Performance Enhancement In Cognitive Radio Systems Using Energy Sensing

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Abstract*- Cognitive Radio Systems have emerged as one of the key enablers in high capacity and high data rate wireless communication systems. As wireless channels are highly random in nature, therefore sensing the spectrum and using the Channel State Information (CSI) to suppress the frequency tones leading to low Signal to Noise Ratio (SNR) is crucial to improve upon the BER performance of the system. Such systems can be efficiently modelled as a Software Defined Radio (SDR). In this paper, a novel technique is proposed in which the channel frequency response is sensed to detect substantially strong tones above a threshold, subsequently the poor tones are suppressed in order to attain high BER.*

Keywords- Channel State Information (CSI) Software Defined Radio (SDR), Signal to Noise Ratio (SNR), Orthogonal Frequency Division Multiplexing (OFDM), Bit Error Rate (BER), Spectrum Sensing.

I. INTRODUCTION

The electromagnetic spectrum is a characteristic asset. The present spectrum authorizing plan is not able to oblige quickly growing demand in wireless communication due to the static spectrum allocation strategies. This allocation prompts increment in spectrum scarcity issue. Cognitive radio (CR) technology is a propelled remote radio design which aims to expand spectrum utilization by distinguishing unused and under-used spectrum in rapidly evolving environments. Spectrum sensing is one of the key strategies for cognitive radio which detects the presence of primary client in authorized licensed frequency band utilizing dynamic spectrum assignment policies to utilize unused spectrum. In many areas cognitive radio frameworks coexist with other radio frameworks, utilizing the same spectrum yet without creating undue interference.[1],[3] The most simple and easy way to implement sensing technique is energy detection.

With Cognitive Radio being utilized as a part of various applications, the territory of spectrum sensing has become progressively vital. As Cognitive Radio technology is being utilized to provide a method for utilizing the spectrum all the more productively, spectrum sensing is key to this application. The ability of Cognitive Radio frameworks to get to spare sections of the radio spectrum, and to continue observing the spectrum to guarantee that the Cognitive Radio framework does not create any undue interference depends totally on the spectrum sensing components of the framework.[4]

Advantages of Cognitive Radio

- Mitigate and solving spectrum access issues.
- Spectrum utilization improves.
- Improves wireless networks performance through increased user throughput and system reliability.
- More adaptability and less co-ordination.

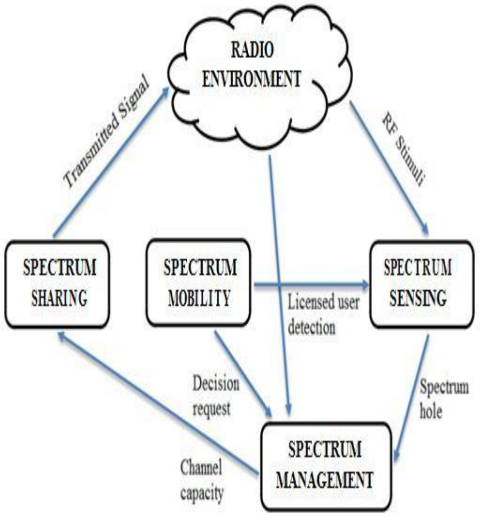


Fig.1 A Typical Cognitive Radio Environment.

For the overall framework to work viable and to provide the required change in spectrum efficiency, the Cognitive Radio spectrum sensing framework must have the capacity to adequately recognize some other transmissions, distinguish what they are and inform the central preparing unit inside the Cognitive Radio so that the required actions can be taken.

II. SPECTRUM SENSING IN COGNITIVE RADIO SYSTEMS

The principal step of spectrum sensing is that it decides the presence of primary user on a band. The cognitive radio has the capacity to impart the result of its detection with other cognitive radios in the wake of sensing the spectrum. The main objective of spectrum sensing is to discover the spectrum status and activity by periodically sensing the target frequency band. The cognitive radio system examines all level of flexibility (time, frequency and space) to predict spectrum usage. There are a few procedures available for spectrum sensing. Spectrum sensing is a system which figures out if a given frequency band is utilized. A wide range of routines are proposed to recognize the presence of signal transmission and can be utilized to improve the detection probability.

