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MIMO-OFDM systems for IEEE 802.11n WLAN Standard using ESPAR antenna

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Abstract

This paper proposes MIMO-OFDM system for IEEE 802.11n using electronically steerable parasitic array radiator (ESPAR) antenna. Although the 2 x 2 MIMO-OFDM system is capable of doubling the capacity without expanding the occupied frequency bandwidth, we can't obtain the additional diversity gain using the linear MIMO decomposition method. The proposed method can improve the bit error rate performance of the MIMO-OFDM receiver by making efficient use of ESPAR antenna. Computer simulation result shows that the proposed scheme gives the additional diversity gain.

Keywords: MIMO-OFDM, ESPAR, HTLTF, decomposition.

1. Introduction

Multiple Input Multiple Output (MIMO) is a technique to increase the transmission bit rate without extending frequency bandwidth (A.C.K.Vishnu Vardhan *et al.* 2008). However, MIMO requires the same number of RF front-end circuits. A single RF MIMO system based on ESPAR (electronically steereable parasitic array radiator) antenna has been proposed in (A.Kalis *et al.* 2008). In this work, transmitter for MIMO wireless communication using single RF front end at the mobile terminal. Although this proposal can reduce the number of RF front-end, it could applied to MIMO-OFDM system. Furthemore, the performance in (A.Kalis *et al.* 2008) for MIMO system 2 x 2 using 3 and 5 element ESPAR antennas still worse than MIMO system. A part of authors has proposed a new diversity scheme based on ESPAR (Electrically Steerable Passive Array Radiator) antenna (S. Tsukamoto *et al.* 2009). In this work, schemes based on ESPAR antenna, whose beam direction is oscillated in the symbol time of the received OFDM signal. This schemes gives diversity gain in a frequency selective fading channels, but the system present in (S. Tsukamoto *et al.* 2009) is still SISO (Single-Input Single-Output) system. ESPAR antenna have been applied in OFDM system use diversity scheme with Maximum Ratio Combining (MRC) and Selection Combining (SC) can obtain gain diversity gain (Arita *et al*. 2012). A new model ESPAR antenna have been presented in (Luther *et al.* 2012). This paper show the low cost of diode varactor used in phase shifter to allows low size device. For MIMO systems, ESPAR antennas are able to reduce the correlation between signals and increase the channel capacity (Haitao Liu *et al.* 2012). In our paper, we propose a MIMO-OFDM system with ESPAR antenna in order to improve the bit error rate performance without sacrificing the transmission data rate. Computer simulation results reviels that the proposed scheme is capable of obtaining additional diversity gain in frequency selective fading channel without reducing the spacial multiplexing capability.

2. ESPAR Antenna-Based Diversity Receiver for OFDM

The proposed MIMO-OFDM with ESPAR antenna is an extension of the ESPAR antenna-based diversity receiver proposed by a part of authors in (A.Kalis *et al.* 2008). In this section, we will briefly introduce the ESPAR antenna-based diversity receiver for OFDM.

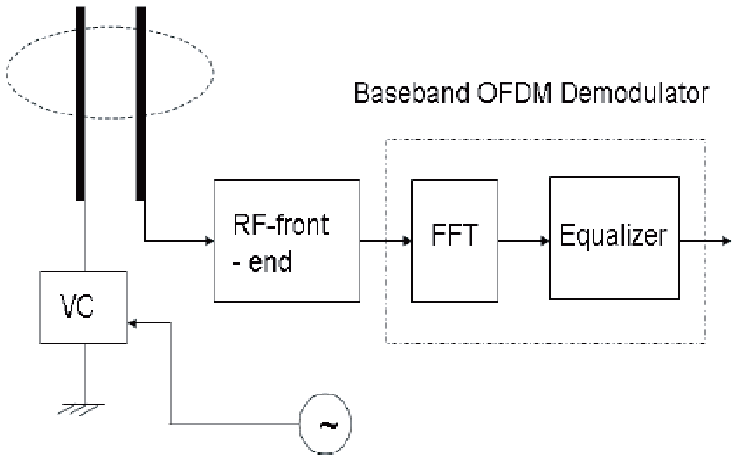

Fig. 1. ESPAR antenna-based diversity receiver for OFDM system

Figure 1 illustrates the block diagram transmitter and receiver system of OFDM ESPAR system. ESPAR antenna in this section is composed of a radiator and a parasitic element terminated with a variable capacitor. Since the radiator and parasitic element are electro-magnetically coupled, the output of the ESPAR antenna is a weighted sum of the received signal at the each element. The principle of ESPAR antenna is introduced in (Kalis *et al.* 2008). In this proposal the reactance varies by the oscillator whose frequency is the same as the subcarrier spacing of the OFDM signal. At the receiver, special equalization is required for reducing the ICI generated by proposed scheme. In the following we derive the channel estimation algorithm for the proposed ESPAR antenna based diversity receiver. The received signal is applied to the FFT processor followed by the frequency domain equalizer. Now let us assume that the transmitted symbol vector in the frequency domain is

