

Timing Synchronization in Cognitive Radio Systems Using Improved Preamble Structure

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Abstract: *In this paper, a new preamble structure is used for the timing synchronization of cognitive radio systems. The preamble is designed to achieve an improved performance by considerably reducing the broad plateau and thereby avoid the need for equalization. The estimation performance is also evaluated by computing the Correct Detection Rate (CDR). The application of the same is analysed in a cognitive radio environment.*

Keywords: Cognitive radio, OFDM, preamble, timing synchronization.

I. Introduction

Every wireless device from mobile phones to police scanners relies on access to radio frequency wireless spectrum. But spectrum scarcity is realized to be a major problem in wireless communication systems. Cognitive Radios (CR) can be a best choice to hold up dynamic spectrum access. In cognitive radio technology, the available radio spectrum is shared between an authorized primary user who possesses the license and a group of unauthorized secondary users and thus enhancing the spectral efficiency. Cognitive radios have the ability to sense the white spaces (unused frequency bands) in the spectrum and can adapt with the changes in the transmission environment, without causing interference with the licensed primary user. IEEE 802.22 WRAN (Wireless Regional Area Network) is the standardization of the application of cognitive radio technique which allows sharing of spectral holes in Television bands (UHF/VHF).

Orthogonal Frequency Division Multiplexing (OFDM) being one of the most flexible schemes for the implementation of cognitive radio technique is used in WRAN as a physical layer modulation scheme. In OFDM, several carriers are employed within an allocated spectral bandwidth and can be considered as a multicarrier modulation scheme with higher bandwidth efficiency. OFDM also has the ability to withstand Inter Symbol Interference (ISI) and Inter Carrier Interference (ICI). OFDM technique achieves this by maintaining a flat attenuation among the narrow subcarriers. By dividing a broadband channel to narrowband subchannels, the effect of frequency selective fading channel can be converted into flat fading. Cognitive Radio technique can be flexibly implemented using OFDM by leaving a set of subchannels unused and can effectively fill the spectral gaps without affecting the licensed primary user.

The technique used for the implementation of cognitive radio in this paper, hereafter called Fragmented Bandwidth Method (FBM) divides the total transmission bandwidth into several subbands. By spectrum sensing methods, vacant subbands can be identified and allocate them for cognitive radios.

Two factors that deteriorate the performance of OFDM systems are timing and frequency offsets. Detecting the correct starting point of the OFDM symbol is unavoidable for acceptable performance. Due to the low computational complexity and fast synchronization speed, preamble based timing synchronization is used here.

In [i] and [ii] conventional preamble based timing synchronization algorithms Schmidl & Cox's and Minn's methods are discussed. Pseudorandom Noise (PN) sequences are used as the preamble in both methods. In this paper, a better preamble structure consisting of CAZAC and PN sequences are used for improving the timing synchronization [iii].

The performance of the timing synchronization can be affected by the presence of interference from the unallocated subbands of the cognitive radios. The use of cyclic prefix with sufficiently long guard intervals provides protection against such interference [iv]. The analysis of timing synchronization in OFDM systems is mostly done by assuming these interferences as narrow band. Modelling the narrow band interference as unmodulated complex sinusoid and the performance analysis of the timing synchronization is proposed in [v].

In this paper, the performance of the modified preamble structure in achieving a better timing synchronization in the presence of primary user interference is analysed. The interference caused by the primary user in the cognitive radio bands are modelled as Additive White Gaussian Noise (AWGN).

