Channel Equalization and ICI Mitigation for OFDM Systems in a Time Selective Channel

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Abstract

OFDM is a powerful transmission technique to achieve high data rates and to suppress intersymbol interference (ISI) in frequency-selective fading channel. However, in wireless environment, especially in the case of high speed train, the channel is time variant because of the relative motion between the transmitter and receiver. The fast channel variations can be modeled by Doppler spread change over one symbol OFDM duration. In such propagation conditions, the orthogonality among subcarriers is destroyed, which results in intercarrier interference (ICI) that may degrades severely the bit error rate performance of OFDM systems. In this paper, we address adaptive channel equalization in OFDM systems kalman filter for channel tracking and Decision Feedback Equalizer DFE are proposed to reduce the performance degradation due to ICI. Simulation and performances of the proposed equalized OFDM system are carried out for different mobile speed.

1. Introduction

Due to ever increasing bandwidth demands in future wireless networks, OFDM technique has recently received considerable attention. The main advantage of OFDM transmission is its ability to achieve high data rates over wireless mobile channels and its robustness to frequency-selective fading channel[1]. In OFDM the individual carriers when employed in a time invariant channel can be made to be orthogonal by the use of a cyclic prefix before each data block, thereby increasing OFDM symbol period and thus mitigating the effect of ISI caused by dispersive fading channel. However, this orthogonality is no longer maintained when the channel is time varying and Doppler frequency shifts arise due to relative motion between transmitter and receiver, which results in intercarrier interference (ICI) [2]. Moreover with the longer symbol duration of OFDM the ICI also called FFT leakage caused by Doppler spread will be increased and degrades the performance of OFDM systems [3]. This problem of ICI is further exacerbated when considering Doppler frequencies, which result from mobile reception in vehicles such as high speed trains. ICI may also be results of OFDM vulnerability to frequency-offset errors caused by oscillators’ inaccuracies at the transmitter and receiver. Only ICI caused by frequency-offset due to the Doppler spread is considered in this paper. Several studies to combat and reduce ICI in OFDM systems exist. One solution is to use optimal techniques for equalization and estimation of the time varying channel. Kalman filter is one of these optimal techniques for performing the channel estimation [4]. Decision Feedback Equalizer (DFE) is an other technique that yields better performance than a linear equalizer for radio channels and has good trade off between performance and computational complexity [5].

The purpose of this article is to analyze the degradation of OFDM over fast time varying fading channel due to ICI and investigate the robustness of use a DFE and Kalman filter in the receiver to improve the system performances.

The paper is organized as follows. In section II a brief description of ICI bounds due to the Doppler spread is presented. The system model and the proposed Kalman filter and DFE equalizer are described in section III. The comparison results of the proposed system for different mobile speed is reported.
in Section III. Finally, section IV summarizes our conclusions.

2. ICI power bounds

Previously, the problem of OFDM with Doppler was addressed in the literature. In particular, Russell et al. and Robertson et al. studied the effect of Doppler spread on OFDM signal and they obtained exact expressions for the ICI resulting from Doppler spread [2][3]. Both analytical and bounds on the ICI power of OFDM in time varying environments have been derived in [6] and references therein. Li et al. derived exact, tight and universal bounds on the average ICI formulas that can be calculated more easily and provide useful insight. It was shown that ICI power depends mainly on the maximum Doppler frequency $f_d$ and the OFDM symbol duration $T_s$.

In the case of flat fading, for OFDM with an infinite number of subcarriers, once the time correlation of the time varying channel $R(\tau)$ is known, the ICI power can be expressed for the Jakes classical model as:

$$P_{ICI} = 1 - \int (1 - |k|J_0(2\pi f_d T_s/x))dx$$

(1)

The tight bounds of the ICI are dependent on the variance of the Doppler spectrum and are given by [6]:

$$P_{ICI} \leq \frac{\alpha_1}{12}(2\pi f_d T_s)^2 - \frac{\alpha_2}{360}(2\pi f_d T_s)^4$$

(2)

$$P_{ICI} \geq \frac{\alpha_2}{12}(2\pi f_d T_s)^2$$

(3)

with $\alpha_1 = 1/2$ and $\alpha_2 = 3/8$ for classical Jakes model.

The universal bound depends only on the maximum Doppler frequency $f_d$ and the symbol duration $T_s$ and is given as:

$$P_{ICI} \leq 1 - \frac{1}{12}(2\pi f_d T_s)^2$$

(4)

This universal upper bound can be used in OFDM systems with any Doppler spectra. The exact expressions for ICI and the various bounds are also applicable to dispersive channels.

