Four time windows averaging channel estimation with real and imaginary TFI pilot signals for OFDM

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Abstract: In orthogonal frequency division multiplexing (OFDM) systems, the pilot signal is inserted to obtain the channel state information (CSI). The time frequency interferometry (TFI) method reduces the number of pilot signals by using the real and null signals and obtains the accurate CSI by averaging the two time windows. On the other hand, many averaging operations are necessary to obtain more accurate CSI. Before now, we have proposed the pilot signal based on the imaginary and null signals. By using these characteristics, in this letter, we propose the real and imaginary TFI pilot signals to obtain the CSI from the four time windows averaging for OFDM systems.

Keywords: OFDM, channel estimation, real and imaginary TFI pilot signals

Classification: Wireless Communication Technologies

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1 Introduction

In the typical techniques with the orthogonally, orthogonal frequency division multiplexing (OFDM) is studied widely [1, 2]. OFDM achieves high capacity transmissions by using multicarrier systems and has been adopted in many standards such as wireless local area network (WLAN), digital broadcasting, and mobile communication systems. In OFDM systems, channel estimation is important to equalize the received signal. These operations should obtain the channel state information (CSI). In general, the pilot signal is inserted to obtain the CSI [3, 4]. Moreover, many pilot signals achieve more accurate CSI by using the averaging operation. On the other hand, they degrade the transmission rate since they consist of the long packet. To solve this problem, the pilot signal based on the time frequency interferometry (TFI) method has been proposed [5, 6]. The TFI method consist of the pilot signal from “1” and “0” in the frequency domain. As a result, the TFI method reduces the number of pilot signals and prevents the expanding of the packet. Moreover, since the TFI method achieves the averaging operation by using the two time windows in the time domain, it improves the accuracy of the CSI. For the averaging operation, the accuracy of the CSI is improved by using several time windows. Before now, we have proposed the pilot signal based on “1” and “0”, “0” and “j”, where j is an imaginary signal [7]. By using these characteristics, in this letter, we propose the real and imaginary TFI pilot signals to obtain the CSI from the four time windows averaging for OFDM systems.

2 Channel model

For the channel model, we assume the L discrete paths propagation channel with the different delay time. In this case, the channel impulse response is obtained as

$$h(\tau) = \sum_{l=0}^{L-1} h_l \delta(\tau - \tau_l),$$

(1)

where $h_l$ and $\tau_l$ are the complex channel gain and the delay time of the lth propagation path with $\sum_{l=0}^{L-1} E|h_l|^2 = 1$, and $E[\cdot]$ is the ensemble average operation. After the fast Fourier transform (FFT) operation, the channel response is given by

$$H(k) = \sum_{l=0}^{L-1} h_l \exp(-j2\pi k \tau_l).$$

(2)
3 Real and imaginary TFI pilot signals

3.1 Transmitter

Fig. 1 shows the block diagram of the proposed system. At the transmitter, OFDM signal is generated and \( N_p \) pilot symbols are inserted to estimate the channel state as shown in Fig. 1(a). Fig. 2 shows the concept of the orthogonal, and the conventional and proposed TFI pilot signals. As shown in Fig. 2(a), the pilot signal based on the orthogonal signal consists of all “1” in the frequency domain. After the IFFT operation, the orthogonal pilot signal outputs the one channel impulse response in \( t = 0 \) as shown in Fig. 2(b). On the other hand, the conventional TFI pilot signal for the \( k \)th subcarrier and the \( i \)th symbol consists of “1” and “0” as

\[
d(k, i) = \frac{\exp(-j2\pi k) + \exp(-j4\pi k\varepsilon)}{2},
\]

where \( \varepsilon = N_g/N_c, N_c \) is the number of subcarriers, and \( N_g \) is the guard interval (GI) length. In this letter, we assume \( \varepsilon = 1/4 \). Observing Eq. (3), as shown in Fig. 2(c), \{\( d(k, i) \}\} is output as \( \{1, 0, \cdots, 1, 0\} \). After the IFFT operation, as shown in Fig. 2(d), Eq. (3) outputs the two channel impulse responses in \( t = 0 \) and \( 2N_g \). Next, the proposed TFI pilot signal for the \( k \)th subcarrier and the \( i \)th symbol consists of “1” and “j” as

\[
d(k, i) = \begin{cases} 
\frac{\exp(-j2\pi k) + \exp(-j4\pi k\varepsilon)}{2} & \text{for } \text{mod}(k, 2) = 0 \\
\frac{-\exp(-j2\pi k) + \exp(-j6\pi k\varepsilon)}{2} & \text{for } \text{mod}(k, 2) = 1.
\end{cases}
\]

Observing Eq. (4), as shown in Fig. 2(e), \{\( d(k, i) \}\} is output as \( \{1, j, 1, -j, \cdots, 1, j, 1, -j\} \). After the IFFT operation, as shown in Fig. 2(f), Eq. (4) outputs the four channel impulse responses in \( t = 0, N_g, 2N_g, \) and \( 3N_g \). Here, in this letter, we assume \( N_g \geq \tau_{L-1} \) and the proposed TFI method has the \( N_g \) time interval to prevent the inter-symbol interference (ISI) and the inter-carrier interference (ICI), where \( \tau_{L-1} \) is the maximum delay spread.

