Signaling-Embedded Preamble Design for OFDM System with Transmit Diversity

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Abstract—In this paper, a signaling-embedded preamble design is proposed for the orthogonal frequency division multiplexing (OFDM) system with transmit diversity. Utilizing the transmit diversity, two identical training sequences (TSs) are embedded in two OFDM symbols separately in discrete Fourier transform (DFT) domain and transmitted by two different antennas simultaneously. The relative distance between the two TSs in DFT domain could be varied in order to indicate several bits of signaling information for the receiver to acquire the transmission parameters signaling (TPS) quickly. Furthermore, the preamble can also be used for frame synchronization, carrier frequency offset (CFO) estimation, and coarse channel estimation. The computational simulations were carried out under both additive white Gaussian noise (AWGN) and multipath channels, and the results demonstrated the design works accurately on the preamble detection, CFO estimation and signaling demodulation under both static and dynamic channels.

I. INTRODUCTION

Wireless communications have received extensive attention nowadays for its wide applications in daily life. In spite of having more convenience than the cable-based communications, it has to deal with the severe propagation channel conditions including the time selectivity caused by the Doppler spread and the frequency selectivity caused by the multipath delay spread [1]. The space diversity techniques, also known as the multiple transmit and receive antenna schemes, have been proposed as efficient techniques to improve the system performance under time-selective fading channels in wireless situations [2]. Among them, the transmit diversity techniques has drawn much attention with reasonable complexity and low cost in receiver [3] [4], especially in broadcasting systems. In recent years, OFDM is utilized to combat frequency-selective fading channels [5], which is widely adopted in digital television terrestrial broadcasting (DTTB) system [6] [7], wireless local area network (WLAN) [5] and so on. Combining these two techniques can acquire robust transmission and thus is believed to achieve better system performance. For instance, the European second generation standard for digital video terrestrial broadcasting (DVB-T2) recommended the combination of transmit diversity and OFDM to achieve more reliable transmission [8]. To accommodate different application environments, wireless communication systems should provide several transmission modes, such as different symbol constellation types, various channel coding rates, multiple choices of guard intervals and so on. Therefore, it is important to have a fast and reliable method to transmit and detect TPS for succeeding processing and data demodulation. In the existing commercialized systems, such as the digital video terrestrial broadcasting (DVB-T) system [9] and the digital television/terrestrial multimedia broadcasting (DTMB) system [7], the TPS is transmitted within the OFDM blocks which occupies additional spectrum. To improve the signaling transmission method and save spectrum resources, a specially designed P1 symbol is employed by DVB-T2 as the preamble of the OFDM signal frame [8]. The P1 symbols could give a quick detection of the DVB-T2 signal and carry basic transmission parameters. However, the P1 symbol uses different sequences to carry the 7 signaling bits, which causes more complexity on the detection of the sequences. An improved preamble design with a pair of training sequences inserted in the DFT domain and their distance indicating the TPS was proposed in [10]. Furthermore, a pseudo-noise (PN) TS design with embedded signaling in the time domain synchronous block transmission (TDS-BT) system is presented in [11]. In this contribution, an OFDM-based preamble for the OFDM system with transmit diversity utilizing improved time-domain structure is proposed. In the given transmit diversity scheme, two identical TSs are embedded in two OFDM symbols separately and transmitted by two different antennas simultaneously. The relative distance between the two TSs in DFT domain could be varied to indicate several bits of signaling information for the receiver to acquire the basic transmission parameters quickly. Furthermore, the preamble structure is well designed and can be used for frame synchronization, CFO estimation, and coarse channel estimation. The rest of the paper is organized as follows. Section II describes the system model for the OFDM system employing transmit diversity and the proposed OFDM-based preamble design. Section III investigates the preamble detection and frame synchronization method, the corresponding CFO estimation and TPS detection algorithm as well. In Section IV the computational simulations are performed to evaluate the proposed methods. Finally, Section V concludes the paper.
II. SYSTEM MODEL AND PREAMBLE DESIGN

