Proceedings of **ITC-CSCC 2000**, Pusan, Korea

A New Polarization Diversity Scheme for Orthogonal Polarization and Frequency Division Multiplexing System

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Abstract: This paper proposes a new polarization diversity scheme for OPFDM (Orthogonal Polarization and Frequency Division Multiplexing). OPFDM is an extension of OFDM (Orthogonal Frequency Division Multiplexing) in conjunction with polarization multiplexing in order to ensure the orthogonality amongst subcarriers. Since OPFDM uses two orthogonally polarized channels, it can easily employ the polarization diversity. In order to get the diversity gain effectively in a frequency selective fading channel, the proposed scheme combines the signals in subcarrier-by-subcarrier basis. The computer simulation results confirm that the proposed scheme is superior to conventional one in the two orthogonally polarized two-ray Rayleigh fading channels with cross-talk between the two channels.

1. Introduction

Orthogonal Frequency Division Multiplexing (OFDM) is an efficient technique capable of establishing high speed digital transmission over severe multipath fading channel. Recently OFDM has widely been studied for digital audio and television broadcasting and in the context of wireless local area networks [1]-[3]. Although OFDM is robust to frequency selectivity of the channel, it is sensitive to the frequency offset between the transmitter and receiver since the frequency span amongst sub-carriers is very small. The inter-channel interference (ICI) caused by the frequency offset degrades the bit error rate (BER) performance of the system.

In order to mitigate the performance degradation due to frequency offset, the authors have proposed a modification of the OFDM scheme, which uses the polarization multiplexing [4][5]. In the proposed scheme, a part of the OFDM signal, which corresponds to the even numbered subcarriers, and the remaining signal, namely, the odd numbered subcarriers, are transmitted using two orthogonally polarized radio waves. Since the adjacent subcarriers are transmitted over the differently polarized channels, the proposed scheme can reduce ICI. Also, the signal structure of the proposed system allows us to estimate and compensate for the frequency offset more effectively than the conventional OFDM. Furthermore, the polarization diversity techniques can easily be applied to the proposed scheme in order to improve the BER performance. In the following, we refer to this scheme as the orthogonal polarization and frequency division multiplexing (OPFDM).

In reference [5], we have proposed an OPFDM with the polarization diversity technique in order to improve further the BER performance. The proposed scheme calculated its diversity weight factors by observing the received signal power of the differently polarized radio waves. Although the diversity scheme improved the BER performance, the improvement was reduced as the frequency selectivity of the channel grows. This is because the diversity weight factors employed in this scheme were no longer optimum for all the subcarriers.

In order to overcome this problem, we propose a new polarization diversity scheme for OPFDM, which separately calculates the maximal ratio combining diversity weight factors for all the sub-carriers. We analyze the BER performance of the proposed scheme in a time-variant multipath fading channel. The computer simulation result verifies that the proposed scheme is superior to the conventional scheme in the two-ray fast Rayleigh fading channel.

2. OPFDM System

Figure 1 shows a block diagram of the transmitter of OPFDM system. Serial binary data streams are divided into two streams, and applied to the Inverse Discrete Fourier Transform (IDFT) based OFDM transmitters for generating the vertically and horizontally polarized radio waves, which is referred to as the vertical transmitter and the horizontal transmitter, respectively. In the vertical transmitter, data are allocated to the odd-numbered sub-carriers, and the even-numbered sub-carriers are not used for transmission of data. In contrast to the vertical one, the horizontal transmitter only uses the even-numbered sub-carriers to transmit the data and the odd-numbered sub-carriers are not used. Then, the output signals are frequency converted to the radio frequency (RF) signals, and transmitted on the vertically and the horizontally polarized electro-magnetic waves, respectively.