3. OFDM System model

In the baseband system, data is modulated with 16QAM modulation. The serial converter transfers blocks of symbol to the modulator. OFDM modulation is performed via N point inverse fast Fourier transform (IFFT) to form OFDM symbols with duration $T_s$ which are transmitted through time varying fading channel with channel impulse response $h(n)$ and $v(n)$ an AWGN with power spectrum density $N_0$ and covariance $R$. If we assume $S(n)$, the transmitted data, the received signal is given by:

$$r(n) = S(n)h(n) + v(n)$$

(5)

The considered baseband radio channel is modeled by a new improved Jakes’ model simulator suggested by Zheng and Xiao [7] to simulate the Rayleigh fading channel. This new model called here Zheng model generates a non-deterministic signal with desired statistical properties that approach Clarke’s theoretical ones even if the number of sinusoids $M$ used to generate the fading process is as small as single digit integer.

At the receiver, OFDM demodulation is accomplished via an FFT. Channel tracking and equalization are performed by a Kalman filter and a DFE equalizer. The Kalman filter assumes that the DFE hard decisions are correct and uses them to estimate the next channel value, while the DFE assumes correct Kalman filter channel estimates and uses them in turn to equalize the channel as detailed in [8].

In order to describe the dynamics of the time varying channel, a first autoregressive process (AR) is used, where the current value is a weighted sum of the previous values plus noise as follows:

$$h(n + 1) = \alpha h(n) + w(n)$$

(6)

$h(n)$ accounts for Doppler effects according to the Zheng model and $w(n)$ denotes the process noise with covariance $Q$.

Using (5), the AR coefficient $\alpha$ and $Q$ can be estimated as given in [9]:

$$\alpha = E[h(n)h_1(n - 1)] = J_0(2\pi f_d T_o)$$

(7)

where $J_0(.)$ is the 0th-order Bessel function and $f_d$ denotes the maximum Doppler shift and $Q = 1 - |\alpha|^2$

(8)

Based on the system equation (6) and the observation equation given by (5), the decision directed Kalman tracking algorithm for the channel impulse response is given as follows in [10]:

Step 1: a-priori estimation (prediction)
\[ \hat{h}[n] = \alpha \hat{h}[n-1], \]  
\[ P_h[n] = \alpha P_h[n-1] \alpha' + Q \]  

**Step 2:** a-posteriori estimation (update)

\[ K_h = P_h[n] \hat{\alpha}[n](\hat{\alpha}[n]P_h[n]\hat{\alpha}[n] + R)^{-1} \]  
\[ \hat{h}[n] = \hat{h}[n] + K_h[n](r(n) - \hat{\alpha}[n]\hat{h}[n]) \]  
\[ P_h[n] = (I - K_h[n]\hat{\alpha}[n])P_h[n] \]  

where \( K_h \) is the Kalman gain and \( P_h \) is the error covariance matrix based on the observations \( \{r[n], r[1], \ldots, r[n]\} \).

The optimal filters coefficients of the DFE equalizer are computed based on the channel impulse response estimation. The design of the optimum MMSE feedforward and feedback \( f_N^{\text{opt}} \) and \( b_n^{\text{opt}} \) using the tap coefficients under the assumption of no error propagation can be calculated as detailed in [8]:

\[ b_n^{\text{opt}} = e_i^T R_s^{-1} \]  
\[ f_N^{\text{opt}} = b_n^{\text{opt}} R_y R_y^{-1} \]  

where \( e_i \) is the vector with first entry and all others zero. The matrices \( R_s, R_y, \) and \( R_y^{-1} \) are formed by a pre windowed channel matrix \( C \) containing estimating and predicting values of coefficients channel. and \( R_s \) and \( R_y \) are formed as:

\[ R_s = R_s - R_y R_y^{-1} R_y \]  
\[ R_y = CR_y C^* + \sigma_v^2 I_{N+1} \]  

\( R_s \) is the autocorrelation of the input constellation signal, \( \sigma_v \) is the variance of the additive white Gaussian noise and \( R_y \) is a banded matrix obtained from \( C^* \), where \( C^* \) denotes conjugate transpose of \( C \).

**4. Results**

The Zheng model is chosen for modeling the time varying channel. A Kalman filter to estimate the time varying channel and a DFE to equalize it are used in reception. The simulation is performed considering several normalized Doppler shifts.

First results are given in figure 1. They illustrate the degradation of the performances of unequalized 16QAM OFDM in the Zheng model. BER performances are given as a function of signal-to-noise ratios in the case of different mobile velocities depicted as normalized fading rate \( f = f_d^* T_s \). We can observe that BER increases with the Doppler spread due to the existence of severe ICI caused by Doppler shifts.

![Figure 1. Unequalized 16QAM OFDM performances over time varying channel.](image-url)
5. Conclusion

This paper proposes the use of DFE based Kalman estimation for channel equalization and ICI mitigation in a 16-QAM OFDM system over time varying channel. Simulations were performed in a new improved Jakes’ model called Zheng model, considering several mobile velocities. Results show that DFE based Kalman channel estimation is able to reduce the performance degradation due to ICI. Combining this technique and iterative processing in the decoding stage of the system will be the next step of our work.

6. References


