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Precoded OFDM System for ICI Mitigation over Time-Frequency Selective Fading Channels*

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Abstract: In orthogonal frequency-division multiplexing (OFDM) systems, the capability to support high mobility is greatly limited by the intercarrier interference (ICI) caused by time-frequency selective fading channels. This paper presents a precoded OFDM system for ICI mitigation. A precoder is introduced to relieve the ICI by transmitting *N*-point composite information symbols at twice the subcarrier interval. A Hadamard-matrix-like pilot pattern is used to recover the composite information symbols in a postprocessor at the receiver. Simulations show that, compared to the conventional self-cancellation scheme, this scheme gives much better signal-to-interference-noise ratio performance with much less overhead. Furthermore, the scheme can support twice the vehicle speed in time-frequency selective fading channels than the standard OFDM systems without ICI mitigation.

Key words: orthogonal frequency-division multiplexing (OFDM); time-varying; multipath; intercarrier interference

Introduction

Orthogonal frequency-division multiplexing (OFDM) systems are robust against frequency selective fading due to the increased symbol duration. However, in highly mobile environments, OFDM signals suffer from not only frequency-selective, but also time-selective fading within one OFDM symbol. To have an acceptable reception quality, the intercarrier interference (ICI) mitigation is indispensable in those applications[1,2].

Previous studies have tried to alleviate effect of the interference. Conventional self-cancellation schemes have been proposed to relieve the carrier frequency offset-induced (CFO-induced) ICI by mapping identical symbols to a group of subcarriers[3,4]. However, these schemes decrease the throughput by 50%. Others have proposed multi-stage equalizers at the receiver for ICI suppression[5,6], but they usually require perfect channel estimation. Most pilot-assisted channel estimation algorithms depend heavily on effective ICI mitigation to improve the signal-to-interference ratio (SIR) at pilot subcarriers. Thus, the ICI mitigation and channel estimation are interdependent, which severely complicates the design.

This paper describes a precoded OFDM system for ICI mitigation. The transmitter uses a precoder to produce *N*-point composite symbols which are linear combinations of *N*-point input information symbols. Then, *N*-point information symbols are transmitted at twice the subcarrier interval. The time-variant channel induced ICI is then reduced by the enlarged frequency interval between information symbols. Furthermore, use of a Hadamard-matrix-like pilot pattern inserted at the transmitter reduces the complexity of the postprocessor at the receiver that utilizes a least square (LS) estimator to recover part of the composite information at even pilot subcarriers. This information is then

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combined with the symbols at odd subcarriers to decompose the rest of the information symbols. In addition, the best performance is obtained by minimizing the mean square error of the LS estimator and optimizing the pilot placement.

1 System Structure and Precoder

Consider an OFDM system with N subcarriers (N is even) and assume that the maximum delay spread is L samples for the system structure depicted in Fig. 1. The transmitter has a precoder where the N-point input information symbols are split into two subblocks, denoted as $\boldsymbol{X}_1$ and $\boldsymbol{X}_2$. These blocks are then passed through two $N/2$-point inverse fast Fourier transforms (FFTs), and assembled by an N-point FFT. The composite symbols are given by

$$\boldsymbol{S} = \boldsymbol{F}\begin{pmatrix} \boldsymbol{F}_1^{-1} & \boldsymbol{0} \\ \boldsymbol{0} & \boldsymbol{F}_1^{-1} \end{pmatrix}\begin{pmatrix} \boldsymbol{X}_1 \\ \boldsymbol{X}_2 \end{pmatrix} \quad (1)$$

where $\boldsymbol{F}$ is the N-point FFT matrix and $\boldsymbol{F}_1$ is the $N/2$-point FFT matrix. After the precoder, an N-point inverse FFT is performed as in standard OFDM systems, and a length M ($M \geqslant L-1$) zero postfix is appended to the inverse FFT output to construct a new OFDM symbol. For clarity, Eq. (1) can be reformulated as

$$\boldsymbol{S}_{\rm e} = \boldsymbol{F}_{\rm e}\begin{pmatrix} \boldsymbol{F}_1^{-1} & \boldsymbol{0} \\ \boldsymbol{0} & \boldsymbol{F}_1^{-1} \end{pmatrix}\begin{pmatrix} \boldsymbol{X}_1 \\ \boldsymbol{X}_2 \end{pmatrix} \quad (2)$$

$$\boldsymbol{S}_{\rm o} = \boldsymbol{F}_{\rm o}\begin{pmatrix} \boldsymbol{F}_1^{-1} & \boldsymbol{0} \\ \boldsymbol{0} & \boldsymbol{F}_1^{-1} \end{pmatrix}\begin{pmatrix} \boldsymbol{X}_1 \\ \boldsymbol{X}_2 \end{pmatrix} \quad (3)$$

