Performance Enhancement of TFI-OFDM with Path Selection based Channel Identification

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Abstract: Recently time-frequency interferometry (TFI)-OFDM has been proposed as a channel identification scheme. TFI-OFDM system can multiplex the same impulse response in twice on the time domain without overlapping to each other. In this case, the required pilot signal is only one. Moreover, by averaging of these impulse responses, the accurate channel impulse responses are obtained. However, if the total channel paths are reduced, the performance might be degraded. This is because the channel identification of TFI-OFDM is operated with averaging the selected spectrum signals from the time windows. For the case with reduced channel paths, the selected time spectrum signals include the noise terms. By applying the FFT operation, these noise terms are spread in the frequency domain. In this case, the channel identification is poorly operated due to the noise. To reduce this problem, in the paper, we propose the channel identification method with path selection for performance enhancement of TFI-OFDM.

1. Introduction

In the present and future mobile communication systems, transmission at higher rates is becoming essential for many services such as video and high quality audio. At a high bit rate, the channel impulse response of a mobile radio channel can extend over many symbol periods and yields severe inter symbol interference (ISI). Orthogonal frequency division multiplexing (OFDM) is one of effective techniques to mitigate ISI. In OFDM, we avoid ISI by increasing the number of subcarriers and hence by reducing the bandwidth constant [1], [2]. Moreover, OFDM has been chosen for several broadband WLAN standards like IEEE802.11a, IEEE802.11g and European HIPERLAN/2, and terrestrial digital audio broadcasting (DAB) and digital video broadcasting (DVB) was also proposed for broadband wireless multiple access systems such as IEEE802.16 wireless MAN standard and interactive DVB-T [3], [4].

In OFDM systems, the pilot signal averaging channel estimation is generally used to identify the channel state information (CSI) [5]. In this case, large pilot symbols are required to obtain an accurate CSI. As a result, the total transmission rate is degraded due to transmission of large pilot symbols. To overcome this problem, time-frequency interferometry (TFI)-OFDM has been proposed [6]. TFI-OFDM system can multiplex the same impulse response in twice on the time domain without overlapping to each other. In this case, the required pilot signal is only one. It means that TFI-OFDM can increase the total transmission rate since the pilot signal does not carry any information. Moreover, by averaging of these impulse responses, the accurate channel impulse responses are obtained. In general, since OFDM system used a wideband spectrum, the total channel paths are increased with comparison of the single carrier system. However, if the total channel paths are reduced, the performance might be degraded. This is because TFI-OFDM system based on two time windows. The channel identification of TFI-OFDM is operated with averaging the selected spectrum signals from the time windows. For the case with reduced channel paths, the selected time spectrum signals include the noise terms. By applying the FFT operation, these noise terms are spread in the frequency domain. From this reason, the performance of TFI-OFDM system would be degraded with the reduced channel paths. To reduce this problem, in the paper, we propose the channel identification method with path selection for performance enhancement of TFI-OFDM. This paper is organized as follows. The system model is described in section 2. In section 3, we show the computer simulation results. Finally, the conclusion is given in section 4.

2. System Model

This section describes the proposed system, which employs time division multiplexing (TDM) transmission for multiple users. The proposed system is illustrated in Fig.1

2.1 Channel Model

We assume that a propagation channel consists of L discrete paths with different time delays. The impulse response \( h(\tau, t) \) is represented as

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

(1)

where \( h_l \) and \( \tau_l \) are the complex channel gain and the time delay of the \( l \)th propagation path, respectively, and \( \sum_{l=0}^{L-1} E[|h_l|^2] = 1 \), where \( E[ \cdot ] \) denotes the ensemble average operation. The channel transfer function \( H(f, t) \) is the Fourier transform of \( h(\tau, t) \) and is given by
\[ H(f,t) = \int_0^\infty h(t,\tau) \exp(-j2\pi f \tau) d\tau = \sum_{i=0}^{\infty} c_{iPN}(k) d(k,i), \]

where \( N_d \) and \( N_p \) are the number of data and pilot symbols, \( N_c \) is the number of carriers, \( T_s \) is the effective symbol length, \( S \) is the average transmitting power, \( T \) is the OFDM symbol length, respectively. The frequency separation between adjacent orthogonal subcarriers is \( 1/T_s \) and can be expressed, by using the \( k \)th subcarrier of the \( i \)th modulated symbol \( d(k,i) \) with \( |d(k,i)| = 1 \) for \( N_p \leq i \leq N_p + N_d - 1 \), as

\[ u(k,i) = c_{iPN}(k) d(k,i), \]

where \( c_{iPN} \) is a long pseudo-noise (PN) sequence as a scrambling code to reduce the peak average power ratio (PAPR). The guard interval \( T_g \) is inserted in order to eliminate intersymbol interference (ISI) due to the multipath fading, and hence, we have

\[ T = T_s + T_g. \]

