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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 accurated 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 sever 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 accurated 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 . In section , we show the computer simulation results. Finally, the conclusion is given in section .

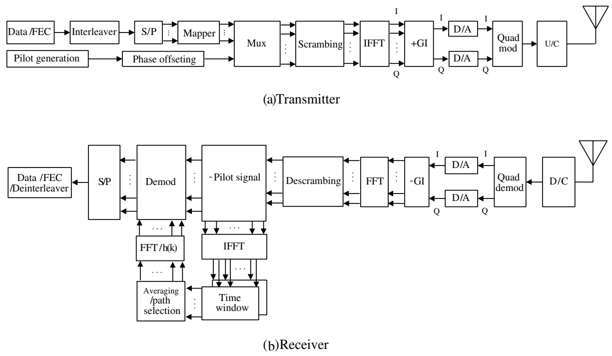

Figure 1. The proposed system.

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

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

where h_l and τ_l are the complex channel gain and the time delay of the lth 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

$$\begin{aligned} H(f,t) &= \int_0^{\infty} h(\tau,t)\exp(-j2\pi f\tau)d\tau \\ &= \sum_{l=0}^{L-1} h_l(t)\exp(-j2\pi f\tau_l). \end{aligned} \quad (2)$$

2.2 Transmitter and Receiver Structure

The transmitter block diagram of the proposed system is shown in Fig. 1(a). Firstly, the coded binary information data sequence is modulated, and N_p pilot symbols are appended at the beginning of the sequence. The proposed system transmit signal can be expressed in its equivalent baseband representation as

$$s(t)=\sum_{i=0}^{N_p+N_d-1} g(t-iT)\cdot\left\{\sqrt{\frac{2S}{N_c}}\sum_{k=0}^{N_c-1} u(k,i) \cdot\exp[j2\pi(t-iT)k/T_s]\right\}, \quad (3)$$

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 kth subcarrier of the ith modulated symbol $d(k,i)$ with $|d(k,i)| = 1$ for $N_p \leq i \leq N_p + N_d - 1$, as

$$u(k,i)=c_{PN}(k)\cdot d(k,i), \quad (4)$$

where c_{PN} 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 inter-symbol interference (ISI) due to the multipath fading, and hence, we have

$$T=T_s+T_g. \quad (5)$$

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

$$g(t)=\begin{cases} 1 & \text{for } -T_g \leq t \leq T_s \\ 0 & \text{otherwise} \end{cases} \quad (6)$$

For $0 \leq i \leq N_p - 1$, the transmitted pilot signal of kth subcarrier is given by

$$d(k,i)=\exp(-j2\pi k/T_s)+\exp(-j4\pi kT_g/T_s) \quad (7)$$

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

$$r(t)=\int_{-\infty}^{\infty} h(\tau,t)s(t-\tau)d\tau+n(t), \quad (8)$$

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

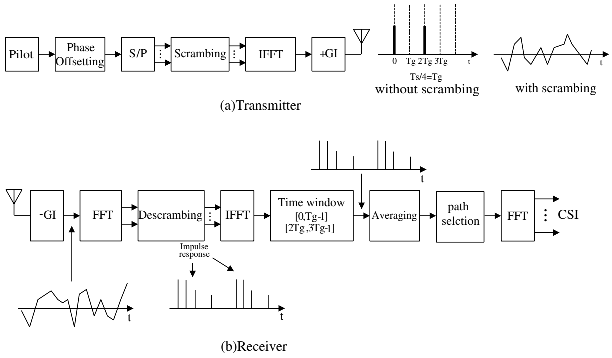

Figure 2. The concept of TFI-OFDM system.

$$\begin{aligned} \tilde{r}(k,i) &= \frac{1}{T_s}\int_{iT}^{iT+T_s} r(t)\exp[-j2\pi(t-iT)k/T_s]dt \\ &= \sqrt{\frac{2S}{N_c}}\sum_{e=0}^{N_c-1} u(e,i)\cdot\frac{1}{T_s}\int_0^{T_s}\exp[j2\pi \\ &\quad \cdot(e-k)t/T_s]\cdot\left\{\int_{-\infty}^{\infty} h(\tau,t+iT)g(t-\tau) \right. \\ &\quad \left. \cdot\exp(-2\pi e\tau/T_s)d\tau\right\}dt+\hat{n}(k,i), \end{aligned} \quad (9)$$

where $\hat{n}(k,i)$ is AWGN noise with zero-mean and a variance of $2N_0/T_s$. After abbreviation [5], Eq. (9) can be rewritten as

$$\begin{aligned} \tilde{r}(k,i) &\approx \frac{1}{T_s}\sqrt{\frac{2S}{N_c}}\sum_{e=0}^{N_c-1} u(e,i)\cdot\int_0^{T_s}\exp[j2\pi \\ &\quad \cdot(e-k)t/T_s]\cdot\left\{\int_{-\infty}^{\infty} h(\tau,t+iT) \right. \\ &\quad \left. \cdot g(t-\tau)\exp(-2\pi e\tau/T_s)d\tau\right\}dt+\hat{n}(k,i) \\ &= \sqrt{\frac{2S}{N_c}}H(k/T_s,iT)u(k,i)+\hat{n}(k,i). \end{aligned} \quad (10)$$

