An Dual-Polarized Transmission System with OFDM Multiplexing

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I. Introduction

In a modern wireless communication system, system resource is often limited by the available frequency bandwidth. Many methods, such as the dual orthogonal polarization technique, can be used to double the capacity of a system that uses only one single polarization. Meanwhile, the orthogonal frequency division multiplexing (OFDM) scheme has been widely adopted in high data rate communication recently[1,2]. To avoid the time-varying degradation and distortion phenomenon[3], the OFDM multiplexing scheme is to divide a broadband communication channel into several orthogonal narrowband ones. By doing so, we can prevent the time-varying distortion of the wireless channel and preserve the high data rate communication requirement. In this paper, we will propose an OFDM multiplexing transmission system that employed simple cross-structure dual-polarized antennas at both the transmitter and receiver. With this structure, two different messages can be simultaneously transmitted from two differently polarized antennas using the same frequency band. Hence, the capacity of the OFDM system can be doubled. Moreover, we modify the one-tap equalizer used in the OFDM system to a cross-structure compensator to achieve the purpose of dual-polarized transmission in a wireless multi-paths channel. This paper is organized as follows: We begin our discussion on the proposed architecture by describing the principle of the dual-polarized system. Section II derives the needed modifications to the OFDM system when the dual-polarized antennas are used. In section III, some numerical simulations of the system on a specified wireless channel are performed. We will demonstrate that the proposed architecture can overcome the limitations of the BPSK channel and the goal of high data rate transmission can be achieved. Conclusions are given in section IV.

II. System descriptions

Consider an $\hat{i}$ oriented antenna with an effective height vector $\vec{e}_{\hat{i}}(\theta,\phi)$ illuminated by a field $\vec{E}_{\hat{i}}(\theta,\phi)$ incident from the direction of arrival $(\mathrm{DOA})(\theta,\phi)$. The induced open-circuited voltage can be expressed by [4]:

$$V_{oc\hat{i}} = \vec{e}_{\hat{i}}^{\,*}(\theta,\phi) \bullet \vec{E}_{\hat{i}}(\theta,\phi) \tag{1}$$

If there are M multi-paths between the transmitter and the receiver, the total open-circuited voltage will be the summation of the induced voltages of these paths and is given by:

$$V_{oc\hat{i}} = \sum_{m=1}^{M} \vec{e}_{\hat{i}}^{\,*}(\theta_m,\phi_m) \bullet \vec{E}_{m\hat{i}}(\theta_m,\phi_m) \tag{2}$$

where (θ_m,ϕ_m) is the direction of arrival (DOA) of the m-th path.

Assume that in a dual-polarized transmission system, there are two different polarized antennas transmitting different messages $E_1(t)$ and $E_2(t)$ respectively using the same frequency. At the receiver, there are also two different antennas with effective heights $\vec{e}_{\hat{1}}(\theta,\phi)$ and $\vec{e}_{\hat{2}}(\theta,\phi)$ oriented in the first $\hat{1}$ and the second $\hat{2}$ polarized directions respectively. The system is shown in Fig-1.

From (2), the induced open-circuited voltages of the $\hat{1}$ and $\hat{2}$ oriented receiving antennas in the wireless M multi-paths communication channel are:

$$V_{oc\hat{1}} = \sum_{m=1}^{M}[\vec{E}_{m\hat{1}}(\theta_{m,}\phi_m) + \vec{E}_{m\hat{2}}(\theta_{m,}\phi_m)] \bullet \vec{e}_{\hat{1}}^{\,*}(\theta_{m,}\phi_m) = a_{\hat{1}} + b_{\hat{1}} \tag{3}$$

$$V_{oc\hat{2}} = \sum_{m=1}^{M}[\vec{E}_{m\hat{1}}(\theta_{m,}\phi_m) + \vec{E}_{m\hat{2}}(\theta_{m,}\phi_m)] \bullet \vec{e}_{\hat{2}}^{\,*}(\theta_{m,}\phi_m) = a_{\hat{2}} + b_{\hat{2}} \tag{4}$$

where the parameters $a_{\hat{1}}$, $a_{\hat{2}}$, $b_{\hat{1}}$ and $b_{\hat{2}}$ are defined as:

$$\begin{aligned} a_{\hat{1}} &= \sum_m \vec{E}_{m\hat{1}}(\theta_{m,}\phi_m) \bullet \vec{e}_{\hat{1}}^{\,*}(\theta_{m,}\phi_m) \\ b_{\hat{1}} &= \sum_m \vec{E}_{m\hat{2}}(\theta_{m,}\phi_m) \bullet \vec{e}_{\hat{1}}^{\,*}(\theta_{m,}\phi_m) \\ a_{\hat{2}} &= \sum_m \vec{E}_{m\hat{1}}(\theta_{m,}\phi_m) \bullet \vec{e}_{\hat{2}}^{\,*}(\theta_{m,}\phi_m) \\ b_{\hat{2}} &= \sum_m \vec{E}_{m\hat{2}}(\theta_{m,}\phi_m) \bullet \vec{e}_{\hat{2}}^{\,*}(\theta_{m,}\phi_m) \end{aligned} \tag{5}$$