The contents of the paper are organized as follows. Section II briefly explains the system model. The method used to implement an improved preamble structure is described in section III. The performance of proposed preamble structure compared to the conventional methods evaluated using MATLAB simulation is explained in Section IV. Finally, the paper is concluded in Section V

II. System Model

A. Spectrum Utilization

The primary users are authorized to use a pre-assigned band of frequencies in the transmission band. The cognitive radio system users also share the same transmission bandwidth. The cognitive radio user must not encroach into the active primary user's frequency band. With spectrum sensing techniques, the cognitive radio transmitter will collect the information about the spectrum. The transmitter deactivates those subcarriers which are found to be busy (presently used for transmission by the primary users). The cognitive radio system has the ability to map the changes in the spectral occupancy and can act accordingly. The system has the capability to activate the previously deactivated subcarriers if they are free to use and deactivate the previously active subcarriers if they are busy. Hence the operation of the cognitive radio system should be in such a way that the cognitive radio user must not interrupt the primary user's transmission. Let the entire common transmission band has a bandwidth W and has N subcarriers in it. According to 802.22 WRAN the number of subcarriers is taken as 2048. By implementing FBM, the entire band W is divided into several subbands. Let the number of subbands be

$B = 16$. Now each subband has N/B subcarriers. To reduce power leakage, only the subbands that shares same borders are selected to be activated. Here there will be

$$m = \frac{B(B+1)}{2} \quad (1)$$

modes of subband selection. Let the number of allotted subbands be B_A . Then the spectrum utilization factor ρ of the CR system is defined as :

$$\rho = \frac{B_A}{B} \quad (2)$$

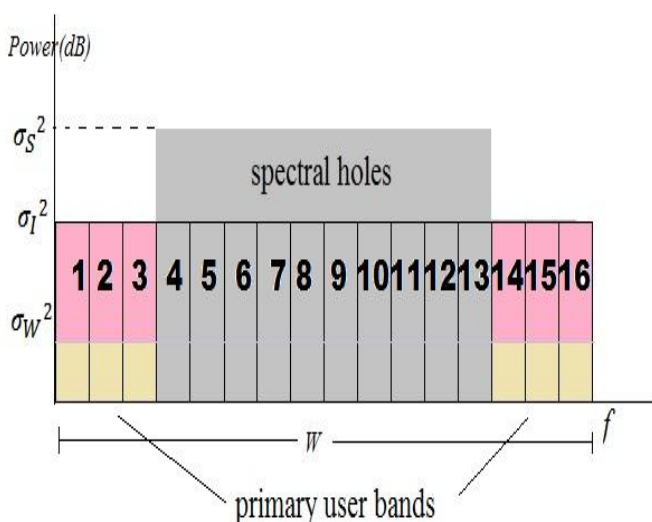


Fig. 1 Frequency representation of FBM

For example, let 10 contiguous subbands starting from subband 4 is activated for CR users as shown in fig. 1. Then the spectrum utilization factor $\rho = 10/16$. This CR system supports a total of 136 modes of subband selection.

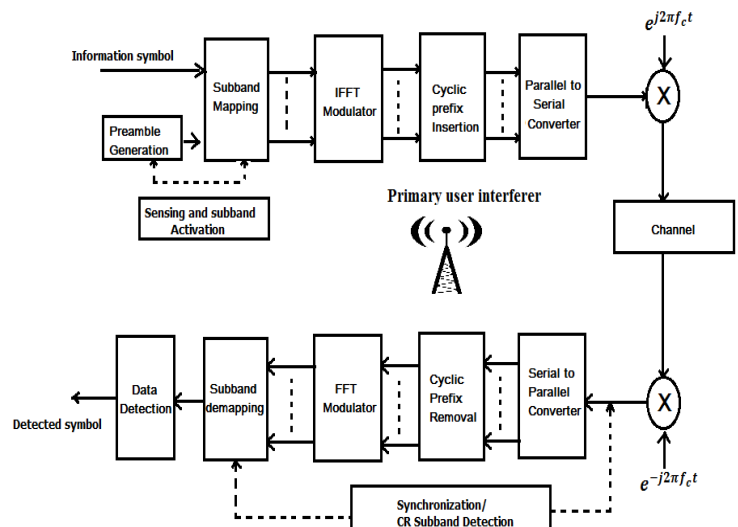


Fig. 2 System Model

B. Transmission Model

The schematic diagram of OFDM based cognitive radio system is shown in fig. 2. The spectrum sensing techniques along with the fragmented bandwidth method enables the set of frequency bands which are vacant and those subbands which are busy are nulled. The set of subbands selected corresponds to a certain mode of the FBM. The average signal power transmitted through the activated subbands is given by:

