Simulation of communication channels and Cognitive radio using spectrum sensing

A mini project report

submitted

by

T.Asha Jyothi, N150740

L.Sowmya, N150313

B.Uma Maheshwari, N150870

Department of Electronics and Communication Engineering

Rajiv Gandhi University of Knowledge Technologies

Nuzvid,India-521202

Certificate

This is certified that the work contained in this project entitled ”Simulation of communication channels and Cognitive radio using spectrum sensing” has been carried out under my supervision and that it has not been submitted elsewhere for a degree.

project guide
Mr.SK.Riyaz Hussain
Department of ECE
Asst.professor
RGUKT Nuzvid

Acknowledgement

First of all we would like to thank our project guide, Mr.SK.Riyaz Hussain, Assistant professor of RGUKT, IIITN, for providing us his time and knowledge during the building and completion of this project. Next we would take the opportunity to pass our thanks to our education institute, Rajiv Gandhi University of Knowledge and Technologies, IIIT Nuzvid campus, for providing ample opportunities and guidance.

Contents

List of Figures

Abstract

Nowadays Simulation plays a key role due to it's ease to effectively evaluate the performance of a communication system. While simulating we have to generate symbols at the input. Generating symbols manually is a difficult task. So we use random number generation techniques to generate them. One of the random number generating technique is transform methods, in that technique we used inverse laplace transform and using this method we can obtain most of the random variables with different distributions. Using these random numbers bit error rates of maximal ratio combining, Multiple input Multiple Output system, OFDM, OFDM with MRC, MIMO can be simulated and are compared with their theoretical expressions. Further we worked on cognitive radio. Most of the frequency bands are only used for a short time and left unused for the rest of the time. So the frequency bands are not effectively used, cognitive radio will resolve this problem. Using the concept of Spectrum Sensing we can identify the free spectrum and can allocate the spectrum to the secondary user. Spectrum can be sensed with the help of energy of the spectrum. Thus with the help of cognitive radio we can efficiently use the radio spectrum.

1 Inverse laplace transform

1.1 Introduction

Simulation modeling solves real-world problems safely and efficiently. It provides an important method of analysis which is easily verified, communicated, and understood. Across industries and disciplines, simulation modeling provides valuable solutions by giving clear insights into complex systems. To do simulation we have to generate huge number of symbols at the receiver side then only channel can be effectively characterized. So in order to generate huge symbols we use random number generation techniques. There are six techniques to generate random numbers.

1. Physical sources
2. Empirical resampling
3. Pseudo random generators
4. Simulation or Gameplay
5. Rejection sampling
6. Transform method

A transform method is used when we have the ability to generate instances of a random variable according to one distribution and we would like instances according to another distribution. One of the most effective method is Inverse laplace Transform.

The inverse Laplace transform is the transformation of a Laplace transform into a function of time. If $L\{f(t)\} = F(s)$ then $f(t)$ is the inverse Laplace transform of $F(s)$, the inverse written as:

$$f(t) = L^{-1}\{F(s)\}$$

We know that PDF and MGF are laplace transform pairs.In the previous method of generating random variables we ensure some drawbacks to avoid it we will use this inverse laplace transform sampling method.

In this method we will take the moment generating function and find it's inverse laplace transform thus gets probability distribution function.But finding inverse laplace transform is a difficult task .To overcome it we have used an approach of finding inverse.The derivation follows as

According to the definition of Laplace transform

$$P_X(x) \xrightarrow{\text{L.T}} P_X(s)$$

$$\hat{P_X}(s) = \int_0^\infty P_X(x)e^{-sx}dx$$

$$P_X(x) = \frac{1}{2\pi j}\int_{a-ju}^{a+ju} \hat{P_X}(s)e^{sx}ds$$

By considering $s = a + ju$, we get

$$P_X(x) = \frac{e^{ax}}{2\pi}\int_{-\infty}^{\infty} \hat{P_X}(a+ju)[\cos(ux) + j\sin(ux)]du$$

On seperating into real part and imaginary part, we get

$$P_X(x) = \frac{e^{ax}}{2\pi}\int_{-\infty}^{\infty} \Big[\Re\big\{\hat{P_X}(a+ju)\cos(ux)\big\} + \Im\big\{\hat{P_X}(a+ju)\sin(ux)\big\}\Big]du$$

