PERFORMANCE OF TRELLIS-CODED 8-DPSK MODULATION WITH CO-CHANNEL INTERFERENCE IN LAND MOBILE RADIO CHANNELS

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ABSTRACT

The BER-performance of uncoded 4-DPSK and coded 8-DPSK (with 8 and 16 state codes) modulation schemes has been studied. A Rayleigh mobile channel and the presence of co-channel interferers has been assumed. Bit error rate (BER) calculations have been performed by means of computer simulation. In this simulations we have assumed a Nyquist signalling and an ideal block interleaving process. Decoding of trellis codes with 8 and 16 states is performed by a soft Viterbi decoder. Results obtained for the uncoded 4-DPSK modulation scheme have been considered as a reference to determine the improvements introduced by the codification process. Remarkable coding gains can be attained for carrier to interference (CIR) average power ratios greater than 20dB. No significant improvements of the BER-Performance seems to be obtained by increasing the number of states in the Ungerboeck codes.

INTRODUCTION

Often the total number of radio channels available to a land mobile radio system will not provide satisfactory service within a metropolitan area on a large coverage area basis. The efficiency of the system can be increased by simultaneously using radio channels in small radio coverage areas or cells inside the metropolitan area. The basis for reuse distance calculations is the minimum CIR for which the radio link still offers acceptable quality. A way of improving the capacity of the land mobile systems would then consist in using digital modulation schemes with good CIR tolerances and without extra bandwidth requirements.

As far as we know, there is a lack of results regarding the behavior of TCM schemes in the presence of co-channel interference for a Rayleigh mobile environment. In this paper we have assessed the CIR tolerances that two specific TCM schemes, suitable for Rayleigh channels, present. In particular, we have investigated the performances of Trellis-Coded 8-DPSK with 8 and 16 state Ungerboeck codes exhibiting no-parallel transitions between states [1]. In the following the system model (modulator, transmission channel, demodulator and a soft Viterbi decoder for coded 8-DPSK) is described for Nyquist signaling. The bit error rate performance is determined by means of computer simulation.

SYSTEM MODEL

The equivalent baseband transmission system is shown in Fig. 1. It either applies to trellis coded 8-DPSK schemes with 8 and 16 state codes if the trellis encoder and soft Viterbi decoder are taken properly. We assume the overall transfer function to be, in absence of the Rayleigh distortion, a raised-cosine with a 0.5 roll-off parameter, equally split into transmitter and receiver. In order to emphasize only the effects of the co-channel interference, perfect automatic frequency control (AFC) and clock recovery are assumed. For modeling the mobile radio channel we have considered a complex-valued stochastic process, A(t), which describes multiplicative non-frequency selective fading. The envelope $|A(t)|$ and the phase $\mathrm{Arg}[A(t)]$ have Rayleigh and uniform distributions, respectively.

A data input bit pair $s_i=(s_{0,i},s_{1,i})$ is fed into a trellis encoder at time iT, which generates the coded 3-bit word $m_i=(m_{0,i},m_{1,i},m_{2,i})$ as a function of its state at the instant (i-1)T and of the data input symbol s_i. The octal mapper, applying mapping by set partitioning [2], converts the 3-bit word m_i into the coded 8-DPSK symbol a_i as given by equation (1),

$$a_i = \exp\left\{ j\cdot\left(m_{2,i}\cdot\pi + m_{1,i}\cdot\frac{\pi}{2} + m_{0,i}\cdot\frac{\pi}{4} \right)\right\} \quad (1)$$

This coded symbols are fed into the block interleaver , with a matrix of NL rows and NC columns, that breaks the channel memory and makes full use of the Ungerboeck codes. The symbols a_i are stored in columns and read out in rows. The numbers of rows and columns are chosen in such a way that the equivalent time spans are equal to or larger than the delay introduced by the soft Viterbi decoder and fade duration. Differential encoding of the interleaver output symbols, b_i, yields the coded 8-DPSK symbol, c_i,

$$c_i=c_{i-1}\cdot b_i \quad (2)$$

which once filtered by the transmission filter provides thecomplex transmitted baseband signal,

$$x(t)=\sum_k c_k\cdot h_T(t-kT) \quad (3)$$

where $h_T(t)$ is the impulsional response of the transmission filter.

