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Performance Evaluation of Spectrum Sensing and Cooperative Communication in AF & DF using ZF & MMSE Equalizers

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Abstract – **Spectrum is a scarce resource and its optimal utilization is guaranteed by cognitive radio technology. In cognitive radio networks, unlicensed users continuously monitor the available spectrum for white spaces by spectrum sensing algorithm. The performance of spectrum sensing is characterized by both accuracy and efficiency. Currently, substantial research effort has been made on improving the sensing accuracy. Several exemplary techniques include energy detectors, feature detectors, and cooperative sensing. In these schemes, either one or multiple secondary users (SUs) perform sensing on a single and the same channel during each sensing period. This strategy on simultaneously sensing a single channel by several SUs may limit the sensing efficiency to a large extent. This paper proposes a relay based cooperative spectrum sensing framework. Simulation of proposed work is carried out on MATLAB 2010a. The impact of signal to noise ratio, probability of detection and throughput has been evaluated on proposed algorithm.**

Keywords –**Cognitive Radio, Secondary Users (SUs), Spectrum Sensing.**

I. Introduction

Recent spectrum usage measurement indicates an undesirable situation that some wireless systems may only use the allocated spectrum to a very limited extent, while others are heavily used [1], [2], [3]. To address the spectrum scarcity and the spectrum underutilization, cognitive radio (CR) has been proposed to effectively utilize the spectrum [4], [5]. In a geographic area, there are two coexisting systems: a primary system and a secondary system. A primary system refers to the licensed system with a legacy spectrum. This system has the exclusive privilege to access the assigned spectrum. A secondary system refers to the unlicensed cognitive system and can only opportunistically access the spectrum holes. Hereby, spectrum holes (or, interchangeably, spectrum opportunities, white spaces) refer to the spectra that are not used by the primary system. Spectrum opportunities may be in the time, space, frequency, or angle (in multiple-input–multiple-output systems) domains, depending on the context and systems. We call the subscribers in the primary system primary users (PUs) and the subscribers in the secondary system secondary users (SUs).

Spectrum sensing is an essential component in CR networks to discover spectrum opportunities. The performance of a CR network is highly dependent on the accuracy and efficiency of the discovered spectrum opportunities. The sensing accuracy refers to the precision in detecting a PU signal such that the PU's communications are not interfered with. The sensing efficiency refers to the number of sensed spectrum opportunities within a sensing period and the resulting overall system performance with respect to throughput and delay. Recent research has spent considerable effort on the sensing accuracy. In the literature, several techniques have been proposed to enhance the sensing accuracy [6], including energy detectors, feature detectors, and cyclostationary detectors [7]. A very promising technique is cooperative spectrum sensing, which has been extensively investigated by exploiting the spatial diversity to combat the unpredictable dynamics in wireless environments [8].

The main objective of this paper is to implement a relay based cooperative spectrum sensing framework. Performance of proposed system is evaluated using SER, SNR, probability of detection and throughput.

II. Proposed Method

Cooperative Spectrum Sensing

The main idea of cooperative sensing is to enhance the sensing performance by exploiting the spatial diversity in the observations of spatially located CR users. By cooperation, CR users can share their sensing information for making a combined decision more accurate than the individual decisions. The performance improvement due to spatial diversity is called cooperative gain. The cooperative gain can be also viewed from the perspective of sensing hardware. Owing to multipath fading and

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shadowing, the signal-to-noise ratio (SNR) of the received primary signal can be extremely small and the detection of which becomes a difficult task. Since receiver sensitivity indicates the capability of detecting weak signals, the receiver will be imposed on a strict sensitivity requirement greatly increasing the implementation complexity and the associated hardware cost. More importantly, the detection performance cannot be improved by increasing the sensitivity, when the SNR of PU signals is below a certain level known as a SNR wall. Fortunately, the sensitivity requirement and the hardware limitation issues can be considerably relieved by cooperative sensing.

