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Improved Preamble Structure for Timing Synchronization in MIMO-OFDM Systems

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Abstract ***— In Multiple Input Multiple Output (MIMO) Orthogonal Frequency Division Multiplexing (OFDM systems, symbol timing synchronization is important inorder to find an estimate of where the symbol starts. In this paper, an efficient preamble structure is proposed for improving the timing synchronization in MIMO-OFDM systems. The proposed short preamble consists of four sub symbols having equal duration. The first and third sub symbols are Constant Amplitude Zero Autocorrelation (CAZAC) sequences while second and fourth are CAZAC sequences weighted by Pseudorandom Noise (PN) sequences. Simulation results show that the proposed preamble structure could provide sharper correlation peak when compared to the conventional Schmidl's and Minn's methods in both AWGN and Rayleigh channels. Also the Correct Detection Rate (CDR) of the proposed method is better than the conventional methods at high SNR values. Hence a better timing synchronization can be achieved.***

Index Terms**— CAZAC, Correct Detection Rate, MIMO, OFDM, Timing Synchronization***

I. INTRODUCTION

Orthogonal Frequency Division Multiplexing (OFDM) is a multicarrier modulation technique which is best suited for future wireless communication systems. OFDM has the advantage of having higher bandwidth efficiency and ability to resist Inter Carrier Interference (ICI) and Inter Symbol Interference (ISI). The basic principle of OFDM is that a high speed data stream is assigned to mutually orthogonal channels. In normal single carrier modulation techniques like BPSK, QPSK etc, the incoming data is modulated using a single carrier while OFDM employs several carriers within the allocated bandwidth. Each carrier uses one of the several available digital modulation techniques (BPSK, QPSK, QAM etc..,). For preserving the orthogonality among carriers, cyclic prefix or guard intervals are inserted among the subcarriers. The length of the cyclic prefix should be longer than the delay spread of the channel to avoid ISI. One of the major challenges in wireless communication systems is fading. In frequency selective fading where different frequency component of the signal experiences different fading, handling the channel is difficult and also the design of receiver become complicated. OFDM overcomes this problem by converting the entire frequency selective channel into narrow flat fading channels.

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Multiple input multiple output (MIMO) systems using several transmit and receive antennas can be employed along with OFDM systems to increase the transmission rate exponentially. MIMO-OFDM is a powerful combination because MIMO takes care of fading loss while OFDM mitigates ISI. When the transmitter does not possess Channel State Information (CSI) this combinational system can achieve very high spectral efficiency. MIMO-OFDM systems are very sensitive to synchronization errors. The overall performance of the system gets deteriorated in the presence of timing and frequency offsets. The main objective of symbol timing synchronization is to detect the start of the received OFDM symbol. For this purpose either data-aided or non-data-aided timing synchronization can be used. Data-aided refers to synchronization using training sequences. Non-data-aided timing synchronization algorithms perform synchronization by estimating the timing and frequency characteristics of received signal. Most of the timing synchronization algorithms are based on preamble approach [1],[2] because of low computational complexity, fast synchronization speed and high estimation accuracy. This paper is organized as follows. Section II briefly introduces the MIMO-OFDM signal model and reviews the conventional Schmidl's and Minn's methods. Section III describes the proposed method and the detection algorithm. The performance of proposed preamble structure compared to the conventional methods evaluated using MATLAB simulation is given in Section IV. Finally, the whole paper is concluded in Section V.

II. SYSTEM MODEL

The block diagram of an OFDM transceiver is shown in Fig.1

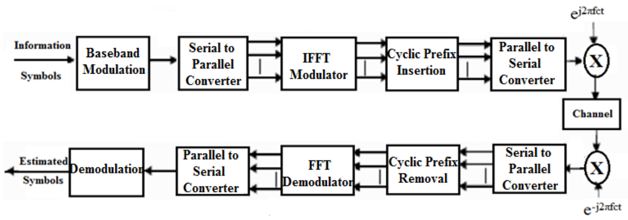

Fig. 1. OFDM Tranceiver

A simple 2x2 MIMO-OFDM system with two transmit and receive antennas are considered here. Fig.2 shows this system. The OFDM symbol transmitted from the i_{th} transmitting antenna is given by [5]

$$S_i(n) = \frac{1}{\sqrt{N}} \sum_{p=0}^{N-1} S_i(\mathrm{p}) e^{\frac{\mathrm{j}2\pi \mathrm{np}}{\mathrm{N}}} \qquad (1)$$