After scrambling, the output signal $r(k,i)$ is given by

$$\begin{aligned} r(k,i) &= \frac{c^*_{PN}(k)}{|c_{PN}(k)|^2}\left\{\tilde{r}(k,i)\right\}, \\ &= \sqrt{\frac{2S}{N_c}}H(k/T_s,iT)d(k,i)+\hat{n}(k,i), \end{aligned} \quad (11)$$

where $\frac{c^*_{PN}(k)}{|c_{PN}(k)|^2}$ is the descrambling operation.

2.3 Conventional Channel Estimation Scheme

Since $T_g = T_s/4$, the same impulse responses can be multiplexed in twice on the time domain. After the pilot signal separation, the pilot signal is converted to the time domain signal $\hat{r}(t)$ again as

$$\begin{aligned} \hat{r}(t) &= \sum_{i=0}^{N_p-1}\sqrt{\frac{2P}{N_c}}\sum_{k=0}^{N_c-1} r(k,i)\exp[j2\pi(t-iT)k/T_s] \\ &= \sum_{i=0}^{N_p-1}\sqrt{\frac{2P}{N_c}}h(\tau,t+iT)\sum_{k=0}^{N_c-1} d(k,i) \\ &\quad \cdot\exp[j2\pi(t-iT)k/T_s]+\tilde{n}(t) \\ &= \sum_{i=0}^{N_p-1}\sqrt{\frac{2P}{N_c}}\sum_{l=0}^{L-1} h_l(t+iT) \\ &\quad \cdot\frac{1}{\sqrt{2}}\left\{\delta(\tau-\tau_l)+\delta(\tau-\tau_l-2T_g)\right\}+\tilde{n}(t), \end{aligned} \quad (12)$$

where P is the power of pilot signals. The converted time domain signal $\hat{r}(t)$ is shown in Fig. 2(b). From Eq. (7), $\sum_{k=0}^{N_c-1} d(k,i)\exp\left[j2\pi(t-iT)k/T_s\right]$ shows two impulses with time shift as $\delta(\tau-2T_g)$, and the output signals are equivalent to time domain multiplexed impulse responses. By averaging of these impulse responses, the noise power can be reduced. Therefore, the impulse response of kth subcarrier $\tilde{H}(k)$ is obtained by

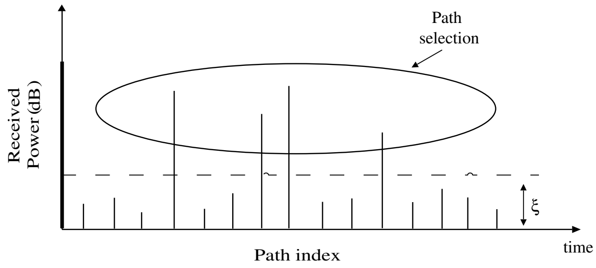

Figure 3. Path Selection.

$$\tilde{H}(k) = \frac{1}{\sqrt{P/N_c}} \sum_{e=0}^{N_c-1} \frac{1}{T_s} \int_0^{T_s} \Big\{ \sum_{l=0}^{L-1} h_l(t+iT) \Big\{ \delta(\tau-\tau_l)+\delta(\tau-\tau_l-2T_g) \Big\} \cdot \exp(-2\pi e\tau/T_s)d\tau \Big\} dt+\eta(k), \quad (13)$$

where $\eta(k)$ 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 fequency 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 ξ. By using the threshold ξ, path selection is operated by

$$\hat{h}(t+iT) = \begin{cases} h(t+iT) & |h(t+iT)|^2 > |\xi|^2 \\ 0 & \text{otherwise .} \end{cases} \quad (14)$$

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

$$\dot{r}(t) = \sum_{i=0}^{N_p-1} \sqrt{\frac{2P}{N_c}} \sum_{l=0}^{L'-1} \hat{h}_l(t+iT) \cdot \frac{1}{\sqrt{2}} \Big\{ \delta(\tau-\tau_l)+\delta(\tau-\tau_l-2T_g) \Big\} + \dot{n}(t), \quad (15)$$

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 $\dot{H}(k)$ is obtained by

Table 1. Channel Model.