The aim of the spectrum sensing is to decide between two hypotheses which are

$x(t) = w(t)$, H0 (Primary User absent)

$x(t) = h * n(t) + w(t)$, H1 (Primary User present)

Where x(t) is the signal received by the CR user, n(t) is the transmitted signal of the primary user , w(t) is the AWGN band, h is the amplitude gain of the channel. H0 is a null hypothesis, which states that there is no licensed user signal. Energy Detection is a simple detection method. The energy detection is said to be a blind signal detector in light of the fact that it overlooks the structure of the signal. Energy detection is based on the rule that, at the receiving end, the energy of the signal to be detected is computed. It estimates the presence of a signal by comparing the energy received and a known threshold λ derived from the statistics of the noise.

If the frequency response of the system is available, then under such a condition, we possess the Channel State Information (CSI).

III. CHALLENGES IN UTILIZATION OF CSI FOR COGNITIVE RADIO SYSTEMS

Problem of BER:A major challenge for any wireless communication system is the frequency selective nature of wireless channels. For multi carrier modulation schemes, frequency selectivity poses a serious problem since different sub carriers are treated by the channel differently. Carriers which belong to the frequency range where the channel gain reduces drastically, undergo heavy attenuation. The attenuation varies with the frequency response of the channel. The result of this phenomenon is variable sub carrier gain or sub carrier strength. While some sub carriers may have satisfactory gain, some may have average gain while others may have extremely low sub carrier gain. The sub carriers with low sub carrier gain or strength tend to adversely affect the Bit Error Rate of the system, since low strength of the carriers would imply low signal to noise ratio (SNR). This eventually introduces errors and results in non-reliable communication. Therefore it is important to suppress sub carriers with low gain or strength to improve the BER performance of the system.

Problem of Outage: Another challenge for D2D communication system is the outage probability. In telecommunication outage defines the system service condition in which a user is completely deprived of service by the system. For a particular system or situation, an outage may be a service condition that is below a defined system operational threshold i.e. below a threshold of acceptable performance.[7] In D2D communication a minimum threshold level is defined for acceptable communication performance, received signal will experience periods of

- Sufficient signal strength or “ non- fade intervals”
- Insufficient signal strength or “ fades”

During the fades user experiences a signal outage. Outage probability determines the amount of signal strength which is less below the minimum noise power. So for proper reception outage probability should be as lowas possible. Thus it is important to improve the signal to noise ratio (SNR) for improving system performance.

IV. MATHEMATICAL MODELLING FOR BER AND OUTAGE OF A COGNITIVE RADIO SYSTEM

Outage: Let a cellular system is indicated for$\Phi = \{C, D\}$, C is cellular communication and D is D2D communication. It is also assumed that the distribution of device nodes of system follows a stationary Poisson point process (PPP) with density of $\lambda_D$in the finite two-dimensional plane. The channel model includes path loss and Rayleigh fading. Therefore, the power of the node i received from j can be expressed as: $P_i \delta_{ij} |X_{ij}|^{-\eta}$, $i, j \epsilon \phi$, $P_i$is the power of node i,$\delta_{ij}$is the Rayleigh fading indexbetween i and j, and it has an exponential distribution with unitmean,$X_{ij}$is the distance between node i and j,$\eta$is thepath loss exponent.Signal to interference plus noise ratio at the receiver k is given as:

$$\mathrm{SINR}_k = \frac{P_k \delta_{k0} R_k^{-\eta}}{\sum_{j\epsilon\phi} \sum_{X_{ji}\,\epsilon\pi_j} P_j \delta_{ji} |X_{ji}|^{-\eta} + N_0}$$

where $\delta_{ji}$is the fading factor on the power transmitted from the desired transmitter to the receiver, $N_0$is the thermal noise power, spectrum sharing systems are interference limited systems, so the thermal noise is negligible in regimes of interest. So the SIR can be used instead of SINR, which allows simplification to:

$$\mathrm{SIR}_k = \frac{\delta_{k0} R_k^{-\eta}}{I_k}$$

$I_k = \sum_{j\epsilon\phi} I_{kj}$ Where I_{kj} is the sum of the power normalized interference from transmitting nodes of system j to the receiver of system k, which is defined as $I_{kj} = \left(\frac{P_i}{P_k}\right) \sum_{X_{jI}\epsilon\pi_j} \delta_{ji} |X_{ji}|^{-\eta}$, for QOS of system k (D2D or cellular users), SIR required to meet a certain threshold: $\mathrm{SIR}_k \geq V_k$, where V_k is target SIR, then the probability of successful transmission can be defined as:

$$\begin{aligned} P(\mathrm{SIR}_k > V_k) &= P\left(\delta_{k0} \geq V_k R_k^{\eta} I_k\right) \\ &= \int_0^{\infty} P\{\delta_{k0} \geq V_k R_k^{\eta} I_k\} f_{Ik}(I)\, dI \\ &= \psi_{Ik}\left(V_k R_k^{\eta}\right) \end{aligned}$$