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where N is the number of sub-carriers for one OFDM symbol. The system is assumed to be operating in a rich multipath environment. The channel between i_{th} transmit antenna and j_{th} receive antenna is given by

$$h_{i,j}(n) = \sum_{q=0}^{N-1} h_{i,j}(q)\delta(n-q) \qquad (2)$$

where $h_{i,j}(q)$ is the q_{th} path gain from the i_{th} transmit antenna to the j_{th} receive antenna. The signal at the j_{th} receive antenna is obtained as

$$r_j(n) = (x_0(n) + x_1(n))\, e^{\frac{-j2\pi\epsilon n}{N}} + w_j(n) \qquad (3)$$

where j= 1,2. w(n) is a white complex Gaussian noise. 'ϵ' is the carrier frequency offset due to Doppler effect and inherent instabilities of transmitter and receiver oscillators.

$$x_i(n) = \sum_{i=0}^{1}\sum_{q=0}^{d-1} h_{i,j}(q) S_i(n-q) \qquad (4)$$

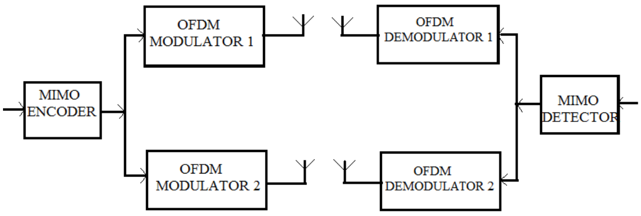

Fig. 2. MIMO-OFDM System

In [1], Schmidl and Cox proposed a long preamble structure having two identical halves which has been adopted into WLAN-based standards IEEE 802.11g [7] and WMAN-based standards IEEE 802.16e [8]. Two halves of the preamble are made identical by transmitting pseudo noise (PN) sequence on the even frequencies and zeroes in the odd frequencies. The time domain structure is shown in fig.3 and can be expressed as [P_N P_N].

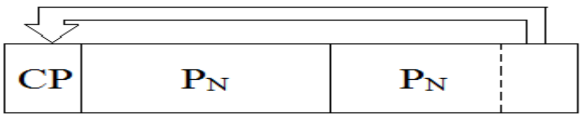

Fig. 3. Schmidl's Method

The timing metric is obtained by taking the sliding autocorrelation (SAC) and is expressed as:

$$M(d) = \frac{|P(d)|^2}{(q(d))^2} \qquad (5)$$

where

$$P(d) = \sum_{k=0}^{\frac{N}{2}-1} r^*(d+k)\, r\left(d+k+\frac{N}{2}\right) \qquad (6)$$

and

$$q(d) = \sum_{k=0}^{\frac{N}{2}-1} r\left(d+k+\frac{N}{2}\right)^2 \qquad (7)$$

r(n) is the received signal in time domain. The main drawback of Schmidl's method is that the sliding autocorrelation of this preamble produces broad plateau around the correct timing position due to the insertion of cyclic prefix which makes it difficult to determine the start of incoming signal at the receiver. To overcome the broad plateau problem of Schmidl's method, Minn [2] proposed a short preamble structure as shown in fig.3. The time domain structure of this preamble can be expressed as [P_N P_N $-P_N$ $-P_N$]. The timing metric corresponding to this preamble structure is

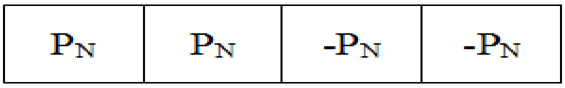

Fig. 4. Minn's Method

$$M_1(d) = \frac{|P_1(d)|^2}{(q_1(d))^2} \qquad (8)$$

where

$$P_1(d) = \sum_{l=1}^{2}\sum_{1=0}^{\frac{N}{4}-1} r^*\left(d+(l-1)\frac{N}{2}+k\right) r\left(d+(l-1)\frac{N}{2}+\frac{N}{4}+k\right) \qquad (9)$$

and

$$q_1(d) = \sum_{l=1}^{2}\sum_{k=0}^{\frac{N}{4}-1} r\left(d+(l-1)\frac{N}{2}+\frac{N}{4}+k\right)^2 \qquad (10)$$

Minn method overcomes broad plateau problem to a certain extend but introduces several sub peaks when the SNR is low which leads to high false detection probability.

