Signal Processing 89 (2009) 1589–1601

Contents lists available at ScienceDirect

Signal Processing

journal homepage: www.elsevier.com/locate/sigpro

Channel identification and interference compensation for OFDM system in long multipath environment

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ARTICLE INFO

Article history:
Received 27 June 2008
Received in revised form
26 November 2008
Accepted 22 February 2009
Available online 9 March 2009

Keywords:
OFDM channel identification
Guard interval
Orthogonality
Leakage error
Periodogram

ABSTRACT

Guard interval (GI) is usually applied to reduce the influence caused by multipath interferences in orthogonal frequency division multiplexing (OFDM) systems. However, the long multipath interferences will deteriorate the orthogonality of the sub-carriers if they have longer delay time than GI. It is illustrated that not only inter-symbol interference (ISI) but also inter-carrier interference (ICI) is caused by the collapse of orthogonality in the received signal. As a result, both the channel identification and equalization become difficult, and the communication performance cannot be guaranteed. In this work, a new channel identification algorithm is proposed to estimate the frequency response function from the spectral periodograms which are compensated by the replica of leakage error. Since most of the computation is performed in the frequency domain through fast Fourier transform, the algorithm has such low computational complexity that it can be implemented easily in applications.

1. Introduction

Orthogonal frequency division multiplexing (OFDM), which adopts multi-carrier modulation, has been widely applied in the services of digital terrestrial broadcasting, asymmetric digital subscriber (ADSL) and 5 GHz wireless LAN. Since the spectra of orthogonal OFDM sub-carriers allow to be overlapped by each other to form an approximate rectangular spectrum, OFDM transmission has high frequency efficiency. Consequently, OFDM has been considered as a powerful candidate for the next generation of communications [1].

In OFDM communications, guard interval (GI) is attached at the header of every effective transmission symbol, consequently OFDM has a strong tolerance against the multipath interferences whose delay time does not exceed GI. However, there are some interferences with long delay time especially in high speed data transmission or mobile communications. Moreover, it is desired to squeeze the length of GI for higher transmission efficiency. If the long delay time of interference exceeds GI, the spectral leakage error, which yields inter-symbol interference (ISI) as well as inter-carrier interference (ICI), destroys the orthogonality of sub-carriers in the received signal, and makes both the channel identification and equalization very difficult. As a result, the communication performance degrades significantly [2]. The error correcting codes and frequency selective diversity can help to equalize the information symbols from the received signal when the multipath interferences do not exceed GI, nevertheless, their effectiveness becomes weak since the components of ISI and ICI interferences, which are caused by the long multipaths, contaminate all the sub-carriers.

The methods dealing with long multipath interference can be classified into two main groups: (1) the direct methods that use specific criteria to design equalizer without channel model; (2) the indirect methods that use

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doi:10.1016/j.sigpro.2009.02.017

the estimated channel model to compensate or cancel the interferences. They can be implemented in the time domain, or the frequency domain, depending on the criterion and optimization procedures of the processing algorithms.

The time-domain equalizers (TEQ) and the spatial equalizers using antenna diversity in the frequency domain are typical direct methods. Their criterion functions are composed of the received signals, desired performance indices and equalizer parameters, and are usually complicated nonlinear functions. For example, the MMSE criterion [3,4], the maximum bit rate criterion [5] in TEQs are solved by nonlinear optimization without explicit channel identification, however, they suffer from computational complexity for nonlinear optimization or slow convergence rate [6]. Differently, some spatial equalizers use antenna array to simplify the computational complexity. For instance, the spatial equalizers extract the interferences exceeding GI through a specific window function [7], or spectral envelope for PSK signals [8]. Nevertheless, the performance of spatial equalizers strongly depends on the capacity of antenna diversity or the signal arrival angle, and these equalizers may not work well in the severe multipath interference environments with restricted number of antenna elements. Though increasing the sampling rate may shorten the length of channel impulse response [9], the circuit complexity restricts its application to the practical systems.

On the other hand, the indirect methods separate the problem into two stages of channel identification and model based equalization design. When the channel has been identified, the immediate ways to the second stage in the time domain are the compensation of the received signal by estimating the interference replica [10,11], and the length compression of impulse response of the combined communication channel, including transmission channel and equalizer [12]. Most of them identify the channel model by RLS or LMS algorithm in the time domain from preamble or training symbols. However, too long impulse response of a communication channel leads to heavy computational load for RLS or slow convergence for LMS, and the identification performance is fragile to observation noise and signal band limitations. Consequently, the higher equalization error occurs. Besides the time domain methods, some frequency domain methods are also developed. For example, an interpolation algorithm has been considered for the frequency response function of channel model between adjacent pilot sub-carriers to reduce computational complexity [13]. However, the function varies dramatically due to the long interference hence the interpolation accuracy cannot be guaranteed when the pilot rate is not high enough. Although the frequency domain methods through Hanning window function to reduce ICI in channel identification [14], or using unused sub-carriers to compensate ISI and ICI [15] are also investigated, the high performance for strong long multipath interferences is not guaranteed.

Channel identification and equalization of OFDM communication with long interferences are more difficult than those in processing of short multipath interferences. To improve the equalization performance, or to simplify the equalizer design, they should consider the difficulties of a large number of parameters required for long impulse response, and a large bit error rate (BER) caused by the collapse of orthogonality in the received signal. In this paper, a novel algorithm of channel identification for long multipath interferences is presented to overcome these difficulties. Compared with other methods, the proposed algorithm has the following features: (1) most of computation is performed by fast Fourier transform (FFT) in the frequency domain, therefore, the complexity in computation can be moderated even though the channel impulse response is very long; (2) the frequency response function of the OFDM channel is estimated from the spectral periodograms, which are tolerant to noise and the symbol estimation errors; (3) the diversity of multiple antennas in their frequency response functions is used to choose the strong orthogonal components for high BER performance of symbol estimation as well as high convergence rate of channel identification; (4) the algorithm is performed iteratively and has the adaptability to the time-varying channels.

The rest of the paper is arranged as follows. In Section 2, the OFDM signals and channel model are addressed, then the properties of interferences with long delay time are investigated in Section 3. Based on the investigated properties, the algorithms of identification and interference compensation are given in Section 4, and their effectiveness is demonstrated by some simulation examples in Section 5.

2. Problem statement

2.1. OFDM signals

Let the period of OFDM information symbol be denoted as N. As shown in Fig. 1, GI attaches a copy of the tail part of effective symbol to its head as a cyclic prefix when the signal is transmitted. The length of GI is denoted as $N_{\rm gi}$, then the practical transmission period denoted as $N_{\rm tx}$ becomes to $N+N_{\rm gi}$.

In the transmission symbol period $N_{\rm tx}$, the transmitted signal in baseband is generated by N-point IFFT as follows:

$$d(k)=\sum_{n=-N/2+1}^{N/2} D(n,l)e^{jn\omega_0(k-lN_{\rm tx})}$$
$$\text{for } lN_{\rm tx}-N_{\rm gi}\leqslant k<lN_{\rm tx}+N, \quad (1)$$

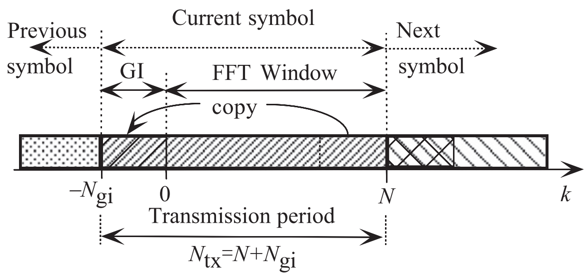

Fig. 1. Guard interval in OFDM signal.