The receiver input complex baseband signal is

$$r(t)=A_0(t)\cdot x(t) + I(t) + w(t) \quad (4)$$

where w(t) is an additive complex white Gaussian noise and I(t) can be written as

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$$i(t) = \sum_{j=1}^{N} i_j(t)\cdot A_j(t) = \sum_{j=1}^{N}\sum_k \alpha_{k,j}\cdot A_j(t)\cdot h_T(t-kT-\tau_j) \quad (5)$$

with $\{i_j(t)\}$ being co-channel interferent signals showing the same nature as the wanted signal, $\{\alpha_{k,j}\}$ the data symbol transmitted by the j-th interferer, N the number of interferent signals, $\{A_j(t)\}$ uncorrelated complex-valued stochastic processes and $\{\tau_j\}$ the interferent signal delays with respect to the wanted signal. The received signal is filtered by the reception filter giving,

$$y(t) = \sum_k c_k\cdot A_0(t)\cdot\Big[\, h_T(t-kT)*h_R(t)\,\Big] + \sum_{j=1}^{N}\sum_k \alpha_{k,j}\cdot A_j(t)\cdot\Big[\, h_T(t-kT-\tau_j)*h_R(t)\,\Big] + n(t) =$$

$$= \sum_k c_k\cdot A_0(t)\cdot h(t-kT) + \sum_{j=1}^{N}\sum_k \alpha_{k,j}\cdot A_j(t)\cdot h(t-kT-\tau_j) + n(t) \qquad (6)$$

where h(t) is the overall impulse response of the transmission channel in absence of Rayleigh distortion and n(t) is an additive complex Gaussian noise. This signal is sampled by an A/D converter at time $t_i = iT-\tau$, where $-T/2\le\tau\le T/2$ determines the sampling time, providing the complex sample,

$$y_i = c_i\cdot A_0(\hat{t}_i)\cdot h(\tau) + \sum_{k\ne i} c_k\cdot A_0(\hat{t}_i)\cdot h(\hat{t}_i-kT) + \sum_{j=1}^{N}\sum_k \alpha_{j,k}\cdot A_j(\hat{t}_i)\cdot h(\hat{t}_i-kT-\tau_j) + n(\hat{t}_i) \qquad (7)$$

As we can see, the wanted sample is affected by a term of intersymbol interference, a term of co-channel interference and a term of Gaussian noise. Assuming a perfect clock recovery, $\tau=0$, we have $h(0)=1$ and $h((i-k)T)=0$, for all $k\ne i$, and so the ISI term vanishes. If we also assume, in order to stress the co-channel interference effects, that all the interferers are synchronized with our system, that is $\tau_j=0$, the complex sample at the output of the A/D converter will be

$$y_i = c_i\cdot A_0(\hat{t}_i) + \sum_{j=1}^{N} \alpha_{j,i}\cdot A_j(\hat{t}_i) + n(\hat{t}_i) = c_i\cdot A_{0,i} + \sum_{j=1}^{N} \alpha_{j,i}\cdot A_{j,i} + n_i \qquad (8)$$

For the Nyquist system one can assume the noise samples n_i to be uncorrelated and so, the average bit energy to spectral noise power density ratio is, for $\tau=0$,

$$\frac{E_b}{N_0} = \frac{E\{|A_{0,i}|^2\}\cdot E\{|c_i|^2\}}{2\cdot\sigma^2} \qquad (9)$$

where E{ } denotes expectation and σ^2 is the variance of the thermal noise in each dimension. The carrier to interference average power ratio is given by

$$\mathrm{CIR} = \frac{E_b}{E_b^i} = \frac{E\{|A_{0,i}|^2\}\cdot E\{|c_i|^2\}}{E\{|A_{j,i}|^2\}\cdot E\{|\alpha_{j,i}|^2\}} \qquad (10)$$

where E_b and E_b^i denote the average bit energy of the wanted and interferent signals, respectively, and $j = 1,\dots N$. In the following we will assume the normalization