III. PROPOSED PREAMBLE STRUCTURE

The proposed short preamble structure is composed of a single time domain OFDM symbol. The preamble symbol consists of four sub symbols inorder to obtain improved timing synchronization. The sequences used as training symbol are Constant Amplitude Zero Autocorrelation (CAZAC) [9] sequences and CAZAC weighted with PN sequences. The weighted sequence is generated by bitwise multiplication of CAZAC sequence with PN sequence of same length. Both sequences are placed alternatively in time domain. CAZAC and PN sequences are used commonly as they are easy to generate and have good autocorrelation properties. Autocorrelation of PN sequence is similar to a Dirac pulse. On the other hand, CAZAC sequences maintain constant amplitude and zero auto correlation means there is no interaction between the users. Short training symbol using CAZAC sequence is shown in fig.4.

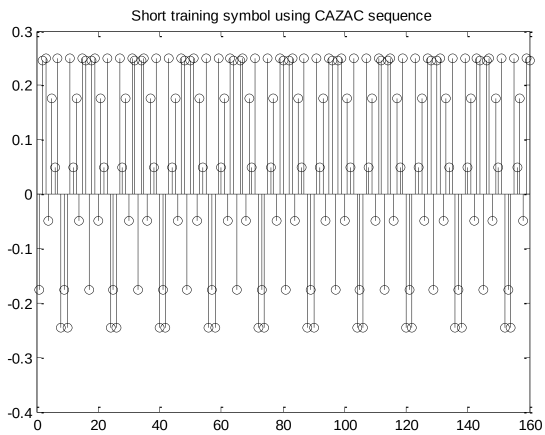

Fig. 5. Short Training symbol using CAZAC Sequence

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CAZAC sequences can be expressed by the following equations :

$$x(n) = \begin{cases} e^{\frac{j\pi M n(n+1)}{N}}, & \text{if } N \text{ is odd} \\ e^{\frac{j\pi M n^2}{N}}, & \text{if } N \text{ is even} \end{cases} \qquad (11)$$

where N is the length of CAZAC sequence, M is a natural number relatively prime to N and 0 ≤ n ≤ N-1. The time domain representation of the proposed preamble is shown in fig 5. C_Z represents CAZAC sequence and W, the weighted sequence which is obtained by the bit wise multiplication of CAZAC with PN sequence. The proposed preamble structure consists of length *'N'* OFDM symbols with its two cyclic extensions, thus the total length of the preamble is 2N.

C_Z	W	$-C_Z$	-W

Fig. 6. Proposed Method

For detecting the start of the frame, the idea is to search for strongly correlated symbols. This is identified by searching the maximum of timing metric. The timing metric for the proposed preamble structure is obtained as

$$M_2(d) = \frac{|P_2(d)|^2}{(q_2(d))^2} \qquad (12)$$

where

$$P_2(d) = \sum_{k=0}^{\frac{N}{4}-1} r^*(d+k)\, r(d+k+N) \qquad (13)$$

and

$$q_2(d) = \sum_{k=0}^{\frac{N}{4}-1} r(d+k+N)^2 \qquad (14)$$

IV. EXPERIMENT RESULT

The methods described in section III are investigated by MATLAB simulations. The number of sub-carriers is chosen to be 256. The modulation technique used is 4-QAM. Rayleigh fading channel selective on frequency with AWGN is considered as the channel model. The result obtained based on the timing metric for the two methods proposed is shown in fig.7.