A. System Model

The block diagram of the preamble conveying TPS in OFDM system with transmit diversity is shown in Fig. 1. The m-sequence and its cyclic shifted version modulated by the TPS are utilized as the TSs to be inserted into two OFDM symbols. After the inverse discrete Fourier transform (IDFT) operation of the OFDM symbols, the two preambles were transmitted separately by two antennas simultaneously. At the receiver, the signals from two channels added naturally and the TS can be derived through the relative distance detected by differential correlation between the received signals and the local TS in the DFT domain [12]. The received signal considering CFO and channel noise is represented as

\[ r(n) = s_1(n-n_0) \otimes h_1(n-n_0) + s_2(n-n_0) \otimes h_2(n-n_0) + e^{j2\pi f_c n} + \nu(n), \]  

where \( n_0, f_c, \) and \( \nu(n) \) denote the arrival time delay, CFO and channel noise and \( \otimes \) is the linear convolution, \( s_i(n), i=1,2 \) are the time-domain transmitted signals in the two transmit antennas, and \( h_i(n), i=1,2 \) are the channel impulse responses (CIR) of the two channels between the two transmit antennas and the receive antenna. The CFO is usually normalized by the sub-carrier spacing \( 1/N \) as,

\[ f_c = m_{int} \cdot \frac{1}{N} + f_{fic}, \]

where \( m_{int} \) is an integer and \( f_{fic} \) is the fractional part of CFO.

B. Preamble Design in DFT domain

In this section, the proposed preamble design for the OFDM system with transmit diversity, in which the TPS is embedded without additional costs, is investigated.

As illustrated in Fig. 2 and Fig. 3, TSs are carried by two OFDM symbols sent via two transmit antennas (abbreviated as TX1 and TX2, respectively). The adopted TSs utilize the m-sequence due to its good auto-correlation property. The OFDM symbol for TX1 has the TS only allocated on the even sub-carriers and the TX2 has the same sequence only on the odd sub-carriers. Furthermore, the TS of TX2 is the cyclic shift of that of TX1, while the TS of TX1 is fixed. The cyclic shift length \( dL \) could be varied to indicate different signaling information. There are totally \( L \) choices for the shift length corresponding to \( \log_2 L \) bits of signaling. The OFDM symbol representations mentioned above are given by,

\[ X_1(2k) = C((k-N/4+L/2-1/2), N/2-L < 2k < N/2+L) \]
\[ X_1(2k+1) = 0, \quad 2k < N/2-L, \text{ or, } 2k > N/2+L \]
\[ X_2(2k+1) = C((k-dL-N/4+L/2-1/2), N/2-L < 2k+1 < N/2+L) \]
\[ X_2(2k+1) = 0, \quad 2k+1 < N/2-L, \text{ or, } 2k+1 > N/2+L \]

where \( X_1(k), X_2(k) \) are the OFDM symbols in DFT domain for TX1 and TX2, respectively, \( C(k) \) is the local m-sequence with length of \( L (L < N/2) \), and the \( (\cdot)_L \) denotes the modular with \( L \) operator.

C. Preamble Design in Time-domain

Since only even sub-carriers are used in TX1, the time-domain signal of OFDM symbol for TX1 is composed of two identical parts, denoted as ‘A’ and ‘A’ and shown in Fig. 2. Moreover, the last half part ‘A’ is copied to the front as CP and also copied to the rear multiplying with negative sign, so the preamble has a structure of \([A,A,A,-A]\). Similarly, the time-domain signal of OFDM symbol for TX2 has an original structure of \([B,-B]\). After being added the prefix -B and postfix B, the preamble structure finally turns to \([-B,B,-B,B]\)

Fig. 1. The system model for signaling transmitting in OFDM system with transmit diversity.

Fig. 2. The OFDM-based preamble for the Tx1.

