OFDM SYSTEM USING CROSS-HANDED CIRCULAR POLARIZATION

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ABSTRACT

This paper proposes the OFDM system that uses circularly polarized waves for improving the system performance. The circular polarization has the characteristic that it cannot receive the waves which are reflected by odd times. Using this characteristic, a modified OFDM system that uses the cross-handed circular polarization(XCP-OFDM) is newly proposed. By using the characteristic of circular polarization, it is clearly seen that the system performance of XCP-OFDM can be improved to a great extent. This is due to a reduction of the interferences caused by reflected waves and inter-channel interference. Both theoretical analysis and system simulation results are described.

I. INTRODUCTION

High speed and high quality digital transmission systems are required for multimedia radio communications. The multicarrier transmission systems are more desirable for high speed and high quality communication than the single carrier transmission systems. The OFDM is a special case in multicarrier transmission, where a single data stream is divided into many subcarriers and transferred in a parallel way. Therefore, the OFDM symbol has long intervals between symbols and this reduces the interferences between adjacent symbols[1]. The OFDM system reduces the necessary bandwidth using the orthogonality between the subchannels[2]. For the orthogonality between the subchannels, the OFDM uses the cyclic prefix as a guard interval. The guard interval is chosen as larger than the channel delay spread, so that multipath components from one symbol cannot interfere with the next symbol. In this guard interval, a copy of the cyclic extension of the frame is fitted. This cyclic prefix can keep the orthogonality between the subchannels[3]. However, when the multipath delay becomes larger than the guard interval the phase transitions of the delayed path fall within the fast Fourier transform(FFT) interval of the receiver. The summation of the first path with the delayed path no longer gives a set of orthogonal waves and results in a certain level inter-channel interference. Therefore, the orthogonality between the subcarriers becomes lost and this degrades a system's performance[4].

In this paper, a modified OFDM system using the cross-handed circular polarization (XCP-OFDM) is newly proposed. The proposed system adopts the characteristic of circular polarization to the conventional OFDM system for the purpose of minimizing the delay spread and the interference of the reflected waves as well as inter-channel interference(ICI). With the theoretical and simulation results, it was found that the proposed XCP-OFDM system has better performance compared to the conventional OFDM system.

II. THE DELAY SPREAD AND BANDWIDTH EFFICIENCY

The basic principle of the OFDM is to split a high-rate serial data stream into a number of

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lower rate parallel streams that are transmitted simultaneously over a number of subcarriers. Therefore, the symbol duration increases with times of the number of subcarriers. When the time delay spread of the channel exceeds the guard interval, the phase transitions of the delayed path fall within the FFT interval of the receiver. In this case, the orthogonality between the subcarriers cannot be maintained. This causes inter-channel interference and makes the system performance degrade. To keep the orthogonality between the subcarriers, the guard interval must stay larger than the time delay spread of the channel. The guard interval should be longer according to increasing time delay spread and therefore the redundancy of guard interval increases.

If an impulse signal $A\delta(t)$ is propagated at time instant $t=0$, the received signal $r(t)$ is as follows:

$$r(t)=\sum_{i=1}^{n} A_i\delta(t-T_i) \tag{1}$$

where n is the number of the radio path, and A_i is the amplitude of the received impulse due to the i-th path, and T_i is the time delay of the i-th arriving impulse. The impulse arrival time T_i is usually characterized by a probability density function and the delay spread σ_T corresponds to its standard deviation. Let $p(T)$ be the probability density function of T, then the $p(T)$ usually shows negative exponential distribution, and the delay spread σ_T can be expressed as follows:

$$p(T)=\frac{1}{\overline{T}}\exp(-T/\overline{T}) \tag{2}$$

$$\sigma_T=\sqrt{E[T^2]-E^2[T]} \tag{3}$$

where, $\overline{T}=E[T]=\int_0^{\infty} T p(T)\,dT$ and $E[T^2]\triangleq\int_0^{\infty} T^2 p(T)\,dT$. From the equation (2) and (3), we can find that the time delay spread becomes small when the impulse arrival time T is small. And also, the time delay spread becomes small when the probability density function $p(T)$ decreases. Therefore, the time delay spread can be reduced if we make the amplitude of the reflected waves to small. By this reason, it can be considered that the characteristic of circular polarization can be used to reduce the time delay spread and improve the performance of an OFDM system.

For most office buildings, the maximum delay spread is in the range of 30ns to 125ns at a frequency range of 4Ghz to 6Ghz[1]. The largest delay spread appears in large buildings, like shopping centers or factories with as much as 125ns, and the smallest delay spread appear with as much as 30ns when the transmitter and receiver are in the same single room. However, it was shown that the delay spread can be reduced by as much as 4.5ns when the circular polarization was used in indoor radio channels[5][6]. This means that if the circular polarization is used in the OFDM system, then the time delay spread can be reduced. By reducing the time delay spread, the orthogonality between the subcarriers can be improved. As a result, the system performance can be improved and the length of the guard interval can be also minimized.