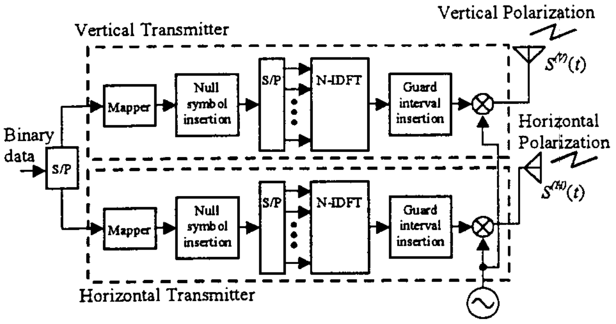
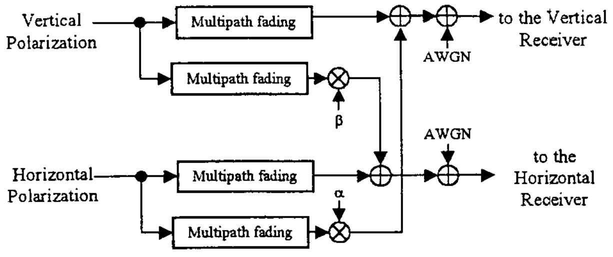


Fig. 1 Block diagram of OPFDM transmitter

We would like to note that the frequency utilization efficiency of the OPFDM system is the same as that of the conventional OFDM system while the frequency span amongst the sub-carriers transmitted in the each of the two polarized radio waves is twice as much as that for OFDM. That is, OPFDM is less sensitive to the random FM noise due to the multipath fading and the frequency offset between the transmitter and the receiver.

3. Polarization Diversity for OPFDM

The literature [6] has shown that the two statistically independent fading channels are obtained by receiving the transmitted signal with two orthogonally polarized antennas. Therefore, the polarization diversity, where the two received signals from the two differently polarized antennas are combined, is capable of improving the BER performance efficiently.



1/α, 1/β : Cross Polarized Discrimination (XPD)

Fig. 2 Channel model for the simulation

In the channel model shown in Figure 2, the vertically and horizontally polarized radio signals propagate through the multipath fading channels. The cross-talk amongst the signals is also modeled as the multipath fading channels. The four multipath fading channels in Figure 2 are statistically independent. The factors, α and β represent the average amplitude of the cross-talk, namely, the cross-polarized discrimination (XPD) of the channel. Since our OPFDM scheme uses two orthogonally polarized radio waves, we can easily apply the polarization diversity scheme to OPFDM.

We have already proposed the polarization diversity scheme for OPFDM [5]. In the following, this scheme is referred to as the conventional scheme. In the conventional diversity scheme, the combined signals are given by

$$y^{(V)}_{(2k),i} = w_i^{V1} x^{(V)}_{(2k),i} + w_i^{V2} x^{(H)}_{(2k),i} \tag{1a}$$

$$y^{(H)}_{(2k-1),i} = w_i^{H1} x^{(H)}_{(2k-1),i} + w_i^{H2} x^{(V)}_{(2k-1),i} \tag{1b}$$

where $x^{(V)}_{(m),i}$ and $x^{(H)}_{(m),i}$ are the m'th demodulated sub-carrier components at the i'th OPFDM symbol in the vertical and the horizontal receiver, respectively. And $w^{(V1)}_i$, $w^{(V2)}_i$, $w^{(H1)}_i$ and $w^{(H2)}_i$ are the diversity weight factors.

In the conventional scheme, the weight factors were calculated by using the average power of the vertical and the horizontal components in an OPFDM signal. We note here that the same diversity weight is applied to all the subcarriers. In a frequency-flat fading channel, the conventional scheme works well, however, the BER performance improvement is limited in a frequency selective fading channel.

In order to overcome this limitation, we propose a new diversity scheme, which calculates the diversity weight factors for every sub-carrier by using instantaneous power ratio in each sub-channel component. Figure 3 shows the block diagram of the proposed diversity scheme.

The proposed diversity receiver is composed of the two DFT-based receivers for the vertically and horizontally polarized radio waves. The received signals are applied to the DFT processors to demodulate and to divide the signal into sub-channels. The diversity weight factors are calculated by the envelope detectors, which estimate the attenuation factors of the channel for all the sub-channels.