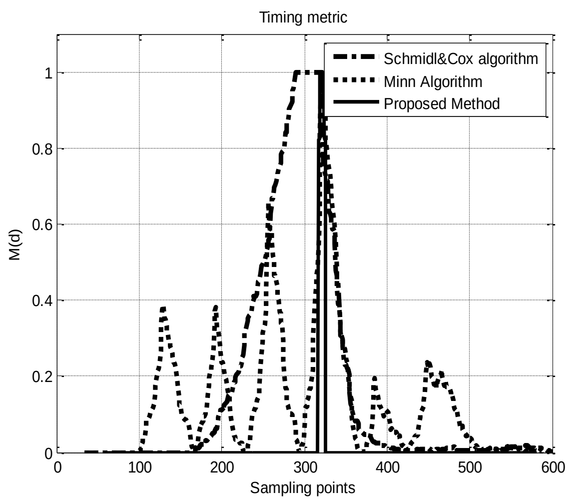

Fig. 7. Proposed Method

Comparison of proposed method with conventional methods shows that the timing metric of proposed preamble is sharper than the Schmidl's and Minn's preambles. So the ambiguity arose while determining the best timing sample point is significantly reduced. The estimation performance is also evaluated by computing the Correct Detection Rate (CDR). The CDR at practical SNR values from 0 to 25 dB is as shown in fig 8.

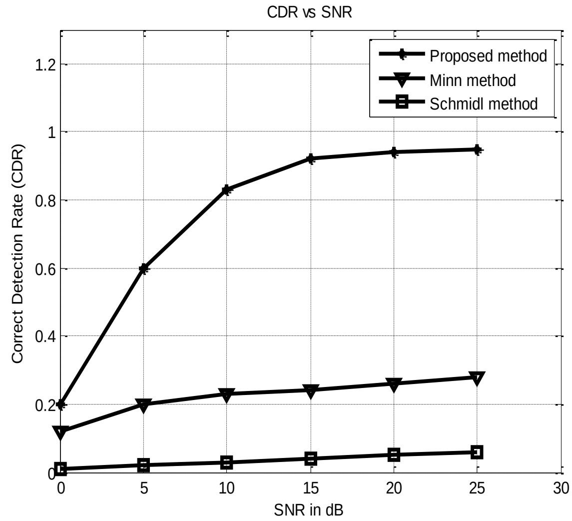

Fig. 8. Comparison of CDR

The correct detection rate is computed by 1000 iterations. The threshold value of the timing metric is set to be 0.5. The simulation result shows that for higher SNRs, CDR of proposed method is more than 0.8 while that of conventional methods are less than 0.5. Thus the proposed method provides better synchronization. The bit error probability of the improved method is also plotted over different SNR values as shown in fig.9

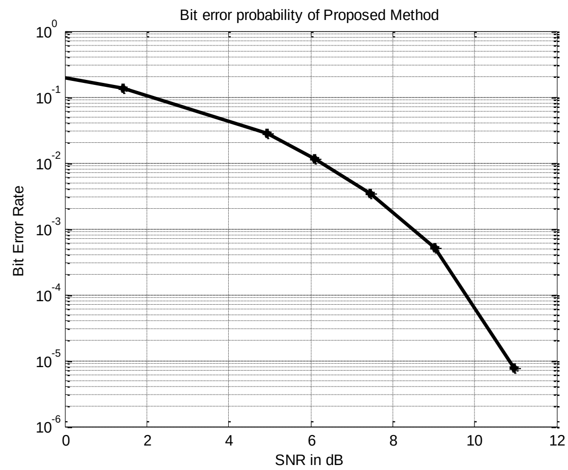

Fig. 9. Bit Error Probability

The improved algorithm is compared with the conventional Schmidl's and Minn's algorithms. The proposed algorithm could eliminate broad plateau of Schmidl's method and sub peaks of Minn's method and provide sharper peak when the sliding autocorrelation of the received signal is taken.

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V. CONCLUSION

This paper proposes an improved preamble structure to achieve better timing synchronization in MIMO-OFDM. Here CAZAC sequences and CAZAC weighted with PN sequences are placed alternatively in time domain. Compared to the conventional Schmidl's and Minn's methods, the proposed preamble structures provide sharper correlation peak and could achieve improved Correct Detection Rate (CDR), thereby providing better timing synchronization. These improved algorithms not only eliminate the broad plateau problem but also mitigates the sub peaks.

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