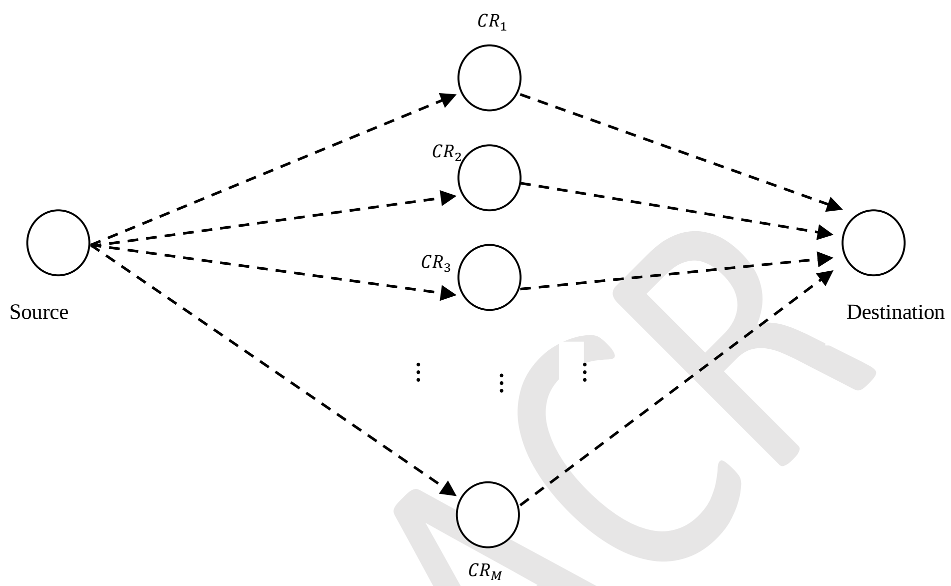

Figure 1: System model

The process of cooperative sensing starts with spectrum sensing performed individually at each CR user called local sensing. Typically, local sensing for primary signal detection can be formulated as a binary hypothesis problem as follows:

$$x(t) = \begin{cases} n(t), & H_0 \\ h(t).s(t) + n(t), & H_1 \end{cases} \tag{1}$$

Where $x(t)$ denotes the received signal at the CR user, $s(t)$ is the transmitted PU signal, $h(t)$ is the channel gain of the sensing channel, $n(t)$ is the zero-mean additive white Gaussian noise (AWGN), H_0 and H_1 denote the hypothesis of the absence and the presence, respectively, of the PU signal in the frequency band of interest. For the evaluation of the detection performance, the probabilities of detection P_d and false alarm P_f are defined.

Cooperative sensing is generally considered as a three-step process: local sensing, reporting, and data fusion. In addition to these steps, there are other fundamental components that are crucial to cooperative sensing. We call these fundamental and yet essential components as the elements of cooperative sensing. In this section, we analyse and present the process of cooperative sensing by seven key elements:

1. Cooperation models
2. Sensing techniques
3. Control channel and reporting
4. Data fusion
5. Hypothesis testing
6. User selection
7. Knowledge base

These elements are briefly introduced as follows:

- Cooperation models consider the modelling of how CR users cooperate to perform sensing. We consider the most popular parallel fusion network models and recently developed game theoretical models.
- Sensing techniques are used to sense the RF environment, taking observation samples, and employing signal processing techniques for detecting the PU signal or the available spectrum. The choice of the sensing technique has the effect on how CR users cooperate with each other.
- Hypothesis testing is a statistical test to determine the presence or absence of a PU. This test can be performed individually by

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each cooperating user for local decisions or performed by the fusion center for cooperative decision.