δ_{k0}Is exponentially distributed, then $\psi_{Ik}\left(V_k R_k^{\eta}\right)$ is the Laplace transform of $f_{Ik}(I)$, which can expressed for $E[e^{-I_k\eta}]$,

$I_k = \sum_{j\epsilon\phi} I_{kj}$, the interference I_{kj} is independent to each other,

$$E[e^{-I_k\eta}] = \prod_{j\epsilon\phi} E[e^{-I_k\eta}],$$

then the probability ofsuccessful transmission can be changed to

$$\left(V_k R_k^{\eta}\right) = \prod_{j\epsilon\phi} \psi_{Ikj}\left(V_k R_k^{\eta}\right)$$

Especially, when the interferingnodes are Poisson pointdistributed:

$$\begin{aligned} \psi_{Ij}\left(V_k R_k^{\eta}\right) &= \exp\left\{-\lambda_j \int_{R^2}^{1} 1\, E\left[e^{-V_k R_k^{\eta} \delta |X|^{-\eta}}\right] dx\right\} \\ &= \exp\left\{-\lambda_j \int_{R^2}^{1} \frac{V_k R_k^{\eta} \delta |X|^{-\eta}}{1 + V_k R_k^{\eta} \delta |X|^{-\eta}}\, dx\right\} \\ &= \exp\left\{-C_\alpha R_k^2 V_k^{2/\eta} \gamma_{kj} \lambda_j\right\} \end{aligned}$$

$\gamma_{kj} = \left(\frac{P_j}{P_k}\right)^{2/\eta}$ Is power ratio, where P_j and P_k are power of system j and k,

$$C_\eta = \left(2\pi/\eta\right)\Gamma\left(2/\eta\right)\Gamma\left(1 - 2/\eta\right),$$

where $\Gamma(x) = \int_0^{\infty} y^{x-1} e^{-y}\, dy$ is a gamma function.

Therefore, success transmission probability of system k is:

$$P(\mathrm{SIR}_k \geq V_k) = \exp\left\{-K_k \sum_{j\epsilon\phi} \gamma_{kj} \lambda_j\right\}$$

here, $K_k = C_k R_k^2 V_k^{2/\eta}$.

Thus the outage probability of D2D receiver is

$$q(\lambda) = \exp\left\{-\frac{2\pi^2}{\eta \sin\left(\frac{2\pi}{\eta}\right)} R_k^2 V_k^{2/\eta} \lambda\right\}$$

BER: We know that probability of error is given as:

$$P_e = P(0)P\left(1/0\right) + P(1)P\left(0/1\right)$$

Provided that system is assumed to be affected only by white noise than

$$P\left(1/0\right) = P\left(0/1\right)$$

So, $P_e = P\left(1/0\right)[P(0) + P(1)]$(4.27)

$P_e = P\left(1/0\right)$Or$P\left(0/1\right)$

$$P_e = \int_{v_{th}}^{\infty} f\left(z/0\right) dz$$

$$= \int_{v_{th}}^{\infty} \frac{1}{\sqrt{2\pi\sigma_{n_0}^2}} e^{\left(\frac{-(z-a_z)^2}{\sigma_{n_0}^2}\right)} dz$$

Assume $\frac{z-a_z}{\sigma_{n_0}}$ = y, $z - a_z$= y.σ_{n_0}

Differentiating above equation we get,

$$d_z = \sigma_{n_0} d_y$$

For z = ∞ , y$\rightarrow \infty$ and z =V_{th}, y = (V_{th} –a_2)/ σ_{n_0}

$$y = \frac{\frac{a_1 + a_2}{2} - a_2}{\sigma_{n_0}}$$

$$= \frac{a_1 - a_2}{2\sigma_{n_0}}$$

We know that Q-function,

$$Q(x) = \frac{1}{\sqrt{2\pi}} \int_{x}^{\infty} e^{\frac{-y^2}{2}} dy$$

Where y = a dummy variable.