Let the signal only exists for $x > 0$ then $P_X(-x) = 0$ on solving this we get

$$P_X(x) = \frac{e^{ax}}{\pi}\int_{-\infty}^{\infty} \Big[\Re\big\{\hat{P_X}(a+ju)\big\}\cos(ux)\Big]du$$

Let $\Re\big\{\hat{P_X}(a+ju)\big\}$ is even with respect to "u" i.e., real part of frequency response of $P_X(x)$ is even. we get

$$P_X(x) = \frac{2e^{ax}}{\pi} \int_0^{\infty} \Big[\Re\{\hat{P_X}(a+ju)\} \cos(ux) \Big] du$$

computation of integration is difficult. So we convert it into discrete summation. Let $a = \frac{A}{2x}$ using trapezoidal rule with step size $h = \frac{\pi}{2x}$ leads to

$$P_X(x;A) = \frac{e^{\frac{A}{2}}}{x} \sum_{n=0}^{\infty} \frac{(-1)^n}{\beta_n} \Re\Big\{\hat{P_X}\Big(\frac{A+2\pi jn}{2x}\Big)\Big\} + E(A) \longrightarrow (1)$$

$$\text{with} \quad \beta_n = \begin{cases} 2 & \text{n = 0} \\ 1 & \text{n = 1,2,....N} \end{cases}$$

Where $E(A)$ is discretization error term.

Using poisson summation we can bound $E(A)$ as

$$|E(A)| = e^{-A}$$

On truncating $eq(1)$ from infinite summation to summing N terms, leads to

$$P_X(x;A,N) = \frac{e^{\frac{A}{2}}}{x} \sum_{n=0}^{N} \frac{(-1)^n}{\beta_n} \Re\Big\{\hat{P_X}\Big(\frac{A+2\pi jn}{2x}\Big)\Big\} + E(A) + E(N) \longrightarrow (2)$$

Where $E(N)$ is truncation error.

As $eq(2)$ is in the form of alternating series, According to Euler summation technique it convergence to Binomial average of a partial series of length $N, N+1, ...N+Q$. It leads to

$$P_X(x;A,N,Q) = \sum_{q=0}^{Q} 2^{-Q} \binom{Q}{q} \Big[\frac{e^{\frac{A}{2}}}{x} \sum_{n=0}^{N+q} \frac{(-1)^n}{\beta_n} \Re\Big\{\hat{P_X}\Big(\frac{A+2\pi jn}{2x}\Big)\Big\}\Big] + E(A) + E(N,Q)$$

Where $E(N,Q)$ is the overall truncation error. It can be estimated by

$$E(N,Q) \simeq \frac{e^{\frac{A}{2}}}{x}\sum_{q=0}^{Q} 2^{-Q}(-1)^{N+1+q}\binom{Q}{q}\Re\left\{\hat{P_X}\left(\frac{A+2\pi j(N+q+1)}{2x}\right)\right\}$$

Using the above equation we can calculate the inverse laplace transform in matlab.

1.2 Simulation Results

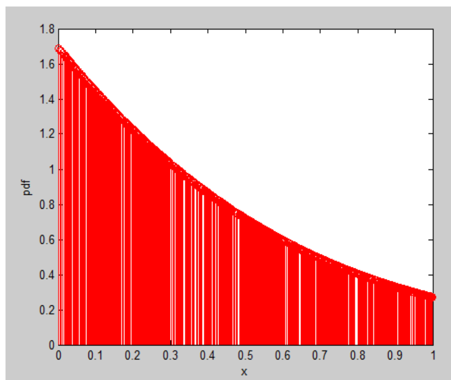


Figure 1: Inverse laplace transform of gamma disribution with alpha=1 and beta=1/2

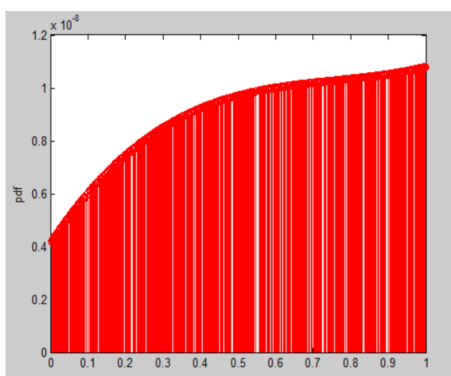


Figure 2: Inverse laplace transform of gamma disribution with alpha=7 and beta=8

1.3 Conclusion

1. Inverse laplace transform sampling is applicable only for the function which has x as a positive random variable.

2. Probability density function of x is real.

3. Frequency spectrum of real part in s-domain is even.

So we can not apply Inverse Laplace Transform to those functions which do not satisfy these conditions.