$$E\{|A_{0,i}|^2\} = E\{|c_i|^2\} = E\{|\alpha_{j,i}|^2\} = 1$$
$$E\{|A_{j,i}|^2\} = E\{|A_{1,i}|^2\} \text{ for all } j,i \in \{1,\dots,N\} \qquad (11)$$

thus, the average bit energy to spectral noise power density and the CIR will be given by Eqs. 13, 14,

$$\frac{E_b}{N_0} = \frac{1}{2\cdot\sigma^2} \qquad (12)$$

$$\mathrm{CIR} = \frac{E_b}{E_b^i} = \frac{1}{E\{|A_{j,i}|^2\}}\quad,\quad j=1,\dots,N \qquad (13)$$

Symbol detection is achieved by a differential decoder which uses the received symbol at the instant (i-1)T as phase reference, so, the detected symbol can be written as

$$z_i = y_i\cdot y_{i-1}^* = c_i\cdot c_{i-1}^*\cdot A_i\cdot A_{i-1}^* + \nu_i = d_i + \nu_i \qquad (14)$$

where ν_i is a complex noise sample which due to the multiplication is non-Gaussian and correlated. Once performed the differential decoding, the detected samples are stored into the block deinterleaver in rows and read out in columns for soft Viterbi decoding.

The trellis encoder used at the transmitter side functions as a "finite state machine", then the Viterbi decoder will be optimum for estimating the maximum likelihood coded symbol sequence. But the noise samples at the Viterbi decoder input are non-Gaussian and are correlated, for that, the use of a proper metric is needed. The cumulative metric that we have used for the path ending at state μ at time iT is given by the negative increase of the quadratic Euclidian distance over a symbol period [3],

$$Q_{\mu,i} = \sum_{k=0}^{L} |z_{i-k} - A_{0,i-k}\cdot A_{0,i-k-1}^*\cdot\hat{d}_{k,i-k}|^2 \qquad (15)$$

where L is the soft Viterbi decoding delay. It has been assumed that two consecutive samples of the Rayleigh mobile channel are aproximately equal,

$$A_{0,i-k} \cong A_{0,i-k-1} \qquad (16)$$

it applies for transmitter data rates much greater than the doppler frequency of the mobile channel.

COMPUTER SIMULATION RESULTS AND CONCLUSIONS

A lot of computer simulation programs have been developed in order to investigate the BER-performance of uncoded 4-DPSK and coded 8-DPSK, with 8 and 16 state codes, modulation schemes for a Rayleigh mobile channel and in presence of co-channel interferers. Results of the simulation for the uncoded 4-DPSK modulation scheme have been considered as a reference to determine the improvements introduced by the codification process. In this case, the detection process has been performed by determining the 4-DPSK, symbol $d_{i,k}$ for which $|z_i - d_{i,k}|$ is minimum. A non-coherent modulation has been adopted instead of a coherent one because of the difficulties in this systems to extract the carrier frequency in a mobile environment. The transmission medium fades are modeled by complex samples $A_{j,i}$, $j=0,\ldots,N$, which real and imaginary parts are two statistically independent Gaussian random variables. All the programs assume an ideal interleaving process, that is, the mobile radio channel appears as memoryless.

Fig's. 2 and 3 show representative results comparing the bit error rate (P_b) versus bit energy to noise spectral density ratio (E_b/N_0) for different carrier to interference average power ratios (CIR). Uncoded 4-DPSK and coded 8-DPSK, with 8 and 16 state codes, modulation schemes and different number of interferent signals are considered. BER-Performance curves for Uncoded 4-DPSK coincide with those obtained analytically by K.R. Wu et alt. (1984), [4]. As we can see, remarkable improvement of the BER-performance can be attained for interference power ratios greater than 20dB. In particular, this apply to the irreducible P_b value obtained for uncoded 4-DPSK (see table 1). No significant improvements of the BER-Performance seems to be obtained with the increasing of the number of states in the Ungerboeck codes.