In OFDM systems, \( T_g \) is generally considered as \( T_s/4 \) or \( T_s/5 \). Thus, we assume \( T_g = T_s/4 \) in this paper. In Eq. (3), \( g(t) \) is the transmission pulse given by

\[ g(t) = \begin{cases} 1 & \text{for } -T_g \leq t \leq T_s \\ 0 & \text{otherwise} \end{cases} \]

For \( 0 \leq i \leq N_p - 1 \), the transmitted pilot signal of \( k \)th sub-carrier is given by

\[ d(k,i) = \exp(-j2\pi k/T_s) + \exp(-j\pi k T_s/T_s) \]

where \( N_p \) is the number of pilot symbols. In this case, pilot signal of the proposed system can multiplex the same impulse responses in twice on the time domain without overlapping to each other as shown in Fig. 2(a). Moreover, due to the superposition of Eq. (7), the transmission power of pilot signals is \( 1/2 \) for \( 0 \leq i \leq N_p - 1 \). The receiver structure is illustrated in Fig. 1(b). By applying the FFT operation, the received signal \( r(t) \) is resolved into \( N_c \) subcarriers. The received signal \( r(t) \) in the equivalent baseband representation can be expressed as

\[ r(t) = \int_0^\infty h(t,\tau) \exp(-j2\pi \tau) d\tau + n(t), \]

where \( n(t) \) is additive white Gaussian noise (AWGN) with a single sided power spectral density of \( N_0 \). The \( k \)th subcarrier \( \tilde{r}(k,i) \) is given by
Figure 3. Path Selection.

\[
\hat{H}(k) = \sqrt{\frac{1}{N_c}} \sum_{i=0}^{N_c-1} h_i(t+iT) \delta(t-iT) + \tilde{n}(t) + \eta(t),
\]

where \( \eta(t) \) is AWGN component.

### 2.4 Proposed Channel Estimation Scheme

In the conventional TFI-OFDM system, if the total channel paths are reduced, the selected time spectrum signals include the noise terms. For case with conventional channel estimation, by FFT operation, these noise terms are spread in the frequency domain. In this case, the channel identification is poorly operated due to the noise. To reduce this problem, we proposed the channel identification method with path selection by considering the noise power as a threshold \( \xi \). By using the threshold \( \xi \), path selection is operated by

\[
h_i(t+iT) = \begin{cases} 
  h_i(t+iT) & |h_i(t+iT)|^2 > |\xi|^2 \\
  0 & \text{otherwise}
\end{cases}
\]

From Eq. (14), Eq. (12) can be rewritten as

\[
r(t) = \sum_{i=0}^{N_c-1} h_i(t+iT) + \tilde{n}(t).
\]

Where \( L' \) is the number of selected paths. In the path selection, high power signals are selected as shown in Fig. 3. Unselected paths are replaced with null signals. When Eq. (15) is converted to frequency response by Fourier transformation, the impulse response of kth subcarrier \( \hat{H}(k) \) is obtained by

\[
\hat{H}(k) = \sqrt{\frac{1}{N_c}} \sum_{i=0}^{N_c-1} h_i(t+iT) \delta(t-iT) + \tilde{n}(t) + \eta(k),
\]

For \( L' \) selected paths, the ensemble average of \( \bar{\eta}(k) \) is represented as

\[
E[|\eta(k)|^2] = E[\frac{1}{L'} \sum_{k=0}^{L'-1} |\eta(k)|^2] = \frac{\bar{\eta}(k)^2}{L'}. \tag{17}
\]

where \( \sigma^2 \) is the variance of noise, \( 0 < m \leq L' \). For example, the case with \( L' = 8 \) and \( N_c = 64 \),

\[
E[|\eta(k)|^2] = E[\frac{1}{L'} \sum_{k=0}^{L'-1} |\eta(k)|^2] = \frac{\eta^2}{L'}. \tag{18}
\]

Observing Eq. (18), we can reduce the total noise power as half of TFI-OFDM.