2 Maximal Ratio Combining

Maximum-ratio combining (MRC) is a method of diversity combining in which, The signals from each channel are added together. The gain of each channel is made proportional to the rms signal level and inversely proportional to the mean square noise level in that channel. Different proportionality constants are used for each channel. Maximum-ratio combining is the optimum combiner for independent additive white Gaussian noise channels. MRC can restore a signal to its original shape.

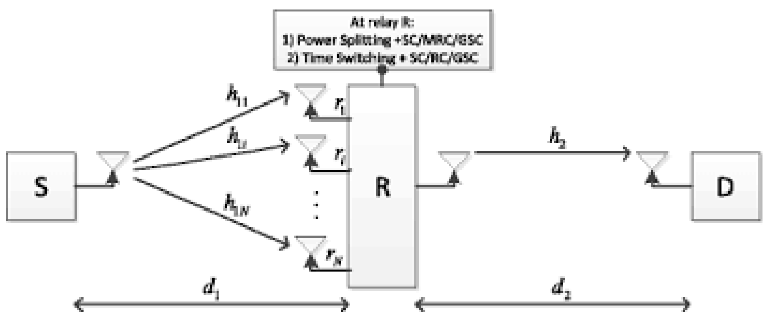


Figure 3: Block diagram for MRC

2.1 BER of MRC

The transmitted symbol from the transmitting antenna will reach the receiving antenna in different channels.At the receiver all the outputs of the receiving antennas will be combined using a weighing vector or receiver vector.

1. We have N receive antennas and one transmit antenna.

2. The channel is flat fading – In simple terms, it means that the multipath channel has only one tap. So, the convolution operation reduces to a simple multiplication.

3. The channel experienced by each receive antenna is randomly varying in

time. For the i^{th} receive antenna, each transmitted symbol gets multiplied by a randomly varying complex number h_i . As the channel under consideration is a Rayleigh channel, the real and imaginary parts of h_i are Gaussian distributed having mean μ_{hi} and variance $\sigma_{hi}^2 = \frac{1}{2}$.

4. The channel experience by each receive antenna is independent from the channel experienced by other receive antennas.

5. On each receive antenna, the noise has the Gaussian probability density function with $p(n) = \frac{1}{2\pi\sigma^2} e^{\frac{-(n-\mu)^2}{2\sigma^2}}$ with $\mu = 0$ and $\sigma^2 = \frac{N_0}{2}$ The noise on each receive antenna is independent from the noise on the other receive antennas.

6. At each receive antenna, the channel h_i is known at the receiver.

7. In the presence of channel h_i, the instantaneous bit energy to noise ratio at i^{th} receive antenna is $\frac{|h_i|^2 E_b}{N_0}$. For notational convenience, let us define,

$$\gamma_i = \frac{|h_i|^2 E_b}{N_0}$$

On the i^{th} receive antenna, the received signal is,

$$y_i = h_i x + n_i$$

where

y_i is the received symbol on the i^{th} receive antenna

h_i is the channel on the i^{th} receive antenna

x is the transmitted symbol

n_i is the noise on i^{th} receive antenna

Expressing it in matrix form, the received signal is,

$y = hx + n$, where

$y = [y_1 y_2 ... y_N]^T$ is the received symbol from all the receive antenna

$h = [h_1 h_2 ... h_N]^T$ Tis the channel on all the receive antenna x is the transmitted symbol and

$n = [n_1 n_2 ... n_N]^T$ is the noise on all the receive antenna. The receiver characteristics of MRC will be,

$$\bar{W} = \frac{\bar{h}}{||\bar{h}||^2}$$

Where $||\bar{h}||^2$ is the magnitude of channel matrix. Finally the Exact bit error rate of MRC for BPSK modulation is,

$$\mathrm{BER_{BPSK}} = \left(\frac{1-\lambda}{2}\right)^N \sum_{l=0}^{N-1} \binom{N+l-1}{l} \left(\frac{1+\lambda}{2}\right)^l$$