$$x = [x_0, x_1, \ldots, x_{N-1}]^T \quad (1)$$

where x_k is data symbols of k-tth subcarriers, N is a number of subcarriers.

The data symbol in time domain is given by

$$v = F^{-1}x \quad (2)$$

where F is the Fourier transformation matrix. That is, the *k*-th column *l*-th raw element of F is $e^{-j2\pi kl/N}$. The transmitted symbol v is then propagated through the multipath fading channel. The received signal component at the *i*- th element is given by

$$q_i = C_i v \quad (3)$$

where C_i, is the channel impulse response matrix corresponding the *i*-th element. The received signal at the input of the baseband demodulation block is given by

$$r = q_0 + Dq_i + z = (C_0 + DC_1)\, v + z = (C_0 + DC_1)F^{-1}x + z \quad (4)$$

where z is the thermal noise component, and $D = \mathrm{diag}(d_k)$ is a diagonal matrix whose *k*-th diagonal element is d_k. The received signal is applied to FFT. The output of FFT is then given by

$$u = Fr = (H_0 + GH_1)\, x + z \quad (5)$$

where

$$H_i = FC_iF^{-1} \quad (6)$$

is a diagonal matrix, whose diagonal elements represents the frequency response.

$$G = FDF^{-1} \quad (7)$$

represents Inter-Channel Interference (ICI) matrix, and z is the thermal noise component in the frequency domain.

2.1 Channel Estimation

According to the (5), the received signal in the proposed scheme was interfered by the adjacent subcarrier signals. That is, the frequency domain equalization is required at the receiver. It is required to estimate the frequency response of the channel for equalizing the signal. In order to estimate the frequency response, the proposed scheme first transmit a pilot symbol before transmitting the data. Now let us assume that the pilot symbol vector in the frequency domain is

$$\mathbf{p} = [p_0, p_1, \ldots, p_{N\text{-}1}]^{\mathrm{T}} \quad (8)$$

where p_k is data symbols of k-th subcarriers. The received signal at the pilot symbol is then given by

$$\mathbf{u} = \mathbf{Fr} = (\mathbf{H}_0 + \mathbf{GH}_1)\ \mathbf{p} + z \quad (9)$$

Now, let us assume that the vector $\mathbf{p}$ and $\mathbf{h}i$ represent the diagonal components of the matrices $\mathbf{P}$ and $\mathbf{H}_i$, respectively. That is, Now, let us assume that the vector $\mathbf{p}$ and $\mathbf{h}_i$ represent the diagonal components of the matrices $\mathbf{P}$ and $\mathbf{H}_i$, respectively. That is,

$$\mathbf{P} = \mathrm{diag}(\mathbf{p}) \quad (10)$$

and

$$\mathbf{H}_i = \mathrm{diag}(\mathbf{h}_i) \quad (11)$$

Then without loss of generality, we can exchange the diagonal matrices and vectors as in

$$\mathbf{u} = \mathbf{Ph}_0 + \mathbf{GPh}_1 + \mathbf{z} \quad (12)$$

The covariance and cross-correlation matrices are now derived as

$$\mathbf{R} = \mathrm{E}[\mathbf{uu}^{\mathrm{H}}] = \mathbf{PR}_{\mathrm{h}}\mathbf{P}^{\mathrm{H}} + \mathbf{GPR}_{\mathrm{h}}\mathbf{P}^{\mathrm{H}}\mathbf{G}^{\mathrm{H}} + \tau_Z^{\ 2}\ \mathbf{I} \quad (13)$$