In the OFDM system that uses the M-PSK mapping, the transmission rate and the bandwidth are as follows[7]:

$$R=\log_2 M\times 1/NT_s\times N \tag{4}$$

$$W=f_{N-1}-f_0+2\delta=(N-1)/NT_s+2\delta \tag{5}$$

Therefore the bandwidth efficiency η is as follows:

$$\eta=\frac{R}{W}=\frac{\log_2 M}{(1-1/N)T_s+2\delta T_s} \tag{6}$$

where, the side lobe $\delta=(1+\alpha)/2NT_s$ and α is a roll-off factor. If we consider the guard interval, the efficiency can be written as follows:

$$\eta=\frac{\log_2 M}{(1-1/N)T_s+2\delta T_s+GI} \tag{7}$$

where, the GI means the bandwidth of the guard interval. From the equation (7), as the number of subcarriers increases the bandwidth efficiency can be improved. Another method to improve the bandwidth efficiency is the reduction of the length of guard interval. In the standardization of IEEE 802.11a wireless LAN, the guard interval is wide and is equal to 16 subchannels[8]. This is 25% compared to the one OFDM frame and about 33% compared to the length of real data channels. Therefore, the bandwidth efficiency can be improved by a maximum of 6dB when the guard interval is minimized to zero.

Ⅲ. OFDM USING CROSS-HANDED CIRCULAR POLARIZATION

The spectrums of the subchannels are overlapped with a spectrum of adjacent subchannels in the conventional OFDM system. This means that a small amount of frequency offset can cause the degradation of the system performance since the orthogonality between the subchannels could not be kept. If the overlapping of a subchannel spectrum can be reduced, then we can minimize the degradation due to the frequency offset. For this reason, the OFDM system using cross-handed circular polarization is proposed. Figure 1 shows the structure of the XCP-OFDM and Figure 2 shows a subchannel spectrum of the proposed system.

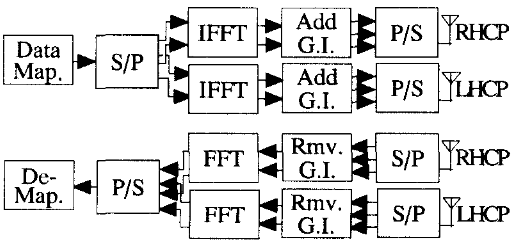

Fig. 1 Structure of the XCP-OFDM

The proposed XCP-OFDM system divides the subchannels into a right-handed circular polarization(RHCP) channel and a left-handed circular polarization(LHCP) channel that alternate each other. In the OFDM system, $x_n(k)$ that is the input signal to the discrete Fourier transform(DFT) module in the receiver can be represented as follows:

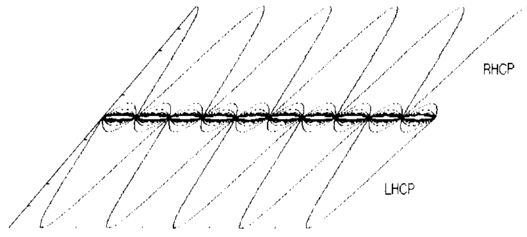

Fig. 2 Subchannel spectrum of the XCP-OFDM

$$x_n(k) = A_k e^{j2\pi f_x k T_s} \tag{8}$$

where A_k is the amplitude of the k-th subcarrier and the f_x is the frequency of the subchannel. When the signal of $x_n(k)$ is added to the DFT module in the receiver, then the output of the DFT module can be represented as follows:

$$\begin{aligned} X_n(K) &= \sum_{i=0}^{N-1} x_n(k) e^{-jKi\frac{2\pi}{N}} \\ &= \sum_{i=0}^{N-1} A_K e^{j2\pi f_x k T_s} e^{-jKi\frac{2\pi}{N}} \\ &= A_K e^{j\pi(f_x T_s N - K)\frac{N-1}{N}} \times \frac{\sin[\pi(f_x T_s N - K)]}{\sin[\pi/N(f_x T_s N - K)]} \\ &= A_K e^{j\pi(M+\zeta-K)\frac{N-1}{N}} \times \frac{\sin[\pi(M+\zeta-K)]}{\sin[\pi/N(M+\zeta-K)]} \end{aligned} \tag{9}$$

where, $f_x T_s N = M + \zeta$, M is the integer and ζ is the component due to the frequency offset that has a range of $0 \le \zeta < 1$. Therefore the total output signals of the DFT module can be represented as follows:

$$X(K) = \sum_{M=0}^{N-1} \left\{ A_K e^{j\pi(M+\zeta-K)\frac{N-1}{N}} \times \frac{\sin[\pi(M+\zeta-K)]}{\sin[\pi/N(M+\zeta-K)]} \right\} \tag{10}$$