The diversity weight factors are now given by

$$w^{V1}_{i,2k} = \frac{\left|x^{(V)}_{(2k),i}\right|^2}{\left|x^{(V)}_{(2k),i}\right|^2 + \left|x^{(H)}_{(2k),i}\right|^2} \tag{2a}$$

$$w^{V2}_{i,2k} = \frac{\left|x^{(H)}_{(2k),i}\right|^2}{\left|x^{(V)}_{(2k),i}\right|^2 + \left|x^{(H)}_{(2k),i}\right|^2} \tag{2b}$$

$$w^{H1}_{i,2k-1} = \frac{\left|x^{(H)}_{(2k-1),i}\right|^2}{\left|x^{(V)}_{(2k-1),i}\right|^2 + \left|x^{(H)}_{(2k-1),i}\right|^2} \tag{2c}$$

$$w^{H2}_{i,2k-1} = \frac{\left|x^{(V)}_{(2k-1),i}\right|^2}{\left|x^{(V)}_{(2k-1),i}\right|^2 + \left|x^{(H)}_{(2k-1),i}\right|^2} \tag{2d}$$

where $w^{(V1)}_{i,m}$, $w^{(V2)}_{i,m}$, $w^{(H1)}_{i,m}$ and $w^{(H2)}_{i,m}$ are the diversity weight factors for the m'th sub-carrier, respectively. The sub-channel signals from the two DFTs are combined with the diversity weight factors. We note here that the diversity combining is performed on a sub-channel by sub-channel basis.

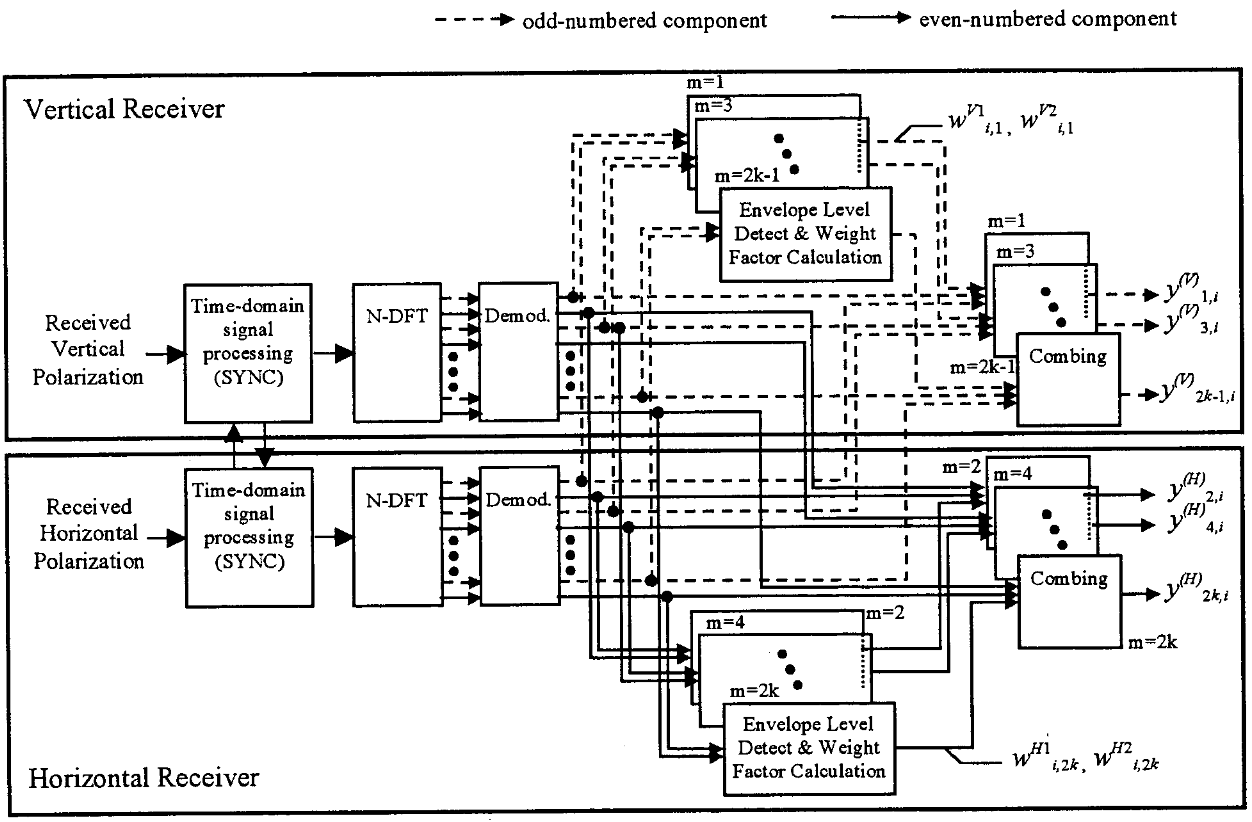


Fig. 3 Block diagram of the proposed diversity scheme

4. Simulation results

We have evaluated the performance of the proposed diversity scheme by computer simulation. The system parameters to run the simulation are shown in Table 1.