And

$$\mathbf{B}_i = \mathrm{E}[\ \mathbf{uh_i}^{\mathrm{H}}] \quad (14)$$

respectively, where

$$\mathbf{R}_{\mathrm{h}} = \mathrm{E}[\ \mathbf{h}_{\mathrm{i}}\mathbf{h}_{\ \mathbf{i}}^{\ \mathrm{H}}] \quad (15)$$

is the covariance matrix of the channel response and $E[\cdot]$ denotes the ensemble average. The cross-correlation matrices are further given by

$$\mathbf{B}_0 = \mathbf{PR}_h \quad (16)$$

and

$$\mathbf{B}_1 = \mathbf{GPR}_h \quad (17)$$

The channel response is finally estimated by

$$\mathbf{h}_i = \mathbf{W}H_i\ \mathbf{u} \quad (18)$$

where

$$\mathbf{W}_i = \mathbf{R}^{+}\mathbf{B}_i \quad (19)$$

is the weight matrix in terms of minimum mean square error (MMSE) criterion, where $\mathbf{R}^{+}$ is the pseudo inverse matrix.

2.2 Frequency Domain Equalizer

From the estimated channel response, we can equalize the received data symbols. We assume the simple ZF equalizer.

3. MIMO-OFDM using ESPAR antenna

In this section we present an 2*x*2 MIMO-OFDM with ESPAR antenna. The receiver block diagrams of the proposed MIMO-OFDM system with ESPAR antenna are respectively shown in Fig. 2. At the receiver in Fig. 2, we use two ESPAR antennas for receiving the signal. The received signals are then applied to the corresponding FFT processors followed by the channel estimator and MIMO decoder. The output of the MIMO decoder is then applied to the demapper to demodulate the symbol.

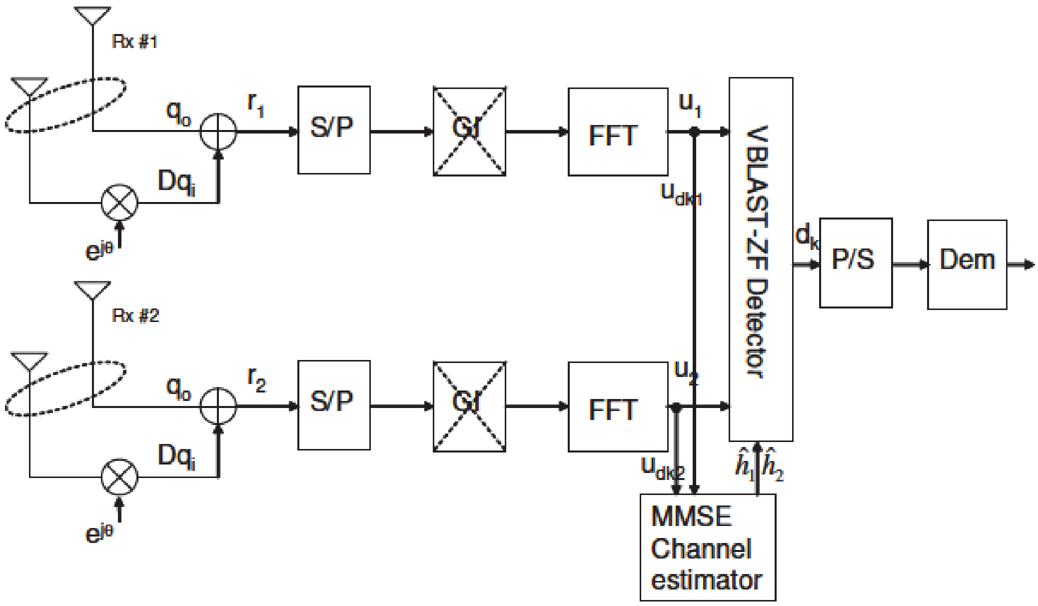

Fig. 2 Block Diagram of Receiver MIMO-OFDM ESPAR

3.1 Channel Estimator

Let the pilot symbol and its cyclic shifted one be **P**1 and **P**2, respectively. Then the received signal at the *i*-th ESPAR antenna in the frequency domain is given by

$$\mathbf{u} = \mathbf{P_1h}_{2i,0} + \mathbf{GP_1h}_{2i+1,0} + \mathbf{P_2h}_{2i,1} + \mathbf{GP_2h}_{2i+1,1} + \mathbf{z} \qquad (20)$$