- Control channel and reporting concerns about how the sensing results obtained by cooperating CR users can be efficiently and reliably reported to the fusion center or shared with other CR users via the bandwidth-limited and fading-susceptible control channel.
- Data fusion is the process of combining the reported or shared sensing results for making the cooperative decision. Based on their data type, the sensing results can be combined by signal combining techniques or decision fusion rules.
- User selection deals with how to optimally select the cooperating CR users and determine the proper cooperation footprint/range to maximize the cooperative gain and minimize the cooperation overhead.
- Knowledge base stores the information and facilitates the cooperative sensing process to improve the detection performance. The information in the knowledge base is either a priori knowledge or the knowledge accumulated through the experience. The knowledge may include PU and CR user locations, PU activity models, and received signal strength (RSS) profiles.

Relaying

There are several cooperative relaying techniques depending on how the relay processes the information. In this paper, we have used two relaying protocols:

- Amplify and Forward (A & F)
- Decode and Forward (D & F)

Each mobile user employs one antenna at the transmitter (Tx) and there is optional receive diversity in the system. We could possibly 'm' antennas at the receiver (Rx) or Destination. LAN is having more than one antenna at the base station. Two nodes T_1 and T_2 may have common destination for each of the nodes, the information bits are encoded by the channel encoder. The coded symbols are properly multiplexed for cooperation.

Node i; i=1,2 transmits the output of the modulator at each discrete time slot 't' is the signal $X_i(t)$j is the received signal by antenna 'j' of the destination at time 't' due to transmission from node 'i'. Received signal antenna $y_j^d(t)$

$$y_j^d(t) = h_j^{i,d}(t)x^i(t) + \eta_j^d(t) \quad (2)$$

$h_j^{i,d}(t)$ is the coefficient reflects the fading level from transmit antenna on node 'i' to the received antenna 'j' ,$1 \le j \le m$. $x^i(t)$ denoted as channel coefficient, $\eta_j^d(t)$ is the noise samples are modulated as independent realizations of a zero-mean complex GRV (Gaussian random variable) with variance $N_0/2$ per dimension.

We describe a variety of low-complexity cooperative diversity protocols that can be utilized in the network of including fixed, selection, and incremental relaying. These protocols employ different types of processing by the relay terminals, as well as different types of combining at the destination terminals. For fixed relaying, we allow the relays to either amplify their received signals subject to their power constraint, or to decode, re-encode, and retransmit the messages. Amount many possible adaptive strategies, selection relaying builds upon fixed relaying by allowing transmitting terminals to select a suitable cooperative (or non-cooperative) action based upon the measured SNR between them. Incremental relaying improves upon the spectral efficiency of both fixed and selection relaying by exploiting limited feedback from the destination and relaying only when necessary. In any of these cases, the radios may employ repetition or more powerful codes. We focus on repetition coding throughout the sequel, for its low implementation complexity and ease of exposition. Destination radios can appropriately combine their received signals by exploiting control information in the protocol headers.

Amplify and Forward (A&F)

It represents the simplest method among the several cooperative techniques and is a non-regenerative relay. Information is sent to the relay through a noisy channel, where it is amplified and forwarded to the destination without further processing. In cooperating Amplify and Forward system, symmetric transmission exists between source and relay.

The source transmitted signal $X_{si}(l)$, the relay transmitted signal $X_{ri}(l)$. Source transmitted signal $X_{si}(l)$ to the destination and it is overhead by the relay as $y_{si,d}(l)$

$$y_{s_i,d}(l) = \sqrt{\varepsilon} h_{s_i d} X_{si}(l) + \eta_{s_i d}(l) \quad (3)$$

Where l=1,2,……..L_1,$L_1$is denoted as length of the first segment. In the second segment, the relay amplifies its overhead signal $y_{s_i r_i}(l)$

$$y_{s_i r_i}(l) = \sqrt{\varepsilon} h_{s_i r_i} x_{s_i r_i} + \eta_{s_i r_i}(l) \quad (4)$$

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Where l=1,2,………L_2,L_2 denoted as length of the second segment using maximum likelihood detection method

$$X^1{}_{ri}(l) = \beta y_{s_i r_i}(l) \tag{5}$$

$X^1{}_{ri}(l)$is denoted as transmitted to the destination through relay.