Table 1. Parameters for simulation

DFT point : N	128	
Number of sub-carriers	Vertical polarization	48
	Horizontal polarization	48
Modulation	DQPSK	
Guard Interval	t_g/t_s = 1/16	
Channel	2 ray Rayleigh fading channel with cross-talk and AWGN	
Linearity of HPA	Linear	
Symbol timing	known at the receiver	
Demodulation	Differential Detection	

Figure 4 shows the BER against E_b/N_0 under a two-ray slow Rayleigh fading environment, where the two rays had the equal gain and the lag between two-rays normalized by the valid symbol period was 1/16. We also assumed that the Cross Polarized Discrimination (XPD) was 6dB. The result shows that the BER performance of the proposed diversity scheme is 2dB better than that for the conventional one at BER=10^{-3}.

Since the fast time variation of the channel impulse response affects the BER performance as well as the frequency offset, we have to investigate the impact of the time variation to the BER performance of the proposed scheme. Figure 5 depicts BER against the normalized Doppler frequency, where XPD = 6dB, E_b/N_0 = 20dB, D/U and τ/t_s of the delayed signal were 0dB and 1/16, respectively. The result indicates that the proposed scheme is superior to the conventional one even in a fast two-ray Rayleigh fading channel.

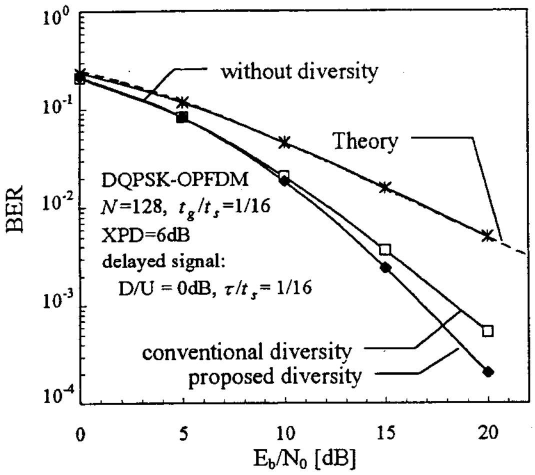


Fig. 4 BER against E_b/N_0 in the two-ray slow Rayleigh fading channel

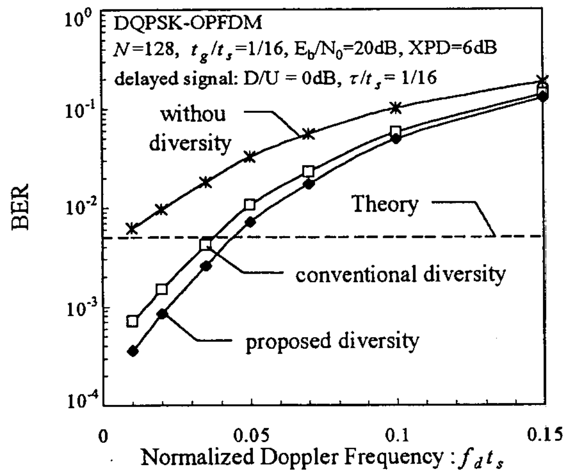


Fig. 5 BER against $f_d t_s$ in the two-ray Rayleigh fading channel

5. Conclusion

In this paper, we have proposed a new polarization diversity scheme for OPFDM systems. In this scheme, the diversity weight factors have been calculated in each sub-carrier by employing the instantaneous power ratio of the each demodulated sub-carrier component. The computer simulation results indicated that this new scheme was superior to the conventional scheme in the two-ray fast Rayleigh fading channel with cross-talk between the polarizations.

References

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