Fig. 3. The OFDM-based preamble for the Tx2.
as shown in Fig. 3. The time-domain signals for two transmit antennas are thus represented as,

\[ s_i(n) = \begin{cases} 
  x_i(n + N/2), & 0 \leq n < N/2 \\ 
  x_i(n - N/2), & N/2 \leq n < 3N/2 \\ 
  -x_i(n - N), & 3N/2 \leq n < 2N 
\end{cases} \]  

(5)

where \( x_i(n), i = 1, 2 \) are the IDFT of the \( X_i(k), i = 1, 2 \), and \( s_i(n), i = 1, 2 \) are the preambles transmitted on Tx1 and Tx2, respectively.

III. DETECTION ALGORITHM

At the receiver, the frame synchronization and fractional CFO estimation could be accomplished by means of the time-domain structure of the preambles. The integer CFO and TPS can be detected after the DFT operation of the received signals. The detailed explanation and analysis are presented as follows.

A. Preamble Detection and Frame Synchronization

Regardless of the noise and the other interferences, the ideal received signal in the receiving antenna is shown in Fig. 4. As shown in Fig. 4, the timing synchronization can be implemented according to the cyclic properties of the proposed preamble. Three cyclic parts are observed and used for slide auto-correlations (SACs) calculated by

\[ R_1(n) = \sum_{l=0}^{N/2-1} r(n+l) \cdot r^*(n+l+N) \]  

(6)

\[ R_2(n) = \sum_{l=0}^{N/2-1} r(n+l) \cdot r^*(n+l+3N/2) \]  

(7)

\[ R_3(n) = \sum_{l=0}^{N/2-1} r(n+l+N) \cdot r^*(n+l+3N/2) \]  

(8)

Then, a product of the three correlation results can make the peak more distinct,

\[ R_c(n) = R_1(n) \cdot R_2(n) \cdot R_3(n) \]  

(9)

Fig. 5 shows the SACs of the received preamble under AWGN channel at signal to noise ratio (SNR) of 5dB. Thus, the start point of the OFDM symbol and the estimated fractional CFO are obtained through the correlation peak as

\[ \hat{n}_0 = \arg \max_n (R_c(n)) \]  

(10)

\[ \hat{j}_{frc} = \arg \left( R_1(\hat{n}_0) \right) \frac{2\pi N}{\arg(\mathbb{1}_i)} \]  

(11)

where \( \arg \max(\cdot) \) and \( \arg(\cdot) \) denote the argument that maximize the function and the phase angle of a complex number, respectively.

The fractional CFO correction is performed based on the estimated frequency error \([?]\). Then N samples from the start point are selected as the OFDM symbol and converted to the DFT domain by N-point DFT operation to perform the following operation.

B. Differential Correlation in the DFT Domain

To achieve larger CFO range, the received OFDM symbol in time domain is firstly compensated by the fractional CFO and then transformed to the DFT domain. The compensated received signals in both time and DFT domains are given by,

\[ y(n) = r(n) \cdot e^{j2\pi f_{frc} n} = [x_1(n) \otimes h_1(n) + x_2(n) \otimes h_2(n)] \cdot e^{j2\pi \frac{\nu}{N} n} + v(n) \]  

(12)

\[ y(k) = \text{DFT}(y(n)) \]  

(13)

\[ = \sum_{i=1}^{2} X_i((k - m_{int})_N) \cdot H_i((k - m_{int})_N) + V(k) \]  

where \( H_i(k), i = 1, 2 \) and \( V(k) \) denote the two channel frequency responses (CFRs) and DFT of the channel noise.

It should be pointed that the integer CFO leads to a cyclic shift of the whole sub-carriers, which could be detected through a cross correlation with the local TS and the shift distance is inferred from the correlation peak position.