Tap	Vehicular A		Pyramid		Pedestrian Channel A		Pedestrian Channel B	
	Delay Time (sample time)	Average Power (dB)	Delay Time (sample time)	Average Power (dB)	Delay Time (sample time)	Average Power (dB)	Delay Time (sample time)	Average Power (dB)
1	0	0	0	-3	0	0	0	0
2	3	-1	1	0	1	-9.7	2	-0.9
3	6	-9	2	-3	2	-19.2	6	-4.7
4	9	-10	4	-3	4	-22.8	10	-8
5			5	0			16	-7.8
6			6	-3				
7			8	-3				
8			9	0				
9			10	-3				
10			12	-3				
11			13	0				
12			14	-3				
Total Paths	4		12		4		5	

$$\dot{H}(k) = \frac{1}{\sqrt{P/N_c}} \sum_{e=0}^{N_c-1} \frac{1}{T_s} \int_0^{T_s} \Big\{ \sum_{l=0}^{L'-1} \hat{h}_l(t+iT) \Big\{ \delta(\tau-\tau_l)+\delta(\tau-\tau_l-2T_g) \Big\} \cdot \exp(-2\pi e\tau/T_s)d\tau \Big\} dt+\bar{\eta}(k). \quad (16)$$

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

$$E[|\bar{\eta}(k)|]^2 = E[|\frac{2L' \cdot \tilde{n}(k,i)}{N_c}|]^2 = \frac{2L' \cdot \sigma^2}{N_c}, \quad (17)$$

where σ^2 is the variance of noise, $0 < m \leq T_g$. For example, the cace with $L' = 8$ and $N_c = 64$,

$$E[|\bar{\eta}(k)|]^2 = E[|\frac{16 \cdot \tilde{n}(k,i)}{64}|]^2 = \frac{\sigma^2}{4}. \quad (18)$$

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 κ=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 8μs, guard interval is 2μs, and a path separation t_{path} = 125ns. 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

Table 2. Simulation parameters.

Data Modulation	QPSK
Data detection	Coherent
Symbol duration	8μs
Frame size	21 Symbols ($N_p = 1, N_d = 20$)
FFT size	64
Number of carriers	64
Guard interval	16 sample times
Doppler frequency	5 Hz
FEC	Convolutional code (R=1/2,κ=7)
Channel model	pedestrina A,B vehicular A, pyramid

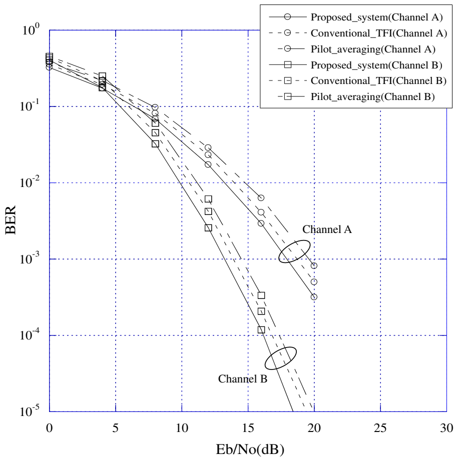

Figure 4. Pedestrian channel models.

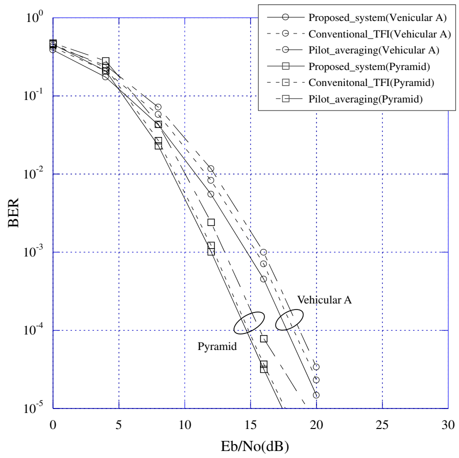

Figure 5. Vehicular and Pyramid models.

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 responsed using the time window with Eq. (16) as shown in Fig. 3. The frequency domain data signal is detected and demodulated using the estimated channel impulse response. After detection, bits are detected by the Vitebi soft decoding algorithm. 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 averaging 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 system achieves 1dB gain compared with the conventional TFI-OFDM. This is because the amount of removed noise is almost same for both channel models. Therefore the performance gains are almost same for both channel models. Moreover, the BER of pedestrian B is better than that of pedestrian A. The relation between the RMS delay spread (τ) and the coherence bandwidth (Bc) is given by Bc $\approx$ 1/50 τ. For a long delay spread, the channel response between subcarriers that interleaved, shows to be totally different. From this reason, we can expect the frequency diversity with FEC and interleaving. The pedestrian B shows a long delay spread compared 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 averaging based OFDM, TFI-OFDM, and the proposed system at Doppler frequency of 5 Hz under the vehicular channel model A and pyramid model. In the vehicular channel model A, the proposed system 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 vehicular channel A model is larger than that of the pyramid channel model. As the same reason of Fig. 4, the pyramid model shows better BER than the vehicular A.

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4. conclusion

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, these noise terms are spread in the fequency domain by FFT operation. In this case, the channel identification is poorly operated due to the noise. To reduce this problem, in the paper, we have proposed the channel identification 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.

References

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