The received signal should be sampled only at the point when K has the value of the integer, because of the subchannel orthogonality. If there is no frequency offset, the component, due to frequency offset ζ has the value of zero. In this condition, the output of DFT can be only seen when K equals M. When K is not equal to M then the output of DFT is zero. This means that the orthogonality between subchannels is kept well. If there happens to be a frequency offset, then the component, due to frequency offset ζ cannot equal to zero. In this case, the output of the DFT module can be obtained even though K is not equal to M. This means that the output signal interfered with the adjacent subchannels, which in turn causes the system performance degrade.

When the frequency offset occurs in the channel, both the amplitude of a wanted signal $X(K)_{so}$ due to the frequency offset and the amplitude of an unwanted signal $X(K)_{Io}$ which indicates a sum of inter-channel interference can be represented as follows:

$$|X(K)_{so}| = \left| A_K \frac{\sin(\zeta\pi)}{\sin(\zeta\pi/N)} \right| \tag{11}$$

$$\begin{aligned} &|X(K)_{Io}| \\ &= \left| \sum_{M=0, M\neq K}^{N-1} \left\{ A_K e^{j\pi(M+\zeta-K)\frac{N-1}{N}} \times \frac{\sin[\pi(M+\zeta-K)]}{\sin[\pi/N(M+\zeta-K)]} \right\} \right| \end{aligned} \tag{12}$$

In the XCP-OFDM system, the subchannel spectrums are divided into the RHCP channel and the LHCP channel. Therefore the magnitude of inter-channel interference can be represented as follows:

$$\begin{aligned} &|X(K)_{Io}|_{XCP} \\ &= \left| \sum_{M=0, M\neq K}^{(N-1)/2} \left[A_K e^{j\pi(2M+\zeta-K)\frac{N-1}{N}} \times \frac{\sin[\pi(2M+\zeta-K)]}{\sin[\pi/N(2M+\zeta-K)]} \right.\right. \\ &\left.\left. + \Gamma_c \times A_K e^{j\pi(2M+\zeta-K+1)\frac{N-1}{N}} \times \frac{\sin[\pi(2M+\zeta-K+1)]}{\sin[\pi/N(2M+\zeta-K+1)]} \right] \right| \end{aligned} \tag{13}$$

where the Γ_c is a reciprocal value of the circular polarization discrimination and it can be written as follows:

$$\begin{aligned} \Gamma_c &= 20\log_{10}\left|\frac{E_{RL}}{E_{RR}}\right| \\ &= 20\log_{10}\left|\frac{E_{LR}}{E_{LL}}\right| \end{aligned} \tag{14}$$

Ⅳ. SIMULATION RESULTS

The computer simulation was conducted with the parameters of the IEEE 802.11a. by Monte Carlo simulation. The simulation diagram is like as the Figure 1. The size of the FFT and IFFT are 64 points and sampling rates are 50ns. The total bandwidth is 20MHz and the mapping method is QPSK. The convolutional coding with the constraint length of 7 and code rade of 1/2 was adopted. Therefore, the data rate is 12Mbps. Multipath channel with 6 rays including direct wave was considered. All 5 reflected waves are considered which have one sampling time interval each other and have a reflection loss of 3[dB] at each reflection.

The following three figures are the signal constellations obtained from computer simulation in order to investigate the influence of the multipath delay in the QPSK-OFDM system. Figure 3 is obtained when the first reflected wave arrives after 6 sampling times and the reflection loss is 3[dB].

Figure 4 is obtained when the first reflected wave arrives after 1 sampling time and the other conditions are the same as in the case of Figure 3. From these two figures, it can be clearly seen