Where,

$$\lambda = \sqrt{\frac{\mathrm{SNR}}{2+\mathrm{SNR}}}$$

And the approximated BER of BPSK will be,

$$\frac{1}{(2\mathrm{SNR})^N} \binom{2N-1}{N}$$

2.2 Simulation Results

The theoritical and simulated resluts of BER of MRC with BPSK modulation with increasing number of antennas.And The theoritical and simulated resluts of BER of MRC with BPSK modulation and QPSK modulation are as follows

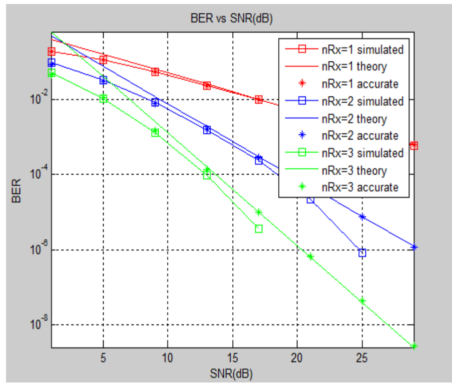


Figure 4: BER of MRC with different number of antennas

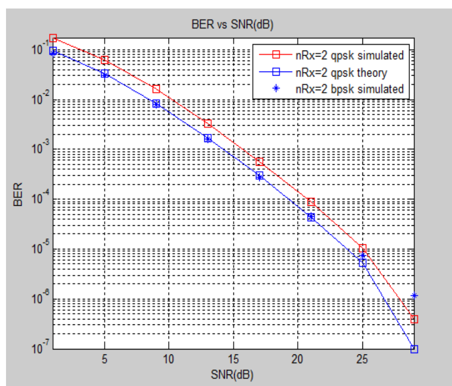


Figure 5: BER of MRC with BPSK and QPSK modulation

2.3 Conclusions

1. The BER of MRC decreases with increasing number of receiving antennas.

2. The BER of MRC for QPSK modulation is higher than that of BPSK modulation.

3. If number of recieving antennas increases the reconstructed symbols matches the input symbols.

3 Multiplie Input Multiple Output

MIMO is highly used in 3G and 4G technologies. MIMO can increase reliability. MIMO increases the data transmission rate. Using MIMO we can send more data in less time.

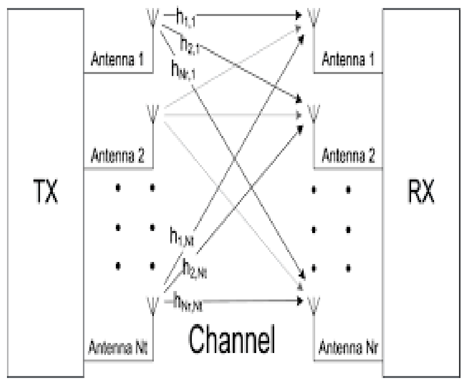


Figure 6: MIMO system

The channel matrix of MIMO is not a square matrix if the number of transmitting and receiving antennas are not same. So modelling a MIMO channel is a bit difficult. If the number of transmiting and receiving antennas are same then channel matrix of MIMO is a square matrix .So it can be invertible.Then at receiver we can get the transmitting symbol by the equation

$$\bar{X} = \bar{H}^{-1}\bar{Y}$$

If the antennas are not same at the number of transmitting antennas are less than the receiving antennas we use Zero Forcing receiver to reconstruct the signal at the receiver.If According to ZF receiver the reconstructed signal is given by

$$\bar{X} = (\bar{H}^H\bar{H})^{-1}\bar{H}^H\bar{Y}$$

where,$(\bar{H}^H\bar{H})^{-1}\bar{H}^H$ is called Pseudo inverse of H

When we multiply the pseudo inverse vector with H we satisfied identity rule.So pseudo inverse also called left inverse of H

3.1 BER of MIMO

3.1.1 Theoritical BER

The theoritical BER of MIMO is same as theoritical BER of MRC .But the no.of antennas are taken as $N = RT + 1$. Where

T = no.of transmitting antennas

R = no.of receiving antennas

So BER of MIMO is

$$\mathrm{P_{BER}} = \frac{1}{(2\mathrm{SNR})^N}\binom{2N-1}{N}$$

Where N=R-T+1

3.1.2 Simulated results

The theoritical and simulated BER of MIMO channel are given below. Simulated graph approximately same as Theoritical graph. The theoritical and simulated BER of MIMO channel with increasing number of receiving antennas are given below.