where $\boldsymbol{F}_{\rm e}$ is a submatrix containing all the even rows of the N-point FFT matrix $\boldsymbol{F}$ and $\boldsymbol{F}_{\rm o}$ is a submatrix containing all the odd rows of $\boldsymbol{F}$. $\boldsymbol{F}_{\rm e}$, $\boldsymbol{F}_{\rm o}$, and $\boldsymbol{F}_1$ are related by[7]

$$\boldsymbol{F}_{\rm e} = [\boldsymbol{F}_1 \mid \boldsymbol{F}_1] \quad (4)$$

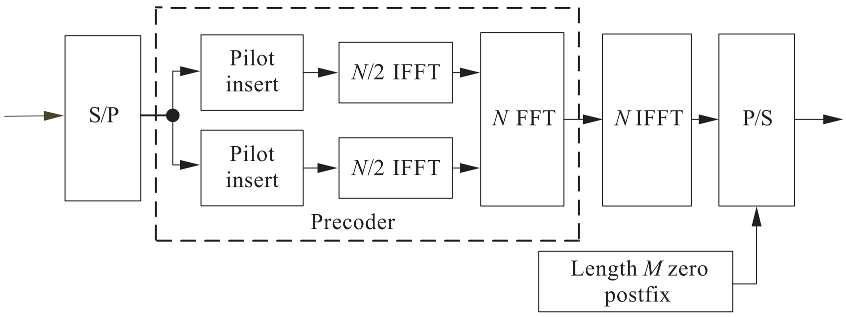
$$\boldsymbol{F}_{\rm o} = [(\boldsymbol{F}_1\boldsymbol{\Lambda}) \mid (-\boldsymbol{F}_1\boldsymbol{\Lambda})] \quad (5)$$

where the operator "|" is matrix concatenation. $\boldsymbol{\Lambda}$ is a phase-rotated diagonal matrix. Therefore, Eqs. (2), and (3) can be simplified as

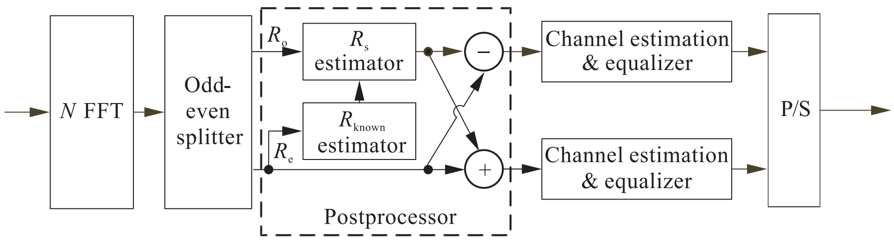
$$\boldsymbol{S}_{\rm e} = \boldsymbol{X}_1 + \boldsymbol{X}_2 \quad (6)$$

$$\boldsymbol{S}_{\rm o} = \boldsymbol{F}_1\boldsymbol{\Lambda}\boldsymbol{F}_1^{-1}(\boldsymbol{X}_1 - \boldsymbol{X}_2) \quad (7)$$

$\boldsymbol{S}_{\rm e}$ is the sum of subblocks $\boldsymbol{X}_1$ and $\boldsymbol{X}_2$, while $\boldsymbol{S}_{\rm o}$ is a phase-rotated version of the difference between $\boldsymbol{X}_1$ and $\boldsymbol{X}_2$. These properties of the subcarrier symbols help reduce ICI induced by time-variant channels with appropriate postprocessing at the receiver.



(a) Transmitter



(b) Receiver with ICI mitigation

Fig. 1 System structure

2 Postprocessor for ICI Mitigation

After the N-point FFT at the receiver, the received frequency symbols, $\boldsymbol{R}$, can be divided into the symbols at the even subcarriers and the symbols at the odd subcarriers, denoted as $\boldsymbol{R}_{\rm e}$ and $\boldsymbol{R}_{\rm o}$:

$$\boldsymbol{R}_{\rm e} = \boldsymbol{F}_{\rm e}\boldsymbol{C}\boldsymbol{F}^{-1}\boldsymbol{S} + \boldsymbol{W}_{\rm e},\ \ \boldsymbol{R}_{\rm o} = \boldsymbol{F}_{\rm o}\boldsymbol{C}\boldsymbol{F}^{-1}\boldsymbol{S} + \boldsymbol{W}_{\rm o} \quad (8)$$