From this equation, we can get the correlation matrix as:

$$\mathbf{B}_{10} = \mathbf{P_1R}_h \qquad (21)$$

$$\mathbf{B}_{11} = \mathbf{GP_1R}_h \qquad (22)$$

$$\mathbf{B}_{20} = \mathbf{P_2R}_h \qquad (23)$$

and

$$\mathbf{B}_{21} = \mathbf{GP_2R}_h \qquad (24)$$

where B_{10}, B_{11}, and B_{20}, B_{21} are cross correlation matrix from first pilot and second pilot respectively. The channel response for MIMO-OFDM ESPAR 2x2 correspondence to first receiver and second receiver respectively is finally estimated by

$$\mathbf{h}_{10} = \mathbf{W_{10}}^H\mathbf{u_1}\mathbf{h}_{11} = \mathbf{W_{11}}^H\mathbf{u_1}\mathbf{h}_{20} = \mathbf{W_{20}}^H\mathbf{u_1}\mathbf{h}_{21} = \mathbf{W_{21}}^H\mathbf{u_1} \qquad (25)$$

and

$$\mathbf{h}_{30} = \mathbf{W_{10}}^H\mathbf{u_2}\mathbf{h}_{31} = \mathbf{W_{11}}^H\mathbf{u_2}\mathbf{h}_{40} = \mathbf{W_{20}}^H\mathbf{u_2}\mathbf{h}_{41} = \mathbf{W_{21}}^H\mathbf{u_2} \qquad (26)$$

where

$$\mathbf{W}_{10} = \mathbf{R}^{-1}\mathbf{B}_{10}\mathbf{W}_{11} = \mathbf{R}^{-1}\mathbf{B}_{11}\mathbf{W}_{20} = \mathbf{R}^{-1}\mathbf{B}_{20}\mathbf{W}_{21} = \mathbf{R}^{-1}\mathbf{B}_{21} \qquad (27)$$

From (25) and (26), we can estimate the frequency response of the MIMO channel.

3.2 MIMO Decoder

After estimation of channel response, MIMO decoding is performed. In the following we use a V-BLAST-based algorithm, which performs the MIMO decoding and frequency domain equalization for ESPAR antennas simultaneously. In the following, we assume the number of subcarriers used for data transmission is 56 as same as IEEE 802.11n standard. Similar to the ESPAR antenna-based diversity receiver in Sec. 2, the inter-channel interference is generated at the ESPAR antenna. Therefore, the number of received symbol is 58. The block diagram of detection processing of two VBLAST processor is shown in Fig.3. In order to reduce the computational cost, we use two half-size V-BLAST processor. The upper and lower frequency components of the FFT output signals are applied to corresponding VBLAST processors. The V-BLAST processors performs MIMO decoding and frequency domain equalization, simultaneously. The algorithm utilize the linear nulling and succesive interference