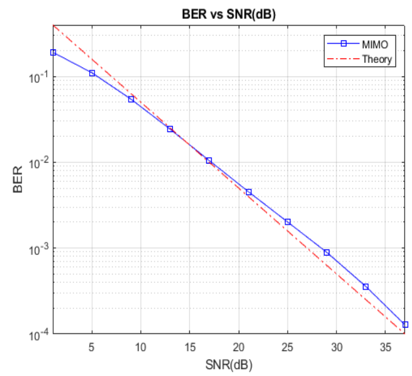


Figure 7: Bit error rate of MIMO channel

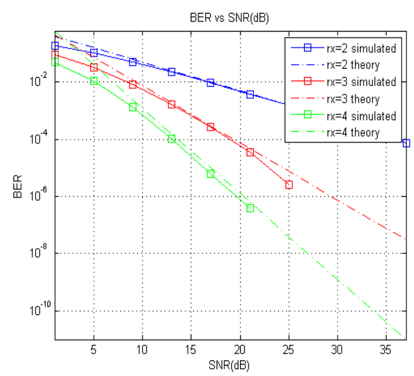


Figure 8: Bit error rate of MIMO channel with increasing number of receiving antennas

3.2 Conclusions

1. The BER of MIMO channel decreases with increasing number of transmitting antennas.

2. The installation cost of MIMO system is higher.

4 Orthogonal Frequency Division Multiplexing

OFDM is a method of encoding a digital data on multiple carrier frequencies,orthogonal sub-carrier signals with overlapping spectra are transmitted to carry data in parallel.Genarally in FDM guard bands are required to protect the leakage adjacent interference,where as in OFDM we overlap the sub carriers orthogonally which consumes low bandwidth.

4.1 Minimum frequency spacing for having orthogonal sinusoidals

The minimum separation between two sinusoidals having frequencies $f1, f2$ of duration T each to be orthogonal,phase difference between the sinusoidals is ϕ it can vary from 0 to 2π

$$\int_0^T \cos{(2\pi f_1 t + \phi)} \cos{(2\pi f_2 t)} dt = 0$$

When the minimum phase difference between sinusoidals is not known then the minimum frequency difference between them is $\frac{1}{T}$ for sinusoidals to be orthogonal. When the phase difference between the sinusoidals is zero then the minimum frequency separation between them $\frac{1}{2T}$.

In discrete form:

$$x(t) = \sum_{K=0}^{N-1} X[K] e^{\frac{j2\pi kt}{N}}$$

$$X[K] = \frac{1}{N} \sum_{t=0}^{N-1} x(t) e^{\frac{-j2\pi kt}{N}}$$

Time domain sample convert into frequency domain samples by applying FFT.

4.2 Use of cyclic prefix in multipath channel

Cyclic prefix where the delayed information from the previous symbol can get stored.The receiver has to exclude the samples from the cyclic prefix which got corrupted from the previous symbol,but it will not affect the frequency of sinusoidals. It provides a guard interval to eliminate inter symbol interference from the Previous symbol.Because of the use of the FFT only the signal is periodic.

4.3 Choosing cyclic prefix duration

Cyclic prefix reduces the data rate,so it has to reduced by designer.Typically Cyclic prefix duration is determined by the expected duration of the multi path.

4.4 OFDM block diagram

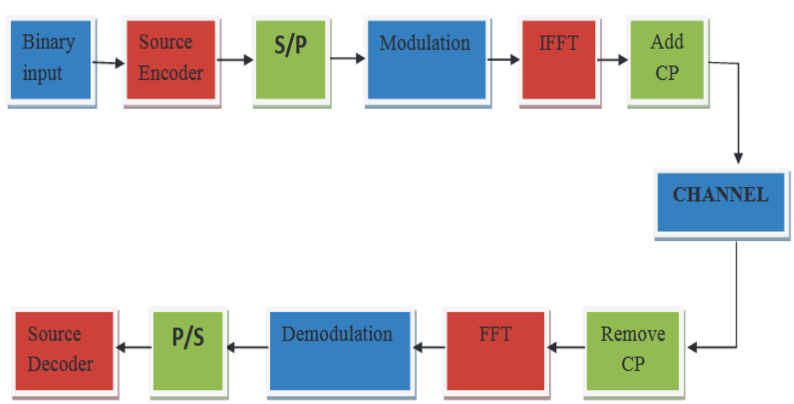


Figure 9: OFDM Block diagram

- Source Encoder:

  In source encoding a signal from information source is generally converted into a digital form.It is effectively used in digital communication system to immunize the digital information from error causing components like noise and interference.