Where $\beta = \sqrt{\frac{1}{|h_{s_i r_i}|^2 \varepsilon + N_{0,s_i,r_i}}}$, $X^1{}_{ri}(l)$ will be transmitted to the destination through relay uplink channel as:

$$y^1{}_{r_i,d}(l) = \sqrt{\varepsilon} h_{r_i d} X_{r_i}(l) + \eta_{r_i d}(l) \tag{6}$$

Where l=1,2……L_2 is indices the length of the second segment signal and $L_1 = L_2$ After the two segments, the destination will be combine the received signal $y_{s_i,d}(l)$ and $y^1{}_{r_i,d}(l)$

Using the Z-F and MMSE detection:

$$r_{s_i,d}(l) = \frac{h^*_{s_i d}\sqrt{\varepsilon}}{N_{0 s_i d}} y_{s_i,d} + \frac{h^*_{r_i d}\ \beta\, h^*_{s_i r_i}\sqrt{\varepsilon}}{|h_{r_i d}|^2 \beta^2 N_{0,s_i r_i} + N_{0,r_i d}} \tag{7}$$

$r_{s_i,d}(l)$ is further passed to a decoder in to retrieve source information from equation (2) and equation (7).The energy symbol (ε) which is normalized in channel nodes p and q. They change independently from (two segment) process yielding a slow fading channel $n_{pq}(l)$ denoted by the additive noise which is modeled as a zero mean, mutually independent complex Gaussian sequence with variance $N_{0,pq}$. For channel between nodes p and q if the instantaneous channel received signal to noise ratio (SNR) is:

$$\gamma_{pq} = \frac{|h_{pq}|^2 \varepsilon}{N_{0,pq}} \tag{8}$$

The average channel received SNR between nodes p, q expressed as:

$$\overline{\gamma_{pq}} = \frac{E\left[|h_{ij}|^2\right]\varepsilon}{N_{0,pq}} \tag{9}$$

If source and relay have similar uplink channel quality as $\overline{\gamma_{s_i d}} = \overline{\gamma_{r_i d}}$, the system is defined as having symmetric up links. If $\overline{\gamma_{s_i d}} \neq \overline{\gamma_{r_i d}}$ the system is defined as having asymmetric uplinks.

Decode and Forward (D&F)

In this case, the relay is regenerative, because it receives the information from the source and it decodes it before retransmitting it to the destination. Decode and forward transmission, the appropriate channel model is for cooperative diversity transmission, we model the channel during the first half of the block is:

$$y_{s_i r_i}(l) = h_{s_i r_i} x_{s_i}(l) + \eta_{r_i}(l) \tag{10}$$

If $l = 1 \ldots \frac{L}{4}$ where $x_{s_i}(l)$ is the source transmitted signal and $y_{r_i}(l)$ is the relay signal. The second half block, we model the received signal,

$$y_{s_i d}(l) = h_{r_j,d} x_{r_j}(l) + \eta_d(l) \tag{11}$$

The source mobile transmits its information as $x_{s_i}(l)$, l=0 . . .$\frac{L}{4}$ during this interval the relay process $y_{r_i}(l)$ by decoding an estimate $x'_{s_i}(l)$ of the source transmitted signal. The relay transmits the signal $x_{r_i}(l) = x'_{s_i}\left(l - \frac{L}{4}\right)$ for l=$\frac{L}{\Delta+1}$- - -- -,$\frac{L}{2}$

Decoding at the relay can take on a variety of forms. For example, the relay might fully decode the source message by estimating the source code word, or it might employ symbol by symbol decoding and allow the destination to perform full decoding. These options allow for trading off performance and complexity at the relay mobile. Because the performance of symbol by symbol decoding varies with the choice coding and modulation. We focus on full decoding in the sequel, symbol by symbol decoding of binary transmissions has been treated form uncoded perspective.