$$\sigma_s^2 = E[|S(n)|^2] \quad (3)$$

where $S(n)$ is the transmitted signal. For the analysis and modelling of the system, it is assumed that the entire band is affected with interference having same average power. The interference caused is modelled as AWGN $I(n)$ with zero mean and variance σ_I^2 . The channel under which the whole analysis is carried out is also modelled as Gaussian channel and this noise $W(n)$ is assumed to have a variance σ_W^2 . The received signal in time domain after analog to digital conversion at the cognitive radio receiver can be expressed as

$$y(k) = S(k) + I(k) + W(k) \quad (4)$$

where $S(k)$ is the transmitted message, $I(k)$ is the interference between subcarriers and $W(k)$ is the channel noise.

The signal to noise ratio in the active subbands can be computed from the knowledge of probability distribution of the corresponding signal and noise. SNR in active subbands can be expressed as

$$SNR = \frac{\sigma_s^2}{\sigma_w^2} \quad (5)$$

Another important quantity Signal to Interference Ratio (SIR) is expressed as

$$SIR = \frac{\sigma_s^2}{\sigma_I^2} \quad (6)$$

The average SNR for the entire band W is expressed as

$$SNR_{Av} = SNR \times \rho \quad (7)$$

Similarly the average SIR is expressed as

$$SIR_{Av} = \frac{\rho}{1-\rho} SIR \quad (8)$$

where ρ is the spectral utilization factor.

C. Preamble Design

In OFDM systems, usually the signal is transmitted as frames with several preambles preceding the data symbols. In [i], a long preamble structure is proposed by Schmidl and Cox which consists of two identical halves prepended by cyclic prefix expressed as $[P_N P_N]$. The two halves are made similar by transmitting PN sequence on the even frequencies and zeroes in the odd frequencies. Cyclic prefix helps to make the system robust to multipath propagation. The timing metric is obtained by taking the sliding autocorrelation (SAC). The timing metric for the instant d is:

$$M(d) = \frac{|P(d)|^2}{(Q(d))^2} \quad (9)$$

where

$$P(d) = \sum_{k=0}^{\frac{N}{2}-1} r^*(d+k) r\left(d+k+\frac{N}{2}\right) \quad (10)$$

and

$$Q(d) = \sum_{k=0}^{\frac{N}{2}-1} r\left(d+k+\frac{N}{2}\right)^2 \quad (11)$$

$r(n)$ is the received signal. But in this method, it is difficult to determine the start of incoming signal at the receiver because sliding autocorrelation of this preamble creates a broad plateau around the correct timing position.

In [ii], Minn proposed a short preamble structure to eliminate the broad plateau issue in Schmidl's method. 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

$$M_1(d) = \frac{|P_1(d)|^2}{(Q_1(d))^2} \quad (12)$$

where

$$P_1(d) = \sum_{l=1}^2 \sum_{k=0}^{\frac{N}{4}-1} r^*\left(d+(l-1)\frac{N}{2}+k\right) r\left(d+(l-1)\frac{N}{2}+\frac{N}{4}+k\right) \quad (13)$$

and

$$Q_1(d) = \sum_{l=1}^2 \sum_{k=0}^{\frac{N}{4}-1} r\left(d+(l-1)\frac{N}{2}+\frac{N}{4}+k\right)^2 \quad (14)$$

The method proposed by Minn could eliminate the broad plateau but several sub peaks were introduced at low SNR values leading to high false detection probability.

III. Methodology

In order to obtain improved timing synchronization performance, a preamble symbol consisting of four sub symbols are used here. Constant Amplitude Zero Autocorrelation (CAZAC) sequences and PN sequences are used as the training symbols. The constant amplitude and zero relative variance maintained by the CAZAC sequence help to avoid interference between the users. CAZAC sequences can be expressed as:

$$c(n) = \begin{cases} e^{\frac{j\pi n(n+1)Z}{L}}, & \text{if } L \text{ is odd} \\ e^{\frac{j\pi Zn^2}{L}}, & \text{if } L \text{ is even} \end{cases}$$

Where L , the length of CAZAC sequence, Z a natural number which is relatively prime to L and $0 \leq n \leq L-1$.

