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Optimization of Non-Contiguous OFDM based Data Transmission Schemes in Cognitive Radio Transceivers

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Abstract: Cognitive radio is an emerging technology for the opportunistic use of under-utilized spectrum. It promises to change the future technological trends forever if employed properly. Spectrum sensing is the major function of a cognitive radio network. This paper proposes a new strategy transmission schemes under study, non-contiguous orthogonal frequency division multiplexing (NC-OFDM) and a modified form of multicarrier code division multiple access (MC-CDMA), are based on conventional OFDM and MC-CDMA schemes to optimize the overall performance in cooperative spectrum sensing. Optimization strategy is proposed in order to optimize the overall performance by varying the SNR. We consider optimization of cooperative spectrum sensing with energy detection to minimize the bit error rate (BER). Here, different error levels are founded by varying the SNR values to find the optimal number of CRs for minimizing the error levels.

Keywords: Cognitive Radio, Spectrum Sensing, Bit Error Rate, NC-OFDM

I. INTRODUCTION

Frequency spectrum is one of the most important resources in communications which is getting scarcer each day as the new communication technologies emerge and the number of wireless systems increases. Various studies reveal that the frequency spectrum allocated to licensed users (primary users or PUs) in different networks is not optimally used. Thus, a great deal of research has been carried out in order to optimally manage and use the frequency spectrum. Part of the frequency spectrum which is not used by licensed users is called spectrum hole. To improve the spectrum efficiency, the cognitive radio has proposed that the spectrum holes should be allocated to unlicensed users (secondary users or SUs). Hence, designing transmission techniques in physical layer is of great importance [1].

OFDM is also an appropriate solution for accessing existing spectrum opportunities in cognitive radio networks where, subcarriers of SU perform transmission in spectrum holes and if the PU wants to reuse its spectrum, the SU must leave PU frequency band in order to prevent interference, by deactivating or nullifying existing subcarriers in those frequency bands. This kind of OFDM is called non-contiguous OFDM (NC-OFDM) [2]. When NC-OFDM is used for transmission by a SU, factors such as allocated power to SU subcarriers, effective bandwidth of each subcarrier and consequently length of cyclic prefix (CP) should be reconfigured by radio resource management [3]. CP is a copy of some final samples of the OFDM symbol and added to data symbol before transmission. If its length is greater than channel delay spread, it removes the inter symbol interference resulting from multipath properties of the channel [4]. Estimating the length of channel delay spread is a difficult task and this length may be large and because CP does not carry useful information, it decreases spectrum efficiency [5]. Like conventional OFDM, CP also exists in NC-OFDM [6], whereas in cognitive radio, the CP not only decreases spectrum efficiency but also causes interference with PUs since a SU transmits in the vicinity of PUs and other SUs.

On the other hand, the effect of deactivating subcarriers when the SU is forced to leave the spectrum has been comprehensively investigated. Also, in this paper, all orthogonal filter banks of the wavelet transform, that is, Haar, Daubechies, Symlets and Coiflets, have been investigated. Also, the wavelet transform in NC-OFDM is aimed at removing CP, increasing the spectrum efficiency and decreasing the interference for both the PUs and SUs. Generally, the goal is to improve the effectiveness of NC-OFDM in the overlay spectrum sharing. The analytical results of SNR in Rayleigh channel show that the SNR level increases as the number of nullified subcarriers of SUs increases [7]. On the other hand, the simulation results of proposed scheme show that the bit error rate (BER) improves with the increase of the number of nullified subcarriers of SUs. Also, in order to select a proper filter order to use in NC-OFDM-based systems, the effect of increasing filter order in orthogonal wavelet families is investigated.

II. COGNITIVE RADIO NETWORK

The performance of a local detector degrades in the presence of propagation effects such as shadowing and fading caused by multipath. These channel conditions may also result in the problem of hidden node. Where a secondary transceiver is outside the listening range of a primary transmitter but close enough to the primary receiver to create interference. This is known as hidden terminal problem. These issues can be overcome using cooperative sensing (CS).Where neighbouring yet geographically distributed SUs cooperate in sensing a common PU transmission. It is achieved by exchanging sensing information among them before making a final decision. Most of the CS schemes stem from the field of distributed detection. Figure 1 shows an example of CS, where N SUs sense listening channels for the PU signal activity and send the sensing information on reporting channels to the fusion center (FC) or to the common receiver, it makes the final decision. It is very unlikely that all the channels between the PU and the SUs will be in a deep fade simultaneously. Thus cooperative detection helps in mitigating the channel effects through multipath diversity. Other benefits of cooperative detection include improved detector performance, increased coverage, simplified local detector design, and increased robustness to non-idealities. Therefore, CS has generated lot of interest in the cognitive radio literature.