Table 1. Irreducible BER values for uncoded 4-DPSK and coded 8-DPSK, with 8 and 16 state codes

Interference Power Ratio (Λ)	Number of interferer signals		
	1	2	3
Uncoded 4-DPSK			
Λ = 10dB	$8.1\cdot10^{-2}$	$1.5\cdot10^{-1}$	$2.0\cdot10^{-1}$
Λ = 20dB	$9.1\cdot10^{-3}$	$2.6\cdot10^{-2}$	$3.5\cdot10^{-2}$
Λ = 30dB	$1.0\cdot10^{-3}$	$2.8\cdot10^{-3}$	$3.9\cdot10^{-3}$
8-State Coded 8-DPSK			
Λ = 10dB	$1.2\cdot10^{-1}$	$2.2\cdot10^{-1}$	$2.7\cdot10^{-1}$
Λ = 20dB	$7.0\cdot10^{-4}$	$5.2\cdot10^{-3}$	$1.3\cdot10^{-2}$
Λ = 30dB	$<3.0\cdot10^{-6}$	$1.0\cdot10^{-5}$	$2.8\cdot10^{-5}$
16-State Coded 8-DPSK			
Λ = 10dB	$1.4\cdot10^{-1}$	$2.3\cdot10^{-1}$	$2.8\cdot10^{-1}$
Λ = 20dB	$4.6\cdot10^{-4}$	$3.6\cdot10^{-3}$	$1.1\cdot10^{-2}$
Λ = 30dB	$<1.0\cdot10^{-5}$	$<1.0\cdot10^{-5}$	$<1.0\cdot10^{-5}$

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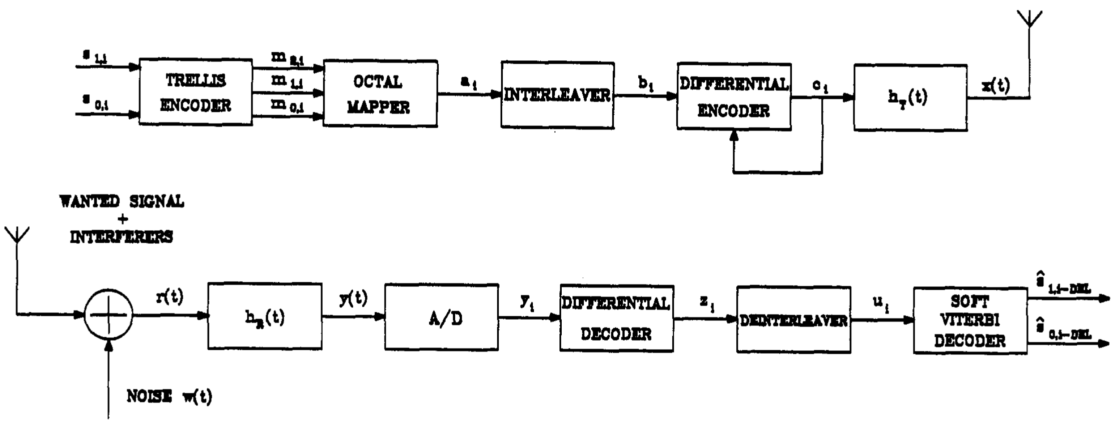

Figure 1. Equivalent baseband transmission system. (a) Emitter. (b) Receiver.