### 3. Computer Simulated Results

In this section, the performance of the proposed system is compared with the pilot signal averaging based OFDM and the conventional TFI-OFDM. Fig. 1 shows a simulation model of the proposed system. On the transmitter, the pilot signals are assigned for each transmitter using Eq. (7). In this case, the proposed system can multiplex the same impulse responses in the receive antenna in twice on the time domain without overlapping to each other as shown in Fig. 2(a). The data stream is encoded. Here convolution codes (rate \( R = 1/2 \), constraint length \( \kappa = 7 \)) with bit interleaving are used. The coded bits are QPSK modulation, and then the pilot signal and data signal are multiplexed with scrambling using PN code to reduce the PAPR. The OFDM time signals are generated by an IFFT and transmitted to the frequency selective and time variant radio channel after cyclic extensions have been inserted. The transmitted signals are subject to broadband channel propagation. In the simulation, we assume that OFDM symbol period is 8\( \mu \)s, guard interval is 2\( \mu \)s, and a path separation \( t_{path} = 125 \)ns. Table 1 shows the channel model [7]. In this simulation we used the modified vehicular A, pedestrian A and B, pyramid channel models. Moreover, we didn’t consider the vehicular B model, since its delay spread is longer than the guard interval. The maximum Dopper frequency is assumed to be 5 Hz.

In the receiver, the guard interval is erased from the received signals and the received signals are S/P converted. The parallel sequences are passed to an FFT operator, which

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<th>Table 1. Channel Model</th>
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<tr>
<td><strong>Path</strong></td>
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<tr>
<td><strong>Delay Time (\mu s)</strong></td>
</tr>
<tr>
<td>1</td>
</tr>
<tr>
<td>2</td>
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<td>3</td>
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<td>4</td>
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<td>5</td>
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<td><strong>Total</strong></td>
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<th>Table 2. Simulation parameters</th>
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<tr>
<td><strong>Data Modulation</strong></td>
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<tr>
<td><strong>Data detection</strong></td>
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<tr>
<td><strong>Symbol duration</strong></td>
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<td><strong>Frame size</strong></td>
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<td><strong>FFT size</strong></td>
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<tr>
<td><strong>Number of carriers</strong></td>
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<td><strong>Guard interval</strong></td>
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<td><strong>Doppler frequency</strong></td>
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<td><strong>FEC</strong></td>
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<td><strong>Channel model</strong></td>
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converts the signal back to the frequency domain. After
descrambling and IFFT, each impulse response can be estimated
by path searching, extracting and averaging twice impulse re-
sponse using the time window with Eq. (16) as shown in Fig.
3. The frequency domain data signal is detected and demod-
ulated using the estimated channel impulse response. After
detection, bits are detected by the Viterbi soft decoding algo-
rithm. The packet consists of $N_p = 1$ pilot symbol and $N_d = 20$ data symbols. Table 2 shows the simulation parameter.

Fig. 4 shows the BER of the conventional pilot aver-
aging based OFDM, TFI-OFDM, and the proposed system
at Doppler frequency of 5 Hz under the pedestrian channel
model A and B. In both channel models, the proposed sys-
tem achieves 1dB gain compared with the conventional TFI-
OFDM. This is because the amount of removed noise is al-
most same for both channel models. Therefore the perfor-
mance gains are almost same for both channel models. More-
over, the BER of pedestrian B is better than that of pedestrian
A. The relation between the RMS delay spread ($\tau$) and the
coherence bandwidth ($B_c$) is given by $B_c \approx 1/50 \tau$. For a
long delay spread, the channel response between subcarriers
that interleaved, shows to be totally different. From this rea-
son, we can expect the frequency diversity with FEC and in-
terleaving. The pedestrian B shows a long delay spread com-
pared with the pedestrian A. Therefore the pedestrian B shows
better BER than the pedestrian A.

Fig. 5 shows the BER of the conventional pilot signal aver-
aging based OFDM, TFI-OFDM, and the proposed system
at Doppler frequency of 5 Hz under the vehicular channel
model A and pyramid model. In both channel models, the proposed sys-
tem achieves 1dB gain compared with the conventional TFI-
OFDM. On the other hand, the BER of the proposed system under the pyramid model achieves a little
gain. This is because the amount of removed noise in vehic-
ular channel A model is larger than that of the pyramid chan-
nel model. As the same reason of Fig. 4, the pyramid model
shows better BER than the vehicular A.

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is poorly operated due to the noise. To reduce this prob-
lem, in the paper, we have proposed the channel identifica-
tion method with path selection. From the simulation results,
the BER of the proposed system achieves 1dB gain compared
with TFI-OFDM in the pedestrian channels. The BER of the
proposed system under the vehicular channel model can be
improved compared with the pyramid model.

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