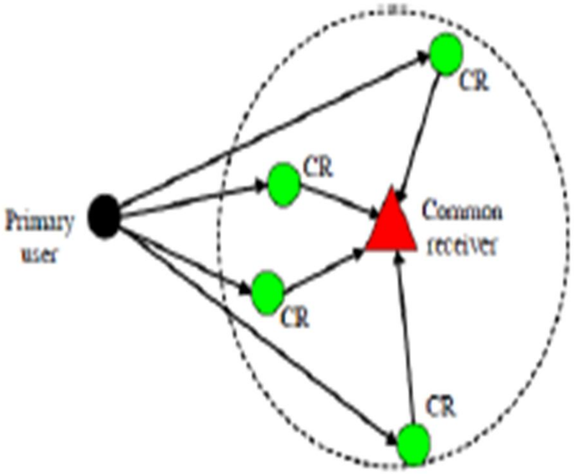

Figure 1: Spectrum sensing structure in a cognitive radio network

A. There Are Mainly Two Types Of Cooperative Spectrum Sensing

1) *Centralized Approach:* In this method, there is a central node within the network that collects all the sensing information from the neighbouring sense nodes within the network. It then process and analyzes the collected information and then determines the frequencies which are used and cannot be used. The cognitive radio central node can also organize the various cognitive radio users to undertake different measurements at different times.
2) *Distributed Approach:* In distributed approach of cognitive radio cooperative spectrum sensing there is no central or master node for all controlling operations. Instead communication exists between the different nodes and they are able to share sense information. However this approach requires for the individual radios to have a much higher level of autonomy and setting themselves up as an ad-hoc network.

Hidden terminal problem makes spectrum sensing more critical to implement. This problem is due to environmental conditions and creates the problems like multipath fading, shadowing. Due to this there may be a wrong interpretation of secondary user and loss of information occurs. So to remove this problem and to achieve efficiency in spectrum sensing, cooperative spectrum sensing is used.

Cooperative spectrum sensing will go through two successive channels: (i) Sensing channel (from the PU to CRs) and (ii) Reporting channel (from the CRs to the common receiver).

B. Advantages Of Cooperative Spectrum Sensing

1) *Hidden Terminal Problem is Reduced:* By using cooperative sensing system, it is possible to reduce the hidden terminal problem because a greater number of receivers will be able to build up a more accurate scenario of the transmissions in the area.
2) *Increase in Agility:* An increase in the number of spectrum sensing nodes by cooperation enables the sensing to be more accurate and better options for channel moves to be processed. There by providing an increase in agility.
3) *Reduced False Alarms:* Due to multiple nodes performing the spectrum sensing, channel signal detection is more accurate and this reduces the number of false alarms.

C. Disadvantage Of Cooperative Spectrum Sensing Significant Disadvantage Of Cooperative Spectrum Sensing Are

1) *Control Channel:* For the different elements within the cognitive radio cooperative spectrum sensing network to communicate, a control channel is required. This will take up a proportion of the overall system bandwidth.
2) *System Synchronization:* It is normally necessary to provide synchronization between all the nodes within the cognitive radio cooperative spectrum sensing network. Accurate spectrum sensing requires a longer period of time than a rough sense to see if a strong signal has returned. By adapting the sense periods, channel throughput can be maximized. But there is a greater need to maintain synchronization under these circumstances.
3) *Suitable Geographical spread of Cooperating Nodes:* In order to gain the optimum sensing from the cooperating nodes within the cognitive network, it is necessary to obtain the best geographical spread. In this way the hidden node syndrome can be minimized, and the most accurate spectrum sensing can be gained.

III. MIMO SYSTEM

In wireless communication environment, the main challenge is to combat multipath fading. Multipath is a phenomenon that occurs due to the arrival of the transmitted signal through different paths. The signal arrives at the receiver through different angles, with different time delays and different frequency shifts. As a result, the signal power at the receiver fluctuate giving rise to fading [6]. Apart from fading, constraints such as low power and limited bandwidth make the communication system designer's task of increasing data rate and reliability more challenging. MIMO technology can be used effectively to meet these requirements by taking advantage of multipath.

