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ScienceDirect

Signal Processing 87 (2007) 148–161

SIGNAL PROCESSING

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New blind frequency offset estimator for OFDM systems over frequency selective fading channels

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Received 2 April 2005; received in revised form 28 April 2006; accepted 4 May 2006
Available online 12 June 2006

Abstract

In this paper, a blind frequency offset estimator for orthogonal frequency division multiplexing (OFDM) systems over frequency selective fading channels based on modeling the unknown channel fading gains as deterministic variables is proposed. In this estimator, the received time domain OFDM samples are first partitioned into subsets, in which neighboring samples are uncorrelated, leading to a tri-diagonal signal correlation matrix for each subset. The ML cost functions from each of the subsets are combined to perform frequency offset estimation. Simulation results show that the proposed frequency offset estimator achieves better performance than the estimators reported in [J.-J. Van De Beek, M. Sandell, P.O. Borjesson, ML estimation of time and frequency offset in OFDM systems, IEEE Trans. Signal Process. 45 (July 1997) 1800–1805] and [X. Ma, G.B. Giannakis, S. Barbarossa, Non-data-aided frequency-offset and channel estimation in OFDM: and related block transmission, IEEE ICC'01, June 2001, pp. 1866–1870]. Moreover, although the power delay profile needs to be known in deriving the proposed estimator, simulation and analytical results show that the performance of the proposed estimator is not sensitive to variation in the power delay profile.

Keywords: Blind frequency offset estimator; Maximum likelihood; OFDM; Frequency selective fading channel; Frequency synchronization

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1. Introduction

Orthogonal frequency division multiplexing (OFDM) systems are vulnerable to frequency synchronization errors that result in the loss of orthogonality among subcarriers and thus the substantial degradation of error probability performance. Therefore, frequency offset needs to be estimated and compensated before symbol detection is performed.

Blind frequency offset estimators, which do not rely on the transmission of pilot symbols, have recently received considerable attention because they are bandwidth efficient. In [1], a maximum likelihood (ML)-based blind joint symbol timing and frequency offset estimator was studied for OFDM systems over additive white Gaussian noise (AWGN) channel, based on modeling the transmitted OFDM signals as Gaussian

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doi:10.1016/j.sigpro.2006.05.003

random variables. In [2], a blind joint estimator similar to that in [1] was proposed based on assuming that the received OFDM signals over time varying frequency selective fading channels can also be modeled as Gaussian random variables. In [3], a correlation-based frequency offset estimator was proposed by exploiting the redundancy of cyclic prefix (CP). In [4], a blind frequency offset estimator utilizing the phase shift introduced by the presence of frequency offset was obtained for OFDM systems with unused subcarriers (virtual subcarriers), and by oversampling the received OFDM signals by a factor of two. All these above mentioned estimators were either frequency offset or joint symbol timing and frequency offset estimators, which are derived based on only one or two received OFDM symbols. In contrast, for several other blind estimators reported in the literature, observation of multiple OFDM symbols at the receiver is needed to guarantee the estimation performance. In [5,6], a subspace-based blind estimator and its equivalent ML-based frequency estimator that take advantage of virtual subcarriers were investigated. In [7], an estimator based on the second order cyclostationarity of received signals was proposed, where a few 100 OFDM symbols were observed to guarantee the estimation performance. A feedback frequency offset estimator, where the ML estimate is obtained iteratively, was proposed in [8]. In general, to obtain the frequency offset estimate, some estimators need the knowledge of SNR and power delay profile to perform estimation [1,8,2], while for some other estimators, such information is not required [3–7].

Fast ML-based blind frequency offset estimators that observe only one OFDM symbol to achieve reliable estimation are desirable for applications with stringent delay requirement. The blind estimator studied in [1] was derived for AWGN channels. It works reliably in AWGN channels, but its performance is degraded considerably when used over frequency selective fading channels. In order to obtain a ML cost function leading to an estimator with closed form expression for frequency selective fading channels, Lv et al. [2] removed the need to specify the distribution of the channel gains by approximating the received OFDM signals as Gaussian random variables. In this paper, we propose a blind frequency offset estimator that is also based on one received OFDM symbol. In this proposed estimator, channel gains are treated as deterministic unknown variables estimated together with the frequency offset. However, conditioned on channel fading gains, the signal correlation matrix with many non-zero entries is expected since neighboring received OFDM samples are correlated in the presence of multipath, and an ML estimator with closed form expression is difficult to obtain. In order to solve this problem, we propose to partition the received time domain OFDM samples into a few subsets, in which neighboring samples are uncorrelated. The partitioning and reconstruction of the received OFDM samples result in a tri-diagonal signal correlation matrix for each subset leading to a practical estimation algorithm. The details on the partitioning of the received samples into subsets and the derivation of the proposed estimator based on these subsets will be elaborated in Section 2. Its performance will be compared with that of the estimators reported in [1,3] in Section 3.

2. Proposed estimators

Consider an OFDM transmission over frequency selective fading channels. The maximum delay spread (normalized to $T_s = 1/B$, where B is the OFDM system bandwidth) is L. The CP with length of N_g samples is appended to the beginning of each OFDM symbol. Normally, $N_g \geqslant L$ is assumed to avoid inter-symbol interference and the resultant redundancy can be used to perform efficient synchronization [9]. We assume that the symbol timing synchronization of the OFDM system has been achieved so that the receiver knows exactly where the OFDM symbol starts. A complete OFDM symbol containing $N + N_g$ samples is observed. The received samples for one OFDM symbol can be written in a compact vector form as

$$\mathbf{r} = [r_1, r_2, \ldots, r_{N_g}, \ldots, r_{N+N_g}], \tag{1}$$

where the kth received sample is given by

$$r_k = \sum_{l=0}^{L_p-1} h_l s_{k-l} \mathrm{e}^{\mathrm{j}(2\pi k \varepsilon / N)} + w_k, \quad k = 1, \ldots, N + N_g. \tag{2}$$

The symbol s_k in (2) denotes the transmitted time domain signal sample and $\sigma_s^2 = E[s_k s_k^*]$ is the symbol energy. The transmitted signal s_k can be modeled as a Gaussian random variable but not white due to the existence of