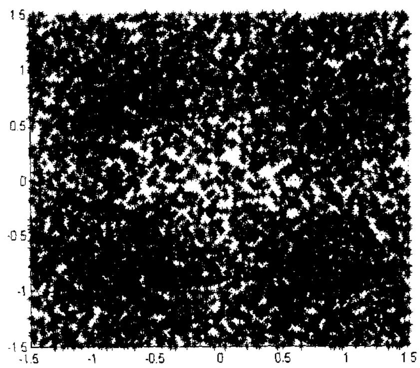

Fig. 3 Constellation when the delay is 6 to 10 sampling times

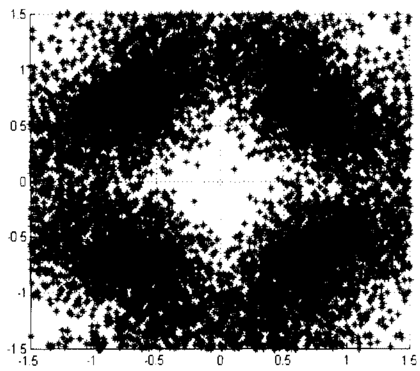

Fig. 4 Constellation when the delay is 1 to 5 sampling times

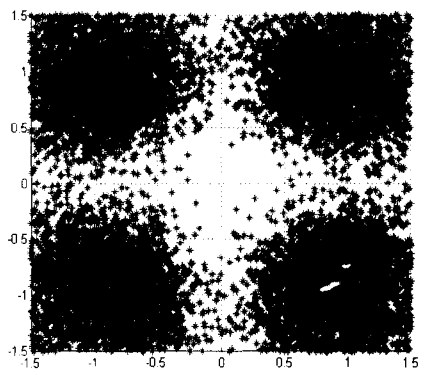

Fig. 5 Constellation when the odd-time reflected waves are eliminated using circular polarization

that the system performance is better when the delay time is small like in Figure 4. Figure 5 shows the constellations when the reflected waves with odd number times were eliminated except for the direct wave and reflected waves with even number times and the other conditions are same as in the case of Figure 4. From this figure it can be clearly seen that if the reflected waves, that are reflected by odd number times, are not received, then the system performance can increase.

Figure 6 shows the BER performance results of the OFDM due to polarization. From this figure, the OFDM system which uses a circularly polarized wave shows the best performance and the horizontally polarized wave shows the worst performance. The circularly polarized wave does not receive the reflected waves which were reflected by odd number times, therefore, the interference caused by the reflected waves is minimized. By this reason, this system shows the best performance results. Meanwhile, the horizontally polarized wave has a higher magnitude of reflection coefficient, therefore the reflected waves have strong amplitudes, which in turn it make severe interference. As a result, the horizontal polarization shows the worst BER performance.

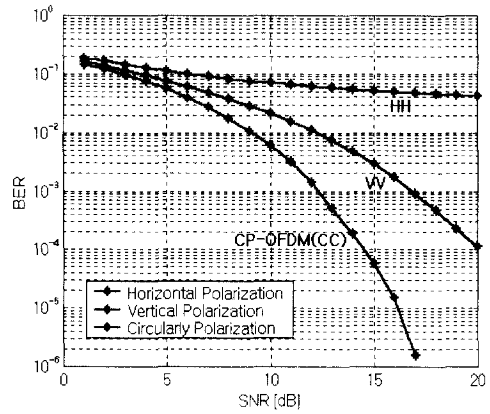

Fig. 6 BER performance of the OFDM due to the polarization

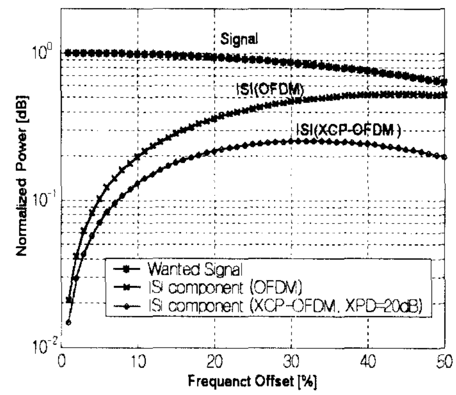

Fig. 7 The Power of the Signal and ICI

Figure 7 shows the power of a wanted signal and inter-channel interference due to frequency offset. In this figure, the power of the wanted signal decreases as the frequency offset increases. Contrary to this, the power of the unwanted signals caused by inter-channel interference increases as the frequency offset. However, Figure 7 shows that the power of the unwanted signals caused by inter-channel interference can be reduced by using cross-handed circular polarization.

V. CONCLUSIONS

In this paper, we adopted the characteristic of circular polarization to the conventional OFDM system in order to improve the system performance. It was found that the interference caused by the reflected waves can be reduced using the characteristic of circular polarization. It was also found that the OFDM system that uses the circular polarization shows the best BER performance when compared with the systems that uses the other polarizations. Using the circular polarization, the BER performance of the OFDM system was improved by about 5[dB] at the BER of 10^{-4}, compared to the vertical polarization. In the proposed XCP-OFDM system, it was shown that the power of the inter-channel interferences caused by the frequency offset can be reduced using cross-handed circular polarization.

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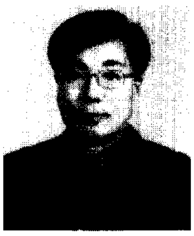

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