The Single Input Single Output (SISO) communication system consists of a single transmits and receive antenna. The capacity of a SISO system is given by Shannon’s capacity equation [7] as,

$$C = \log_2(1 + SNR)\, bits/\sec/Hz \qquad (1)$$

The multi-antenna systems can offer an advantage in terms of array gain, diversity gain, and multiplexing gain.

A. Array Gain

The coherent combining of wireless signals at the receiver end results in increase in SNR. This increase in SNR is called array gain. The coherent combining can be achieved through spatial processing at transmitter or receiver or both the locations.

B. Diversity Gain

Diversity gain can be achieved by providing multiple independent copies of the signal in space, time or frequency. When multiple copies of the signal are available at the receiver, the probability of receiving at least one copy correctly increases. Thus, the diversity gain is an improvement in link reliability.

C. Multiplexing Gain

The multiplexing gain is an increase in data rate without any additional power or bandwidth. This gain can be achieved by transmitting multiple independent data streams.

Quadrature amplitude modulation (QAM) is the name of a family of digital modulation methods and a related family of analog modulation methods widely used in modern telecommunications to transmit information. It conveys two analog message signals, or two digital bit streams, by changing (*modulating*) the amplitudes of two carrier waves, using the amplitude-shift keying (ASK) digital modulation scheme or amplitude modulation (AM) analog modulation scheme. The two carrier waves of the same frequency are out of phase with each other by 90°, a condition known as orthogonality and as quadrature. Being the same frequency, the modulated carriers add together, but can be coherently separated (demodulated) because of their orthogonality property. Another key property is that the modulations are low-frequency/low-bandwidth waveforms compared to the carrier frequency, which is known as the narrowband assumption.Phase modulation (analog PM) and phase-shift keying (digital PSK) can be regarded as a special case of QAM, where the magnitude of the modulating signal is a constant, but its sign changes between positive and negative. This can also be extended to frequency modulation (FM) and frequency-shift keying (FSK), for these can be regarded as a special case of phase modulation.QAM is used extensively as a modulation scheme for digital telecommunication systems, such as in 802.11 Wi-Fi standards. Arbitrarily high spectral efficiencies can be achieved with QAM by setting a suitable constellation size, limited only by the noise level and linearity of the communications channel.[1]

IV. PROPOSED METHODOLOGY

A. System Model

We consider a cognitive network with K number of CR's. One primary user and one fusion center (i.e., common receiver).The spectrum sensing is done by each CR independently. The decision taken by CR is sent to the fusion center and the fusion center will decide whether the primary user is present or not. To determine this we are considering two hypotheses: The received signal will be

$$x_i(t) = \begin{cases} w_i(t) \\ h_i(t)s(t) + w_i(t) \end{cases} \qquad (2)$$

When the signal is received at the ith CR in timeslot t, s(t) is the PU signal. $h_i(t)$is the complex channel gain of the sensing channel between the PU and ith CR. $w_i(t)$ is the Additive White Gaussian Noise (AWGN).We assume that the sensing time is lesser than the coherence time of the channel. The coherence time is the time duration over which the channel impulse response remains constant. So $h_i(t)$ will be time invariant ($h_i(t) = h_i$) i. e., time independent. Also we assume that during sensing time, PU does not change its state. We use energy detection technique as PU signal is unknown. For each ith CR by energy detection we found average probability of detection, false alarm, missed detection over AWGN channel with following equations:

$$P_{f,\lambda} = \frac{\Gamma(u, \frac{\lambda_i}{2})}{\Gamma(u)} \qquad (3)$$

$$P_{d,i} = Q_u(\sqrt{2\gamma_i}, \sqrt{\gamma_i}) \qquad (4)$$

$$P_{m,i} = 1 - P_{d,i} \qquad (5)$$

Where $ʎ_i$ is the energy detection threshold and Υ_i is the instantaneous signal to noise ratio (SNR) at the ith CR. Also u is the time-bandwidth product of the energy detector. Γ (a) is the gamma function and Γ (a, x) is the incomplete gamma function.

$$\Gamma(a, x) = \int_x^\infty t^{a-1} e^{-t}\, dt \qquad (6)$$

In transmitter detection we have to find the primary transmitters that are transmitting at any given time. We consider a system of one cognitive radio (CR), one primary user (PU) when a signal from PU is transmitted; the received signal by the CR for the detection of PU can be modelled under two hypotheses (H_0 & H_1), is gives as follows

H_0:y(t) = n(t) PU is absent
H_1:y(t) = h*s(t) + n(t) PU is present

Where y (t) the received signal by secondary users. s (t) is the transmitted signal of the primary user, h is the channel coefficient and n (t) is AWGN with zero mean and σ2 variance (i.e. N (0. σ2)). The output is considered as the test statistic to test the two hypotheses H_0 and H_1.