Combining using Maximal Ratio Combining

This research work uses Maximal Ratio Combining (MRC). It overcomes the limitations of selection combining: it combines the input signals in all diversity branches. MRC has been considered as the optimal combining technique in the presence of additive white Gaussian noise (AWGN) because of its capacity to boost the instantaneous output SNR. This is demonstrated as below. Assume a system with N_d diversity branches, the instantaneous output SNR is given by:

$$SNR = \left(\frac{E_b}{N_0}\right) \frac{\left|\sum_{i=1}^{N_d} \mu_i \beta_i e^{j\theta_i}\right|^2}{\left|\sum_{i=1}^{N_d} \mu_i\right|^2} \tag{12}$$

Where E_b is bit energy; N_0 is noise spectral density, μ_i is the combining weight and β_i and θ_i are the magnitude and phase of the received signal respectively.

To obtain the maximum instantaneous output SNR, Cauchy-Schwarz inequality is applied, giving the maximum value as:

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$$SNR \leq \left(\frac{E_b}{N_0}\right) \frac{\left|\sum_{i=1}^{N_d} \mu_i\right|^2 \left|\sum_{i=1}^{N_d} \beta_i e^{j\theta_i}\right|^2}{\left|\sum_{i=1}^{N_d} \mu_i\right|^2} = \left(\frac{E_b}{N_0}\right) \sum_{i=1}^{N_d} \beta^2{}_i = \sum_{i=1}^{N_d} SNR_i \quad (13)$$

The only condition to reach this maximum value is to set:

$$\mu_i = c\beta_i e^{-j\theta_i} \; for \; i = 1,2, \dots . N_d \quad (14)$$

Where c is some arbitrary complex constant. Therefore, according to (14), in MRC, the magnitude of the combining weight is proportional to the magnitude of the received signal, and the phase of the combining weight is the negative value of the phase of the received signal.

The maximum SNR in (13) also suggests that MRC can produce an output SNR equal to the sum of the individual SNRs in each diversity branch. It follows that MRC can offer the advantage of producing an acceptable output SNR even when none of the SNR in individual branches is acceptable.

Equalizer

Proposed research work uses two following equalizers:

- Zero Forcing Equalizer
- Minimum Mean Square Error Equalizer

Zero Forcing Equalizer

Zero Forcing Equalizer is a linear equalization algorithm used in communication systems; it inverts the frequency response of the channel. The name Zero forcing corresponds to bringing down the Inter Symbol Interference (ISI) to zero in a noise free case. This will be useful when ISI is more predominant when comparing to the noise.

ZF can be implemented by using the inverse of the channel matrix H to produce the estimate of transmitted vector $\tilde{x}$.

$$\tilde{x} = H^{\dagger}r = H^{\dagger}(Hx) = x \quad (15)$$

Where $(.)^{\dagger}$ denotes the pseudo-inverse. However when the noise term is taken into account, the post-processing signal is given as fallow:

$$\tilde{x} = H^{\dagger}R = H^{\dagger}(Hx+n) = x + H^{\dagger}n \quad (16)$$

With the addition of the noise vector, ZF estimate, that is $\tilde{x}$consists of the decoded vector x plus a combination of the inverted channel matrix and the unknown noise vector. As the pseudo-inverse of the channel matrix may have high power when the channel matrix is ill-conditioned, the noise variance is accordingly improved and the performance is corrupted. To alleviate for the noise improvement introduced by the ZF detector, the MMSE detector was proposed, where the noise variance is taken into account in the construction of the filtering matrix G.