Thus, probability of error can be expressed as

$$P_e = \frac{1}{\sqrt{2\pi\sigma_{n_0}^2}} \int_{\frac{a_1-a_2}{2\sigma_{n_0}}}^{\infty} e^{\left(-y^2/2\right)} \sigma_{n_0} dy$$

In terms of Q-function, probability of error can be expressed as

$$P_e = Q\left[\frac{a_1 - a_2}{2\sigma_{n_0}}\right]$$

In case of matched filter, P_e is given as

$$P_e = Q\left[\sqrt{\frac{(a_1 - a_2)^2}{4\sigma_{n_0}^2}}\right]$$

When more than one signal is transferred through the matched filter then h (t) = x(τ-t) where x(t) =x_1 (t)- x_2 (t) then $\frac{(a_1-a_2)^2}{\sigma_{n_0}^2}$ corresponds to its maximum possible of $\frac{E_D}{\frac{N_0}{2}}$,

V. SYSTEM DESIGN

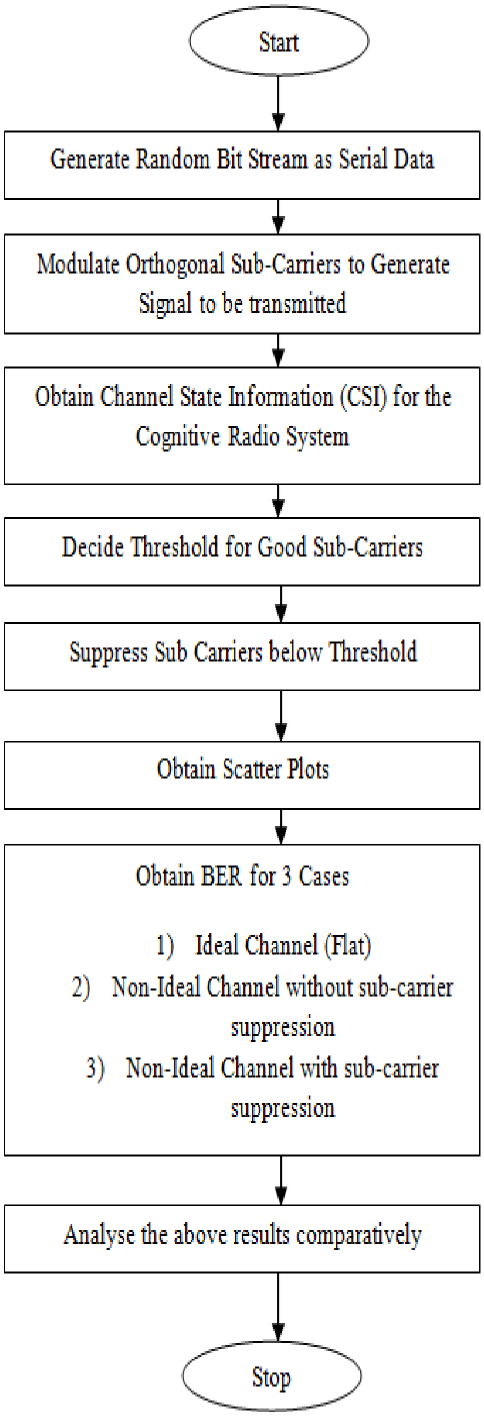


Fig.2 Flowchart of Proposed Methodology

VI. OBTAINED RESULTS

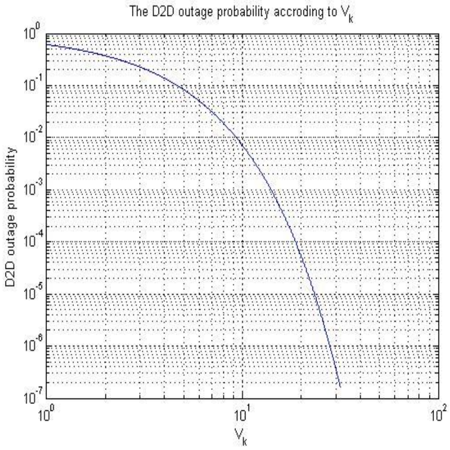


Fig.3 Outage Probability under Device to Device Scenario

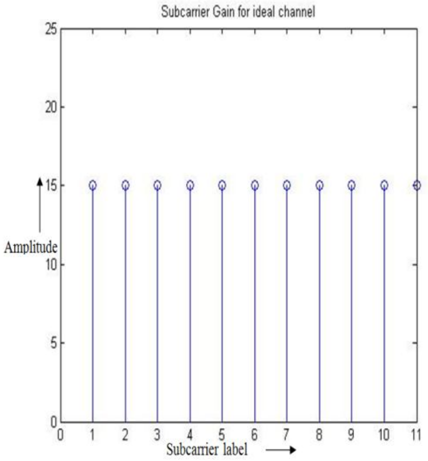


Fig.4 Ideal Channel (FLAT)