Based on the mathematical modeling of (3) and (4), a simple cross-structure compensator for correcting the cross-polarized degradation in the dual-polarized system is proposed and is shown in Fig-2.

The dual-polarized channel can be modeled as Fig-3. Using the notations in Fig-2 and Fig-3, the cross-structure two outputs $V_{o\hat{1}}$ and $V_{o\hat{2}}$ can be expressed as:

$$\begin{bmatrix} V_{o\hat{1}} \\ V_{o\hat{2}} \end{bmatrix} = \begin{bmatrix} w_{11} & w_{21} \\ w_{12} & w_{22} \end{bmatrix} \begin{bmatrix} a_1 & b_1 \\ a_2 & b_2 \end{bmatrix} \begin{bmatrix} E_{\hat{1}}(t) \\ E_{\hat{2}}(t) \end{bmatrix} \tag{6}$$

In order to compensate the channel distortion and to eliminate the cross-polarization for the OFDM system, the weightings should be chosen as:

$$\begin{bmatrix} w_{11} & w_{21} \\ w_{12} & w_{22} \end{bmatrix} = I_2 * \begin{bmatrix} a_1 & b_1 \\ a_2 & b_2 \end{bmatrix}^{-1} = \begin{bmatrix} a_1 & b_1 \\ a_2 & b_2 \end{bmatrix}^{-1} \tag{7}$$

where I_2 is the 2 by 2 identity matrix. Meanwhile, Fig-4 shows the block diagram of the OFDM system. From (7), we can see that the one-tap equalizer of the conventional OFDM system can be modified to the cross-structure compensator for dual-polarized transmission. It should be noted that we can evaluate the parameters a_1, a_2, b_1, b_2 by sending a set of known symbols (such as pilots symbols in OFDM system).

III. Simulation and Analysis

In this section, we simulate the experiments based on the proposed transmission system to verify the practicality of the system. Table-1 lists the specifications of the wireless channel used in the simulations. We randomly generate the binary data sequence for processing. All the sub-channels use the same BPSK modulation in this simulation. The size for serial to parallel conversion and the IFFT transformation is 64. We also assume that both the transmitting and receiving antennas use the same ideal element dipoles that are oriented in the 1 and 2 directions. Besides, the effective height of the element dipoles at the receiving site can be expressed by (8):

$$\hat{e}_1(\theta,\phi) = 1.5(\cos\theta\cos\phi\hat{\theta} - \sin\phi\hat{\phi})$$
$$\hat{e}_2(\theta,\phi) = 1.5(\cos\theta\sin\phi\hat{\theta} + \cos\phi\hat{\phi}) \quad (8)$$

Fig-5 shows the simulation results at 50KBps data rate. It is clear that without any signal processing, the BER cannot be reduced even if we increase the SNR. Fig-6 shows the comparison of the results with and without the OFDM multiplexing scheme. The results show that transmission system with OFDM multiplexing has a better performance than the system without the OFDM multiplexing. This is because the signal can be coherently integrated from the LOS and the multi-paths but not the noise. Then, we increase the data rate of the channel to 200KBps. Fig-7 shows that when the data rate of the symbol exceeds the coherent bandwidth of the channel, the BER cannot improve even though the SNR is increased if the OFDM multiplexing is not used. But if we employ the proposed OFDM multiplexing polarized system in the same environment, a satisfactory result is obtained because a broad-band channel is divided into several orthogonal sub-channels, avoiding the frequency selective fading of the channel. Fig-8 demonstrates the result of an 256×256 image with 256 gray levels received in the proposed architecture at SNR=12dB.

IV. Discussions and Conclusions

In this paper, we propose a novel dual-polarized transmission system with OFDM multiplexing. The purpose of using the dual-polarized frequency reuse scheme is to double the capacity of the OFDM system. We modify the one-tap equalizer of the OFDM system to a cross-structure compensator to enable dual-polarized signals be transmitted in an OFDM multiplexing environment. Simulation results show that simple cross-structure compensator can efficiently reuse the frequency band and can still perform well even under the multi-paths channel. The only requirement is that the weightings should be adjusted adaptively in accordance with the change of environment.

