CHANNEL ESTIMATION FOR ITERATIVE DECODING OVER FADING CHANNELS*

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Abstract A method of coherent detection and channel estimation for punctured convolutional coded binary Quadrature Amplitude Modulation (QAM) signals transmitted over a frequency-flat Rayleigh fading channels used for a digital radio broadcasting transmission is presented. Some known symbols are inserted in the encoded data stream to enhance the channel estimation process. The pilot symbols are used to replace the existing parity symbols so no bandwidth expansion is required. An iterative algorithm that uses decoding information as well as the information contained in the known symbols is used to improve the channel parameter estimate. The scheme complexity grows exponentially with the channel estimation filter length. The performance of the system is compared for a normalized fading rate with both perfect coherent detection (corresponding to a perfect knowledge of the fading process and noise variance) and differential detection of Differential Amplitude Phase Shift Keying (DAPSK). The tradeoff between simplicity of implementation and bit-error-rate performance of different techniques is also compared.

Key words Codes; Iterative decoding; Channel estimation

I. Introduction

One of the major disturbances that affect the transmission of digital information over its link is fading. The need for reliable digital transmissions in digital broadcasting applications has motivated a great deal of work in developing fading resistive techniques. One of the most challenging tasks is the estimation of the time varying fading parameters (i.e., fading amplitude \{a_n\} and phase \{\theta\}). Several recent studies have demonstrated that turbo codes can achieve remarkable bit error performance over a Rayleigh flat-fading channel\[^{[1,2]}\]. However, many of the published simulation studies make two unrealistic assumptions. The first assumption is that the fading is fully interleaved and thus the fading amplitudes are statistically independent realizations of a Rayleigh random variable. In order to make this assumption valid, a channel interleaver is required, which must have a depth greater than the ratio \(T_c/T_s\), where \(T_c\) is the channel coherence time and \(T_s\) is the symbol duration. There are many instances when this requirement is not met such as the communication is between a fixed base station and a slowly moving mobile. When the fading rate is very low, the interleaver does not satisfactorily separate the fading and the Bit-Error-Rate (BER) performance suffers. The second assumption is that precise estimates of the noise variance and fading amplitudes are available at the decoding algorithm. In practical systems, however, these channel parameters, called Side Information (SI) in the literature, must be estimated at the receiver.

The issue of noise variance estimation in turbo codes was first addressed in the literature by Jordan and Nichols\[^{[3]}\]. The discussion of channel estimation for turbo codes in Ref.\[^{[3]}\] is limited to the effect of noise variance estimation errors on turbo codes operating over binary

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symmetric and Additive White Gaussian Noise (AWGN) channels. It is shown that turbo codes could tolerate noise variance estimation errors of less than 3dB in an AWGN environment, but estimation errors greater than 3dB sharply degrade performance. No discussion is provided regarding how the noise variance estimate is obtained or how fading amplitude estimation errors affect the performance of turbo codes on flat-fading channels. Noise variance estimation was also discussed in Ref.[4], which proposed a simple estimator. Simulation results show that using this estimator does not degrade the performance in AWGN channel with respect to the case of having perfect channel estimates. An alternative approach to the noise variance estimation problem was presented by Ref.[5], which recommended setting the noise variance equal to a "break-point", that is to simply use the variance that corresponds to the desired operating point.

In this paper, an iterative algorithm for decoding and channel estimation in slow frequency-flat Rayleigh fading channels is proposed. The impressive performance achieved by the iterative decoding of the parallelly concatenated convolutional or turbo codes has stimulated several researches to consider applying the iterative architecture in the other sub-modules of the receivers. In Ref.[6], Hagenauer has called this architecture the turbo processing principle and outlined that it can be used to improve the performance of almost all the receiver sub-modules. When the punctured convolutional codes proposed in Ref.[7] are used over a frequency-flat Rayleigh fading channels, estimates of the carrier phase \{\theta_n\} are required to coherently detect the transmitted symbols and estimates of the fading amplitude \{a_n = |c_n|\} are required by the iterative decoder. When the Signal-to-Noise Ratio (SNR) is sufficiently high and the normalized fading rate is sufficiently low, the channel phase \{\theta_n\} can be accurately estimated using a Phase-Locked-Loop (PLL). In this case, the amplitude \{a_n\} of the fading process can be estimated separately from the phase. Ref.[8] discussed the impact of fading amplitude estimates on performance and proposed an estimator for the fading amplitude and noise variance. In particular, the PLL will not provide accurate phase estimates if either the SNR is too low or the normalized fading rate is too high. In the absence of phase estimates, alternative methods for estimating the complex channel gains are required if coherent detection is desired. A method was proposed in Ref.[9] that uses pilot symbols and pilot tones to assist estimation prior to decoding. In the pilot tone approach, called Pilot Tone Assisted Modulation (PTAM), a sinusoidal waveform of constant frequency is added to the modulated signal. In the pilot symbol approach, called Pilot Symbol Assisted Modulation (PSAM), a known symbol is periodically inserted into the transmitted stream of traffic, i.e., code symbols[10]. The pilot symbol-based technique was extended in Ref.[11] to incorporate channel estimation within the turbo-decoding algorithm. In Ref.[9], all of the estimation is performed prior to the first iteration of turbo decoding. In Ref.[11], it is shown that additional performance gains can be achieved by refining the channel estimates after each iteration of turbo decoding. In their proposed solution, tentative decisions produced after each iteration of turbo decoding are used to assist channel estimation prior to the next iteration. By performing channel estimation after each decoder iteration, performance is significantly improved compared with the estimation prior to the first decoder iteration. In this paper, an iterative estimation technique for punctured convolutional codes operating over a Rayleigh fading channel is discussed.

The main drawback of incorporating pilot symbols into the transmission is an expansion of the required bandwidth and therefore a loss of spectral efficiency. In Ref.[12], a modification of the system was proposed that allows pilot symbols to be used without a