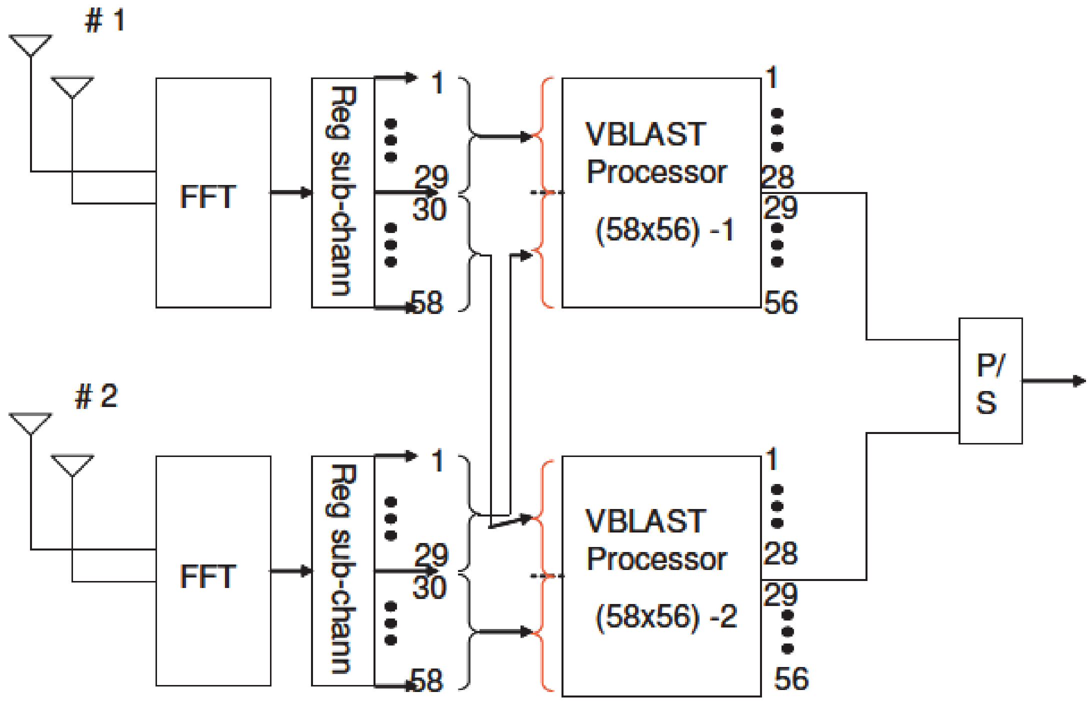

Fig. 3 VBLAST Detection

cancellation process to estimate N transmit symbols from the received signal vector [6]. The symbol is first detected using a linear process such as ZF or minimum mean square error (MMSE). The detected symbol is regenerated, and the corresponding signal portion is substracted from the received signal vector. This cancelation process results in a modified received signal vector with fewer interfering signal component. These processes are repeated, until all N symbols are detected.

4 Numerical Results

4.1 System Parameter

The transmitted symbol belong to a QPSK constellation and are obtained from the information bits through of usual modulation. In this simulation we use pilot sequence of HTLTF (High Throughput Long Training Field) based on IEEE.802.11n [3] for frequency is 20 MHz. The total number of subcarriers is 56, Pilot sequence is HTLTF, QPSK Modulation, VBLAST detection, 2x2 antenna dimension.

4.2 Performance Assessment

This section we show output simulation for MIMO-OFDM ESPAR 2Tx-2Rx. The results of the simulation under Rayleigh fading channel environment is shown in Fig.4.

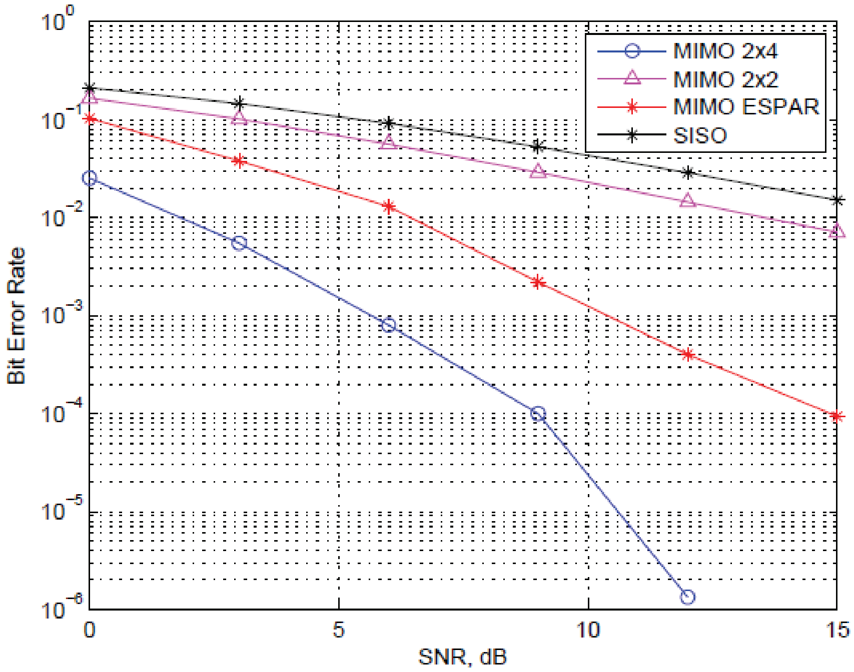

Fig. 4. BER Performance for MIMO-OFDM ESPAR

The performances is compared to the corresponding performance of MIMO-OFDM conventional system 2Tx-4Rx, 2Tx-2Rx and SISO system, respectively using the same modulation schemes. As can be seen from the Fig.4, MIMO-OFDM ESPAR yields results better than MIMO conventional system 2Tx-2Rx and SISO system. As it is known that MIMO conventional system 2Tx-2Rx can't get diversity gain as a MIMO conventional 2Tx-4Rx, but MIMO-OFDM ESPAR 2Tx-2Rx can yields better performance for increasing diversity gain than MIMO-OFDM conventional 2Tx-2Rx. But MIMO-OFDM ESPAR 2Tx-2Rx is worse than MIMO conventional 2Tx-4Rx, because the fewer number of antennas.

5 Conclusion

This work has shown that MIMO-OFDM receiver using a single active antenna array architecture such as ESPAR antenna it is possible to achive spectral efficiency gain comparable. In future research we will implementation espar antenna for MIM)-OFDM system using Universal Software Radio Peripheral (USRP).

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