1) H_1: Corresponds to the presence of both signal and noise We can define three possible cases for the detected signal:
2) H_1 turns out to be TRUE in case of presence of primary user i.e. P (H_1 / H_1) is known as Probability of Detection (P_d).
3) H_0 turns out to be TRUE in case of presence of primary user i.e. P (H_0 / H_1) is known as Probability of Missed-Detection (P_m).
4) H_1 turns out to be TRUE in case of absence of primary user i.e. P (H_1 / H_0) is known as Probability of False Alarm (P_{fa}).

This method is used for deciding the absence or presence of primary user with the help of secondary user by sensing the received signal power from the primary user. To do the measurement one energy detector is used. Based on the signal strength of primary user's signal it decides that whether the channel is available for the secondary users or not. For this process secondary user doesn't require the prior information regarding primary user such type of signal, modulation scheme etc. so spectrum sensing using energy detection method is called as a non-coherent detection.

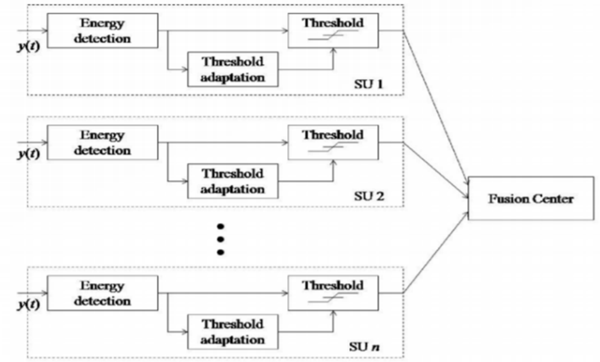

Figure 2: Block diagram for cooperative spectrum sensing

V. SIMULATION RESULT

This section describes the MATLAB-based simulation platform that provides interactive access to check the performance and comparative analysis for energy detection method theoretically as well as practically by varying various Parameters.

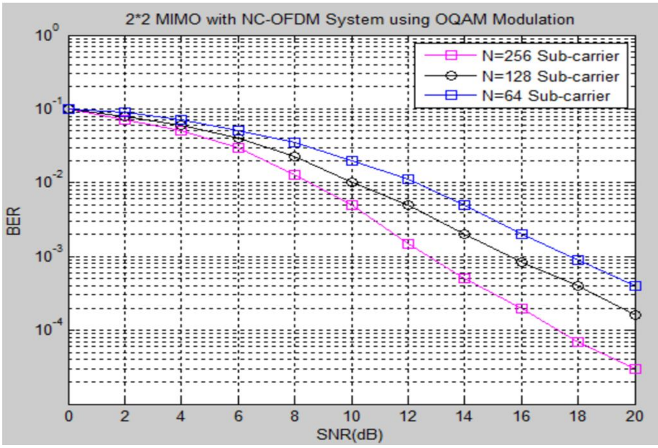

Figure 3: 2×2 MIMO with NC-OFDM System using OQAM Modulation

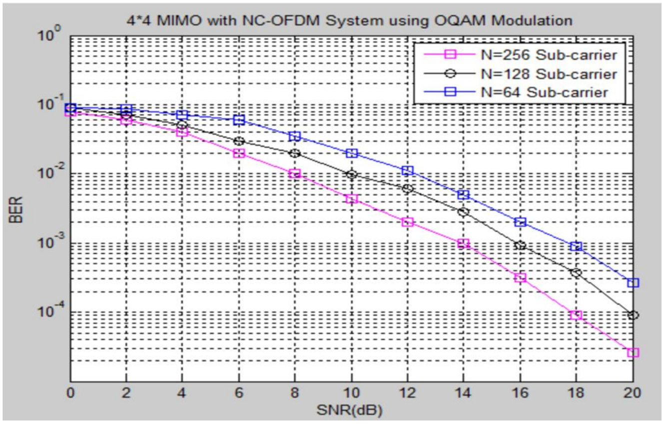

Figure 4: 4×4 MIMO with NC-OFDM System using OQAM Modulation

VI. CONCLUSION

We have studied the cooperative spectrum sensing with energy detection using formula and modelling the system. We analyzed the system with optimum voting rule for minimum error rate and K/2 is optimal value. Also, optimization of threshold has been done with minimum values of probability of missed detection and false alarm probability. We analyzed the system, for the less probability of missed detection and false alarm probability so that spectrum allotted correctly to secondary user. We proposed the fast sensing algorithm and calculated least number of CR's a given error bound.

