,k} \in [-\lfloor I \cdot (2^{m_a} - 1/2) \rfloor, \ldots, \lfloor I \cdot (2^{m_a} - 1/2) \rfloor]. \tag{13}$$

By replacing $w_{n,k}$ with $\tilde{w}_{n,k}$ in (9), and $\varphi_{n,k}$ with $\tilde{\varphi}_{n,k}$ in (10), all $d^i_{n,k}$ can be computed at initialization time and stored into a bit RI table. Moreover, $\tilde{w}_{n,k}$ and $\tilde{\varphi}_{n,k}$ can be directly used for a fast index computation to read the bit RI values from the bit RI table. From Fig. 1 it can be seen that the SNR penalty due to quantization and limitation is for all investigated $M-$ DAPSK levels and $I \geq 4$ less than 0.25 dB.

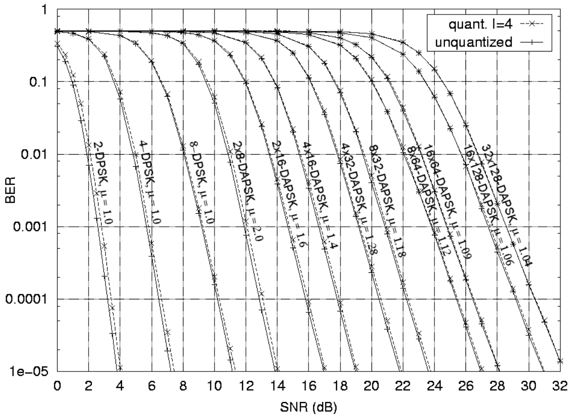

Fig. 1. Performance of unquantized and quantized M-DAPSK demodulation over an AWGN channel with convolutional code $l_c = 7$, $R_c = 1/2$.

The computational complexity of the speed-optimized soft-decision demodulation turns out to be proportional to $\log_2(M)$.

CONCLUSION

We have proposed a real-time speed-optimized multilevel DAPSK soft-decision demodulation for a generic indoor transmission system. The optimization of the processing speed is based on an early stage limitation and quantization of the received signals, which allows for a table look-up on a symbol-by-symbol basis. Especially for high-level DAPSK this leads to a significant reduction of the computational complexity that becomes proportional to $\log_2(M)$. We have shown that for $I \geq 4$ the preprocessing causes an SNR penalty of less than 0.25 dB for all investigated M-DAPSK levels up to $M = 4096$.

Our proposed real-time soft-decision demodulation is not limited to multicarrier systems and may also be applied to other QAM constellations with coherent, quasi-coherent or non-coherent soft-decision demodulation.

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