Minimum Mean Square Error Equalizer

Minimum Mean Square Error (MMSE) approach alleviates the noise enhancement problem by taking into consideration the noise power when constructing the filtering matrix using the MMSE performance-based criterion. The vector estimates produced by an MMSE filtering matrix becomes,

$$\tilde{x} = [[(H^H H + (\sigma^2 I))^{-1}] H^H] r \quad (17)$$

Where σ^2 is the noise variance. The added term ($1/SNR = \sigma^2$, in case of unit transmit power) offers a trade-off between the residual interference and the noise enhancement. Specifically, as the SNR raises large, the MMSE detector converges to the ZF detector, but at low SNR it prevents the worst Eigen values from being inverted. At low SNR, MMSE becomes Matched Filter,

$$[(H^H H + (\sigma^2 I))^{-1}] H^H \approx \sigma^2 H^H \quad (18)$$

At high SNR, MMSE becomes ZF:

$$(H^H H + (\sigma^2 I))^{-1}] H^H \approx (H^H H)^{-1} H^H \quad (19)$$

Energy Detector at Destination

Energy detection (ED) is the most optimal choice for the spectrum sensing where it is difficult for the CR to get the adequate information about the licensed user waveform. The ED is the most suitable choice when the CR has information about the power of the random Gaussian noise. The basic approach behind this technique is the power estimation of the licensed user (primary user) signal. In this technique, energy of the desired transmitted signal is detected then this detected energy is compared with a threshold value. The threshold is a pre-defined value. If the detected energy is below than threshold value then it is pretended that the licensed user is not present and the spectrum is free. Oppositely, if the detected energy is above the threshold value then it is assume that the spectrum is not free.

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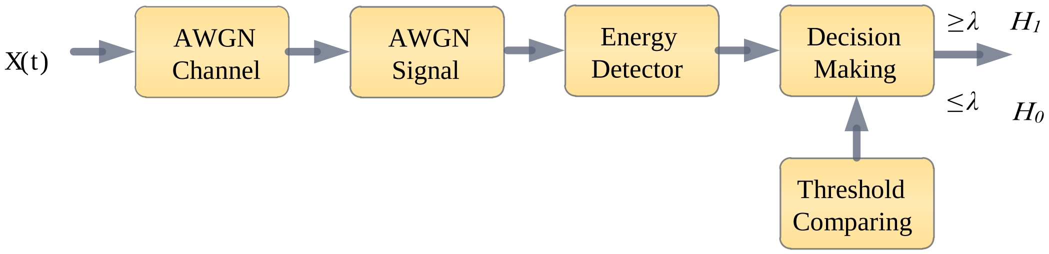

Figure 2: Block Diagram of the Energy Detection

III. Simulation And Results

The performance of proposed algorithms has been studied by means of MATLAB simulation.