3.2 Receiver

At the receiver, as shown in Fig. 1(b), the time domain received pilot signal is given after separating from the received OFDM signal as
where $P$ is the pilot symbol power, $w(t)$ is additive white Gaussian noise (AWGN), and $\sqrt{2P/N_c}$ means the normalized power for the pilot signal. As shown in Fig. 2(g), the orthogonal pilot signal outputs the $L$ channel impulse responses in $[0, N_g - 1]$. On the other hand, as shown in Fig. 2(h), the conventional TFI pilot signal outputs the $2L$ channel impulse responses. In this case, $\zeta(t)$ for Eq. (5) is defined as

$$\zeta(t) = \delta(t - t_l) + \delta(t - t_l - 2N_g).$$

Observing Eqs. (5) and (6), the conventional TFI pilot signal averages the $L$ channel impulse responses in $[0, N_g - 1]$ and $[2N_g, 3N_g - 1]$. Here, the amplitude of these channel impulse responses is half of the orthogonal pilot signal. Therefore, the conventional TFI pilot signal obtains the same channel impulse responses as the orthogonal pilot signal by using the averaging operation. Moreover, since the averaging operation adapts the channel impulse response between the different time windows, the conventional TFI pilot signal is reduced from the noise variance $\sigma_n^2$ for the orthogonal pilot signal to $\sigma_n^2/2$ by averaging the two time windows. Next, as shown in Fig. 2(i), the proposed TFI pilot signal outputs the $4L$ channel impulse responses. In this case, $\zeta(t)$ for Eq. (5) is defined as

$$\zeta(t) = \frac{\delta(t - t_l) - \delta(t - t_l - N_g) + \delta(t - t_l - 2N_g) + \delta(t - t_l - 3N_g)}{2}.$$
TFI pilot signal. Moreover, the proposed TFI pilot signal is reduced from the noise variance $\sigma_n^2$ to $\sigma_n^2/4$ by averaging the four time windows. Therefore, the proposed TFI pilot signal obtains more accurate CSI compared with the orthogonal and conventional TFI pilot signals. After the FFT operation, the channel response is obtained from Eq. (5) and the received OFDM signal is equalized and demodulated as shown in Fig. 1(b).

### 4 Computer simulation results

In this section, we evaluate the system performance of the proposed method by using the computer simulation. As shown in Fig. 1, at the transmitter, the original data signal is coded by the convolutional code for the rate $1/2$ and the constraint length 7 with the interleaving. After the serial to parallel (S/P) conversion, the parallel signal is modulated for a quadrature phase shift keying (QPSK) and the pilot signal is inserted. The time domain signal is generated by the IFFT operation and GI is inserted. The time domain signal is transmitted to the receiver. In a propagation channel, we assume that the symbol duration is 10 $\mu$s, the GI length is 2 $\mu$s, and the path model is a 15 paths Rayleigh fading at Doppler frequency of 5 Hz. At the receiver, GI is eliminated after the S/P conversion. By the FFT operation, the time domain signal is converted to the frequency domain signal and is detected by the zero-forcing (ZF) equalization. The detected signal is demodulated for a QPSK and is decoded by the Viterbi soft decoding algorithm. The packet consists of $N_c = 64$ subcarriers, $N_d = 20$ data symbols, and $N_p = 1$ or 2 pilot symbols. For Fig. 3, “Ortho.$(N_p = 1)$” and “Ortho.$(N_p = 2)$” are the conventional methods based on the orthogonal pilot signal for $N_p = 1$ and 2, respectively. Moreover, “Con. TFI” and “Pro. TFI” is the conventional and proposed TFI methods for $N_p = 1$.

#### 4.1 MSE performance

Fig. 3(a) shows the mean square error (MSE) versus $E_b/N_0$ for the conventional and proposed methods. The MSE between the ideal and estimated channel responses is defined as

![Fig. 3. MSE and BER versus $E_b/N_0$.](image-url)
\[ E_{mse} = \frac{1}{N_c} \sum_{k=0}^{N_c-1} \frac{|H(k) - \tilde{H}(k)|^2}{|H(k)|^2}, \]  
where \( H(k) \) and \( \tilde{H}(k) \) are the ideal and estimated channel responses, respectively. In MSE = -10 dB, the conventional method based on the orthogonal pilot for \( N_p = 2 \) shows about 3.5 dB gain compared with \( N_p = 1 \). This is because the conventional method based on the orthogonal pilot for \( N_p = 2 \) mitigates the noise influence by averaging the two pilot symbols. The conventional TFI method shows about 2 dB gain compared with the conventional method based on the orthogonal pilot for \( N_p = 2 \). This is because the conventional TFI method mitigates the noise influence by averaging the two time windows and reduces the transmission and noise power by inserting the null signal. Moreover, the proposed TFI method shows about 2 dB gain compared with the conventional TFI method. This means that the four time windows averaging for the proposed TFI method is effective compared with the two time windows averaging for the conventional TFI method.

4.2 BER performance

Fig. 3(b) shows the bit error rate (BER) versus \( E_b/N_0 \) for the conventional and proposed methods. In BER = \( 1 \times 10^{-5} \), the conventional method based on the orthogonal pilot for \( N_p = 2 \) shows about 2 dB gain compared with \( N_p = 1 \). The conventional TFI method shows about 1 dB gain compared with the conventional method based on the orthogonal pilot for \( N_p = 2 \). Moreover, the proposed TFI method shows about 1 dB gain compared with the conventional TFI method. These results are the same reason as the MSE case and mean that the proposed method is also effective in the BER case.

5 Conclusion

In this letter, we have proposed the real and imaginary TFI pilot signals to obtain the CSI from the four time windows averaging for OFDM systems. The proposed method consists of the pilot signal based on the real and imaginary signals and achieves the averaging operation by using the four time windows. From the computer simulation results, the proposed method has shown the best MSE and BER performances compared with the conventional method based on the orthogonal and TFI pilot signals.

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