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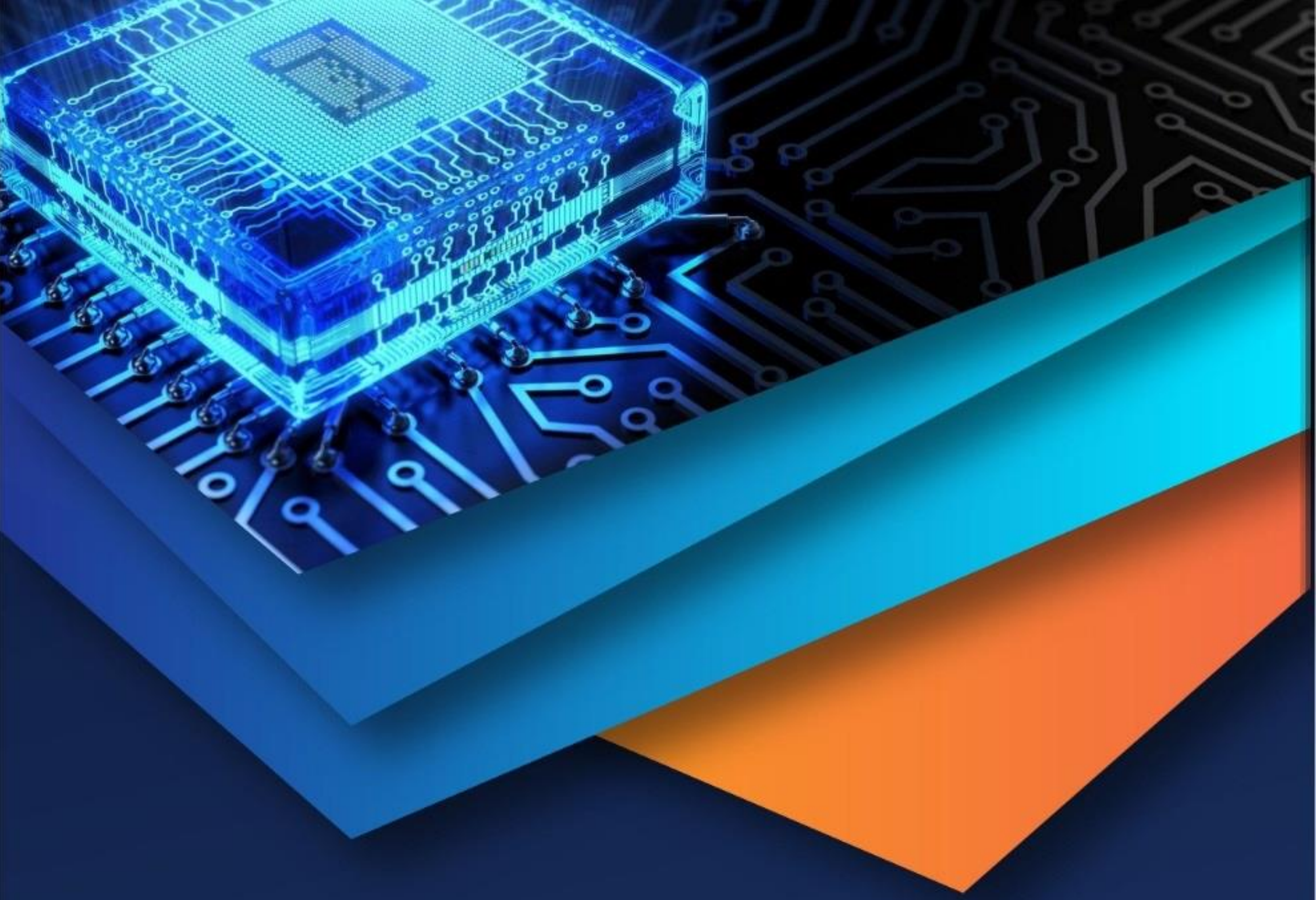

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