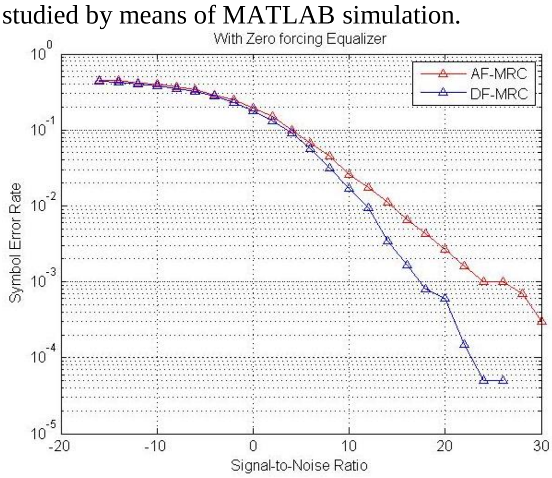

Figure 3: Comparative analysis of SER for AF-MRC and DF-MRC using ZF equalizer

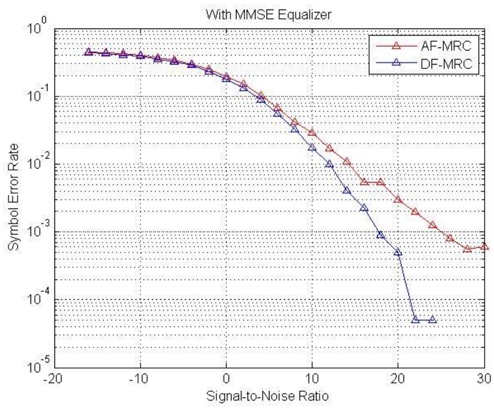

Figure 4: Comparative analysis of SER for AF-MRC and DF-MRC using MMSE equalizer

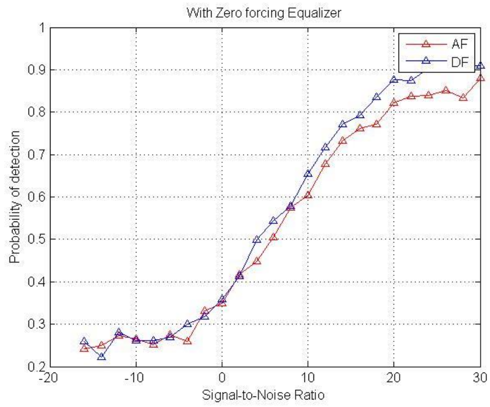

Figure 5: Comparative analysis of probability of detection for AF and DF using ZF equalizer

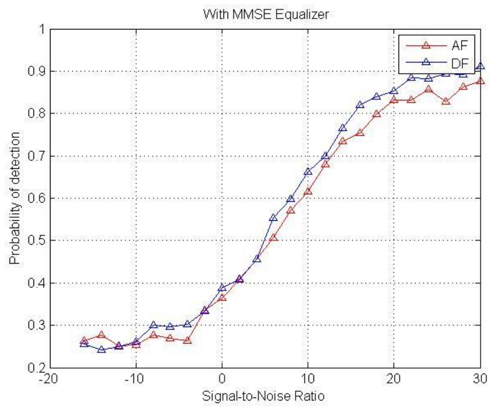

Figure 6: Comparative analysis of probability of detection for AF and DF using MMSE equalizer

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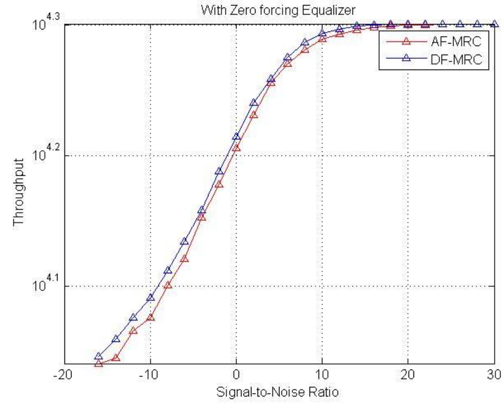

Figure 7: Comparative analysis of throughput for AF-MRC and DF-MRC using ZF equalizer

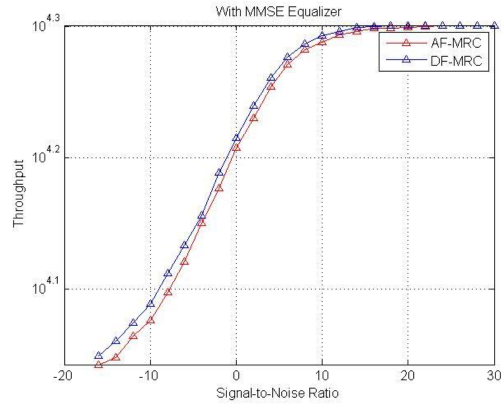

Figure 8: Comparative analysis of throughput for AF-MRC and DF-MRC using MMSE equalizer

IV. Conclusion

Spectrum is a very valuable resource in wireless communication systems and it has been a major research topic from last several decades. Sensing provides awareness regarding the radio environment so that the spectrum opportunities can be efficiently reused while limiting the interference to the primary user. Cooperative sensing is an effective technique to improve detection performance. Cooperative sensing over wideband has recently gained much attention. This paper proposes a relay based cooperative spectrum sensing framework. Proposed algorithm is successful to detect primary at:

Minimum Sensing Time: 10µ sec.

Probability of False Alarm: 0.1.

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