As mentioned in [12], the normal cross-correlation might be degraded by the phase rotation. Furthermore, under multipath channels, the cross-correlation will also be deteriorated by the channel frequency-selectivity. Thus, the D-spaced differential correlation algorithm should be adopted. Fig. 6 represents the diagram of the differential correlation operation. The algorithm...
exploits the differential property of the m-sequence, namely the differential operation of an m-sequence is the cyclic shifted version of itself [11], which is described as

\[ C^{(D)}(k) = C(k) \cdot C^*((k - D)L) = C((k - M(D))L) \]  

(14)

where D is the differential length. Therefore, the differential correlation result is given by

\[ \text{Corr}_D(k) = \sum_{l=0}^{L-1} R_D(k + l) Z_D^*(l) \]  

(15)

where \( R_D \) and \( Z_D \) are the differential correlation results of the received signal and the local m-sequence in DFT domain, respectively, i.e.,

\[ R_D(k) = Y'(k) \cdot Y^* \]  

(16)

\[ Z_D^*(k) = C'(k) \cdot C^* \]  

(17)

where the \( Y'(k) \) is the length-2L sequence in the middle of \( Y(k) \), and the \( C'(k) \) is the original m-sequence padding with zeros between each adjacent sub-carriers, and illustrated as

\[ Y'(k) = Y(k + N/2 - L), k = 0, 1, ..., 2L - 1 \]  

(18)

\[ C'(k) = \begin{cases} 
C(k/2), & k = 0, 2, ..., 2L - 2 \\
0, & k = 1, 3, ..., 2L - 1 
\end{cases} \]  

(19)

The correlation results in (15) are expected to generate two peaks, as illustrated in Fig. 7. The simulation examples are performed under AWGN channel at SNR = 0dB with CFO = 0 and 300 kHz, respectively. The integer CFO could be estimated from the shift length of the first peak from its reference position when CFO=0, while the signaling is detected from the distance between those two peaks.

IV. SIMULATION RESULTS

In this section, computer simulations were implemented to evaluate the performance of the proposed OFDM-based preamble design. The simulation parameters are listed in Table I. The length of TS is chosen to be 255 indicating nearly 8-bit TPS. We adopt the AWGN channel and Brazil-A channel model [7] to evaluate the detection algorithm with the maximum Doppler spreads of \( fd=20 \) Hz and \( 60 \) Hz, respectively. The profiles of Brazil-A channel are listed in Table II. Firstly, the TPS could only be detected after correct frame synchronization. The detection performance of the preamble is evaluated by the false probability and the missed probability of the SAC peak detection, which is analyzed in [13]. Hereby, we present the computer simulation results for the detected probability, the lost probability, as well as the false probability of frame synchronization in both AWGN and Brazil-A channel in Fig. 8. Both simulation results show that the preamble could be detected and the frame could be synchronized with no error when the signal-to-noise power ratio (SNR) is above -5dB. For the proposed signaling-embedded method, since the TPS is carried through the cyclic shift length of two TSs on the different OFDM symbols, only both peak positions are correctly detected then the TPS could be obtained. The false
A new signaling preamble design for the OFDM systems with transmit diversity has been presented in this paper, which utilizes the m-sequence allocated in OFDM symbols for different antennas with relative distance indicating TPS. The simulation results show that the method for preamble detection has satisfactory precision and is simultaneously robust to CFO for OFDM systems with transmit diversity in both AWGN channel and dynamic multipath channel. Furthermore, the design can be used to perform frame synchronization, estimate the CFO and transmit the TPS without additional cost. The proposed signaling-embedded preamble design is expected to give a robust TPS transmission method for other OFDM systems with transmit diversity.

\[ P_{f,TPS} = 1 - (1 - P_{f,peak})^2 \]  

where \( P_{f,peak} \) is the false probability of the single differential correlation peak detection. In the signaling detection algorithm, the TPS is detected together with the integer CFO estimation, which are depicted in Fig. 9.

In Fig. 9, six cases are simulated, corresponding to the CFO estimation and signaling detection under AWGN channel, the Brazil-A channel with maximum Doppler spread of 20Hz and of 60Hz, respectively. It can be observed that the system performance will get worse with the deterioration of the propagation channels. Furthermore, the CFO estimation has better precision than the signaling detection under the same conditions.

**REFERENCES**