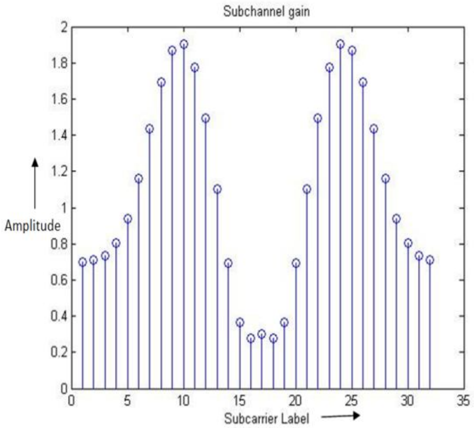


Fig.5 Non-Ideal Channel (Frequency Selective)

S.No	BER	Ideal Channel	Using all carriers(tones)	Proposed System
1.	10^{-1}	9 dB	19 dB	15 dB
2.	10^{-2}	12.5 dB	26 dB	24 dB
3.	10^{-3}	14 dB	28 dB	25 dB

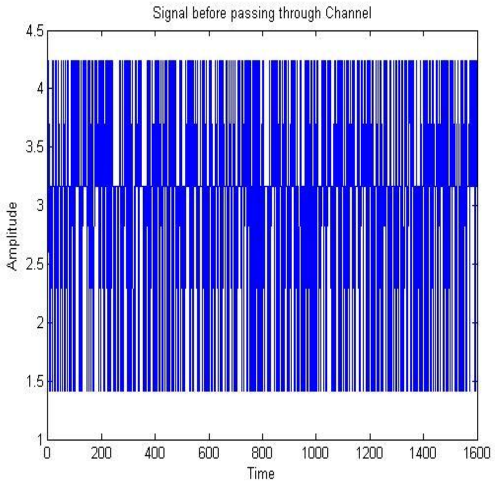


Fig.5 Original time-domain signal

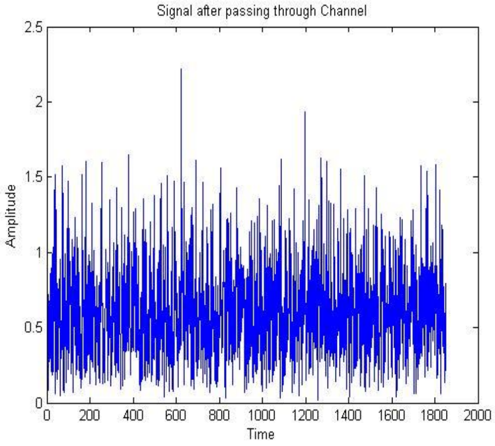
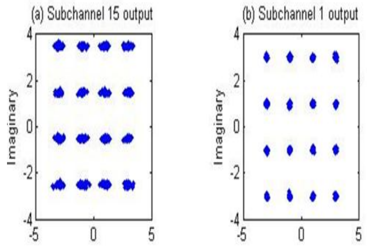


Fig.6 Time-domain signal after passing through frequency selective channel



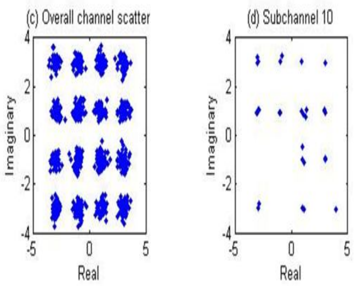


Fig.7 Obtained Scatter Plots

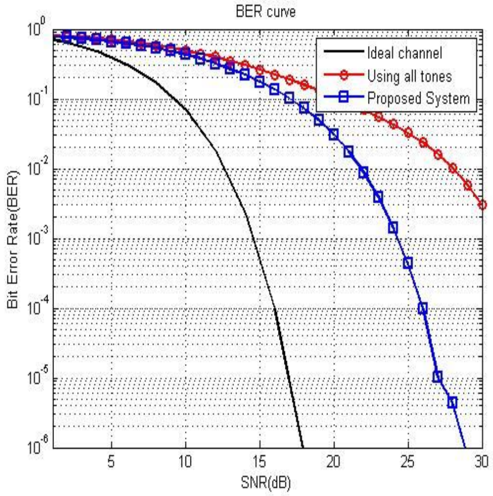


Fig.8 Comparative BER Performance

VII. CONCLUSION

Here we have presented an algorithm that senses the frequency spectrum of the channel in order to detect poor frequency tones which would yield low values of SNR and hence high Bit Error Rate (BER) for the system. It has been shown that the proposed system attains better values of BER compared to a system without employing this technique. Also a comparative analysis with an ideal channel with flat frequency response has been shown. The system outage has also been considered with increasing separation between transmitter and receiver.

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