V. Reference

[1] Richard Van Nee and Ramjee Prasad, "OFDM for wireless Multimedia Communications", Artech House, 2000.

[2] Digital Video Broadcasting (DVD); Implementation guidelines for the use of MPEG-2 Systems, Video and Audio in satellite, cable and terrestrial broadcasting applications, ETSI Standard ETR154, September 1997 3rd Edition.

[3] Zou, W.Y.; Yiyan Wu, "COFDM: An overview", IEEE Transactions on Broadcasting, Vol. 41, No. 1, March 1995 Page(s): 1-8.

[4] Warren L. Stutzman, Gary A. Thiele, "Antenna Theory and Design", 2nd edition, 1998 John Wiley and Sons. Inc.

Table-1 Simulated Wireless Channel Specifications

Wireless channel	1LOS+3Multi-paths wireless channel
Delay time	T0=0sec, T1=2μsec, T2=3μsec, T3=6μsec
Coherent Bandwidth	~1/6μsec=166KHz
Angle of arrival (AOA)	LOS + 3 arbitrary arrival Multi-paths
Number of channel (N)	1 or 64
Data rate	50KBps or 200KBps
Operating frequency	5GHz
Doppler spread	0Hz

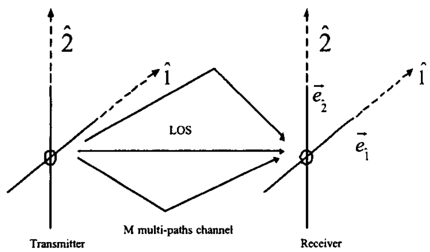

Fig-1. Illustration of the dual-polarized antennas in the multi-paths channel

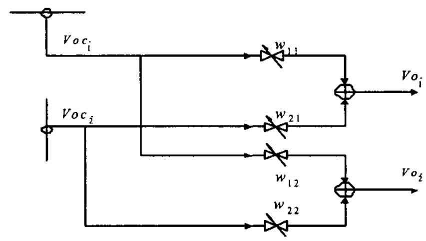

Fig-2. Architecture of the proposed cross-structure compensator.

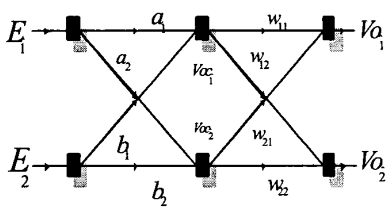

Fig-3 Model for the wireless channel and the proposed receiver.

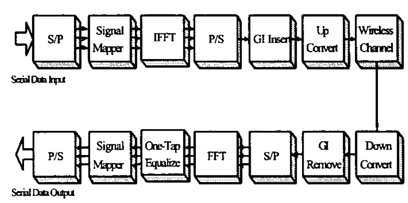

Fig-4. Architecture of the conventional OFDM transmission system.

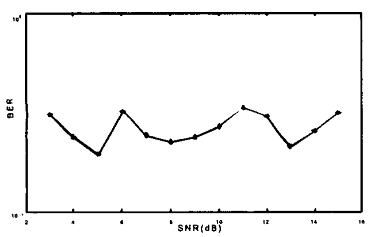

Fig-5. Simulated results for BPSK modulated signal without using the proposed cross-structure compensator.

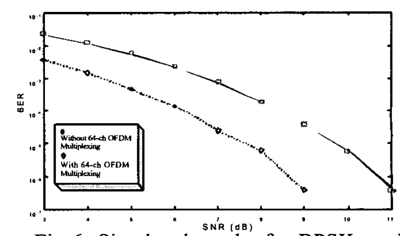

Fig-6. Simulated results for BPSK modulated signal with or without OFDM multiplexing scheme. Both use the proposed cross-structure receiver.

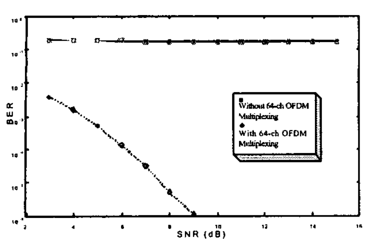

Fig-7. Simulated results for BPSK modulated signal with or without OFDM multiplexing scheme. Both use the proposed cross-structured receiver.

Fig-8 Received image using the proposed OFDM-based dual-polarized transmission system with SNR=12dB.