Analytical Performance Evaluation of a Class of Receivers with Joint Equalization and Carrier Frequency Synchronization

P. Pedrosa[(1,2)], R. Dinis[(1,3)] and F. Nunes[(1,2)]
[(1)]Instituto de Telecomunicações, 1040-001, Lisboa, Portugal
[(2)]Instituto Superior Técnico, Universidade Técnica de Lisboa, 1040-001 Lisboa, Portugal
[(3)]Faculdade de Ciências e Tecnologia, Universidade Nova de Lisboa, 2829-516 Caparica, Portugal

***Abstract*—In this paper we consider an SC-FDE (Single Carrier Frequency-Domain Equalization) block transmission with residual frequency errors. We employ frequency-domain iterative DFE (Decision Feedback Equalization) receivers denoted by Iterative Block-Decision Frequency Equalization (IB-DFE), which are combined with a Decision-directed (DD) Carrier Frequency Offset (CFO) estimator. This estimator produces a CFO estimate within each iteration of the equalizer. We develop a model to predict the performance of IB-DFE receivers with joint detection and carrier frequency synchronization[1].**

I. Introduction

Due to an increased demand for wireless services, future systems are required to support high quality of service at high data rates. For such high data rates, the time-dispersion effects associated to the multipath propagation can be severe. In this case, conventional time-domain equalization schemes are not practical. Alternative techniques employing block transmission, with appropriate cyclic extensions and employing FDE (Frequency-Domain Equalization) techniques have been shown to be suitable for high data rate transmission over severely time-dispersive channels without requiring complex receivers. The most popular modulations based on this latter concept are the OFDM (Orthogonal Frequency Division Multiplexing) modulations [1]. An alternative approach based on the same principle are block transmission SC modulations (Single Carrier) combined with FDE (also denoted SC-FDE) [2]. Both schemes have similar implementation complexities, nevertheless SC-FDE schemes require simpler receivers. In this paper we consider the SC-FDE approach.

A promising IFDE (Iterative FDE) technique for SC-FDE, denoted IB-DFE (Iterative Block-Decision Feedback Equalizer), was proposed in [3]. This technique was later extended to diversity scenarios and layered space-time schemes (see [4] and references therein.) These IFDE receivers can be regarded as iterative DFE (Decision Feedback equalizer) receivers with the feedforward and the feedback operations implemented in the frequency domain. An IB-DFE receiver with joint post-equalization carrier frequency synchronization was presented in [5]. This receiver can be regarded as a modified turbo equalization scheme where, for each iteration, we perform DD (Decision-directed) CFO (Carrier Frequency Offset) estimation.

In order to maintain high power and spectral efficiencies, the cyclic prefix, which is longer than the overall channel impulse response length, should be a small fraction of the block duration. As a consequence, we usually need large blocks for severely time-dispersive channels, with hundreds or even thousands of symbols and, typically the frequency errors cannot exceed a small fraction of the inverse of the block duration. This means that we have higher sensitivity to frequency errors for larger blocks, making accurate carrier synchronization mandatory. Frequency errors usually originate from the frequency mismatch between the oscillators at the transmitter and receiver. Another possible source of frequency errors is the Doppler frequency shift caused by relative motion between the transmitter and the receiver.

While discussing carrier synchronization, two synchronization levels have to be distinguished, namely, carrier phase and carrier frequency synchronization. Furthermore, depending on the magnitude of the carrier frequency offset two types of synchronization can be attained, namely, a coarse synchronization and a fine synchronization. Usually, algorithms for fine synchronization require some type of previous coarse frequency estimation. Typically, fine carrier frequency synchronization systems are designed to deal with frequency offsets less than 10% of the symbol duration. Also, based on the degree of knowledge that the receiver has on the transmitted signal, these systems can be separated into three categories: data-aided (DA); non-data aided (NDA); and decision-directed (DD) ([6], [7] and references therein.)

A DD method for the estimation of the carrier frequency offset was presented in [8]. There, a CFO estimator that relies on data decisions to produce an estimate of the CFO is analyzed. If the receiver had perfect knowledge on the transmitted data, the CFO estimate would be unbiased. However, since we rely on estimates of the data symbols, which contain errors, the CFO estimates are biased. Finally, the statistics of the bias were determined and a model for the

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