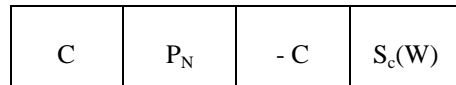


Fig.3 Preamble using CAZAC and PN

Fig. 3 shows the time domain structure of the preamble used. 'C' is the CAZAC sequences and 'P_N' represents PN sequences. By bitwise multiplying the CAZAC sequences with the PN, a new weighted sequence is obtained which is represented as 'W'. In order to obtain S_c(W), a scrambling operation is done by multiplying W with $(-1)^n$. The effect of narrow band interference can be reduced considerably with the aid of this scrambling operation.

At the receiver, by searching the strongly correlated symbols, the start of the frame can be detected. This is identified by searching the maximum of timing metric:

$$M_2(d) = \frac{|P_2(d)|^2}{(Q_2(d))^2} \quad (15)$$

The maximum value of $M_2(d)$ indicates the start of the frame. where

$$P_2(d) = \sum_{k=0}^{\frac{N}{4}-1} r^*(d+k) r(d+k+N) \quad (16)$$

and

$$Q_2(d) = \sum_{k=0}^{\frac{N}{4}-1} r(d+k+N)^2 \quad (17)$$

The timing metric has its peak value at the correct symbol starting point which is ensured by the correlation property of the sequences used as training symbol. The preamble design with different sub symbols could sharpen the correlation peak when compared with the Schmidl's method and Minn's method.

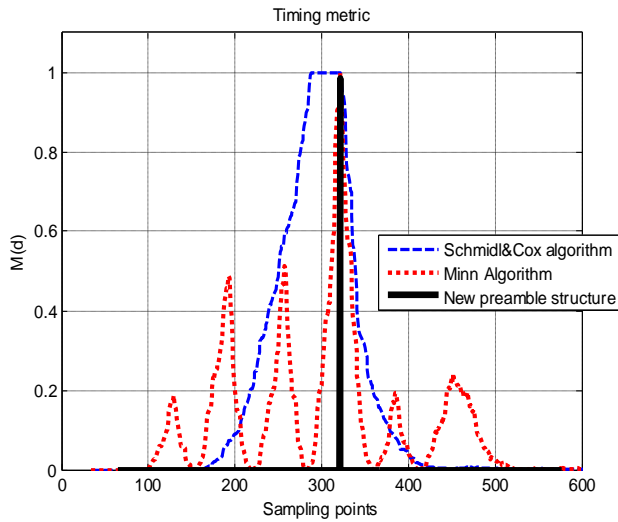


Fig. 4 Comparison of timing metrics

IV. Simulation Results

MATLAB simulations are used to implement the methods described in section III. 4-QAM is the modulation technique used. Frequency selective Rayleigh fading channel

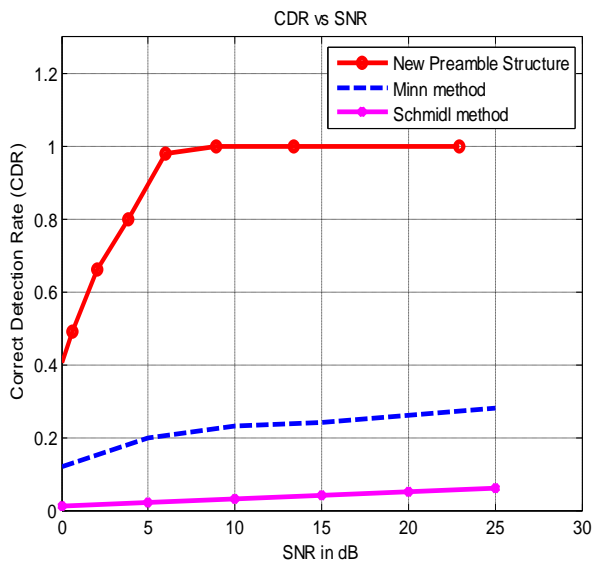


Fig. 5 CDR Comparison

with AWGN is taken as the channel model. The timing metric for the new preamble structure compared with the conventional methods are shown in fig. 4.