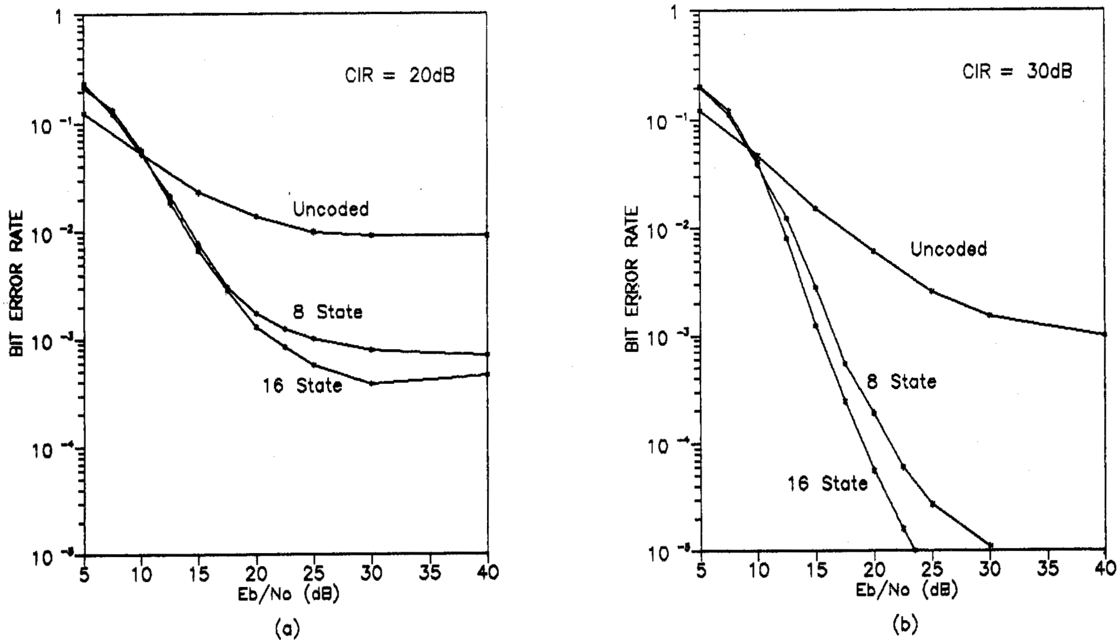

Figure 2. Bit error rates for uncoded-4DPSK, 8 state coded-8DPSK and 16 state coded-8DPSK in the presence of a single co-channel interferer.

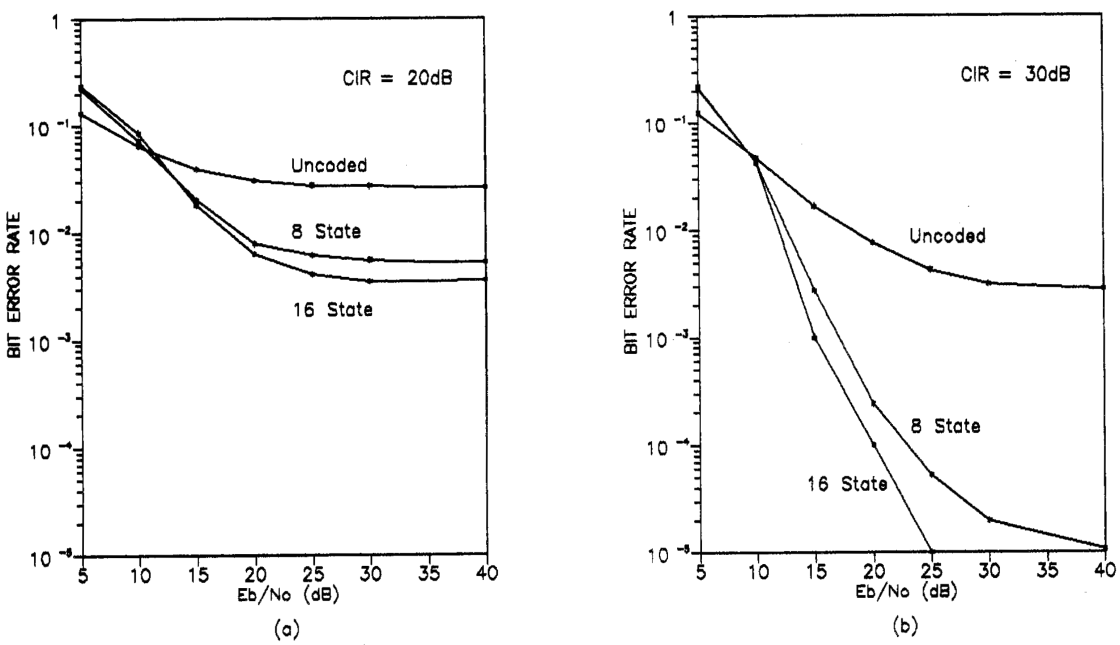

Figure 3. Bit error rates for uncoded-4DPSK, 8 state coded-8DPSK and 16 state coded-8DPSK in the presence of two co-channel interferers.