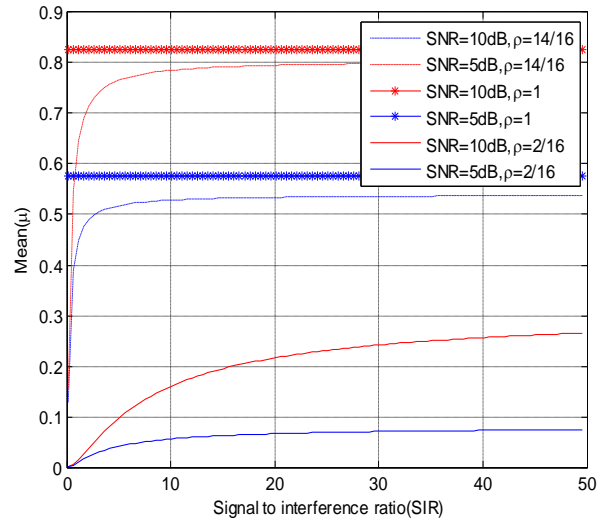


Fig. 6 Mean of timing metric for N=2048

Comparison shows that the timing metric using new preamble structure has a sharper correlation peak when compared with the existing methods. The difficulty in determining the start of the symbol is reduced significantly. The broad plateau issue in Schmidl's algorithm and the presence of subpeaks in Minn's algorithm could be eliminated in the new method. The Correct Detection Rate (CDR) versus SNR is also plotted for 1000 iterations. The threshold taken is 0.5. The simulation result in fig. 5 shows that the CDR of proposed method is more than 0.8 for higher SNRs which ensure better synchronization.

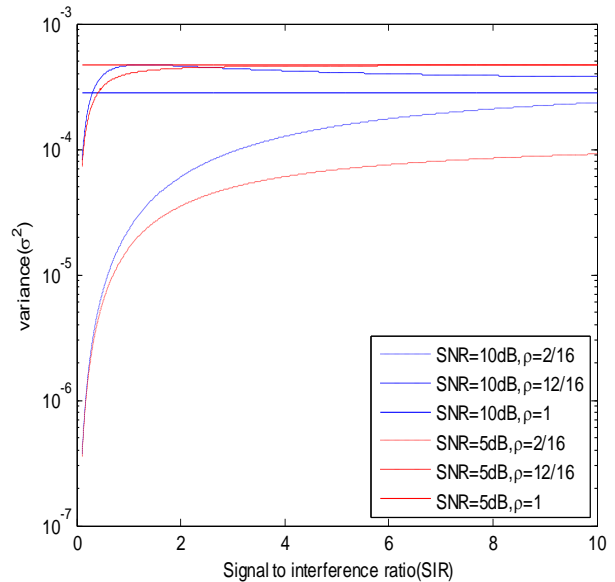


Fig. 7 Variance of timing metric for N=2048

The mean of timing metric for N=2048 is shown in fig. 6 and the variance of timing metric for the same value is shown in

fig. 7. The observations show that the timing metric approaches the maximum spectral utilization factor scenario for large values of SIR. As the spectral utilization factor ρ decreases, the value of SIR needed to get the required output increases as seen in the figures. The same result can be observed in the case of variance also.

V. Conclusion

The paper investigates the performance of an improved preamble structure for timing synchronization in Cognitive Radio system. The modified preamble structure mitigates the effect of narrow band interference. The simulated result shows better results than conventional timing synchronization algorithms and can be effectively implemented in cognitive radio systems. The simulation results also show that the spectral utilization factor has an important role in the system performance. Finally, the modified preamble structure and its application for the implementation in cognitive radio system gives satisfactory results both in the case of timing synchronization and spectral occupancy.

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