- Modulator:

  The modulator converts the input bit stream into an electrical waveform suitable For transmission over the communication channel.The modulator is capable of multiplexing many signals without any distortion.

- Demodulator:

  The extraction of the message from the information bearing waveform produced by the modulation is accomplished by the demodulator.

- Inverse Fast Fourier Transformation(IFFT):

  FFT is used to convert data from time domain signal to frequency domain signal, at the receiver opposite process is occur.IFFT performs the transformation very efficiently and maintain the orthogonality.Due to no interference occurs in the subcarriers.

4.5 Simulation Results

BER of OFDM system is given by

$$BER = \frac{1}{2}\Big(1 - \sqrt{\frac{\frac{L}{N}SNR}{2 + \frac{L}{N}SNR}}\Big)$$

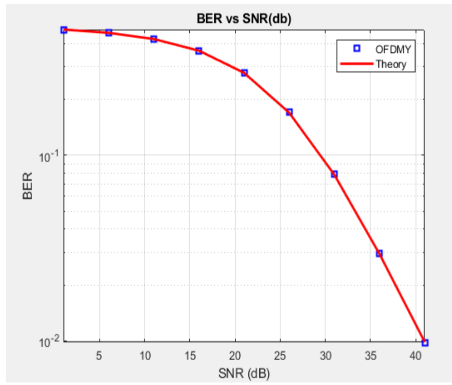
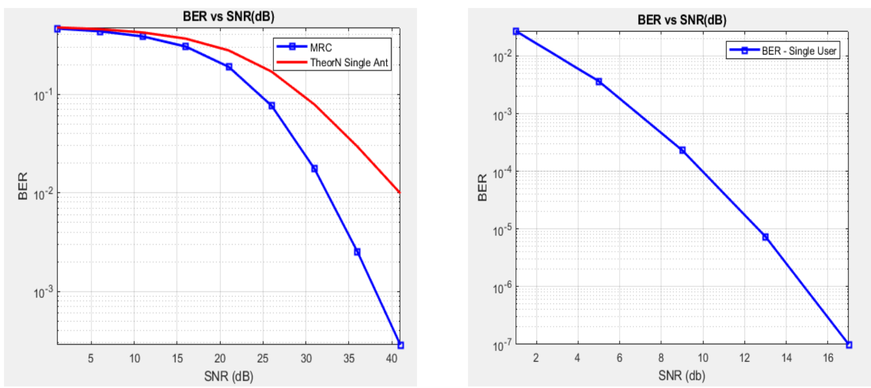


Figure 10: BER of OFDM



(a) OFDM using MRC

(b) OFDM using MIMO

Figure 11: OFDM using MRC and MIMO

4.6 Conclusion

1. By using OFDM we can decrease the ISI of the system.
2. It is broad band transmission.
3. We can store the data easily.
4. Effective data transmission is possible by this OFDM technique.

5 Cognitive Radio using Spectrum Sensing

5.1 Introduction

The enormous usage of electronic devices and wireless appliances, which are mainly used for sharing interactive content like audio, video, etc., has resulted in excessive spectral usage. But, the spectrum hasn't been utilized efficiently and most of the frequency bands are only used for a short time and left unused for the rest of the time. This kind of spectral usage is prevalent in cellular connections. The frequencies that are allotted for cellular connections have been left unused for a long time from late night to early morning and are being extensively used during peak hours mainly the daytime. Generally, the spectrum of radio frequency is distributed in such a way that it is fixed to certain users called licensed users and it cannot be used by unlicensed users even though the spectrum is not in use. This type of spectrum allocation doesn't let unlicensed users access the spectrum even if it is free. This inefficient use of spectrum leads to spectral holes. To overcome the problem of spectral holes and increase the efficiency of the spectrum, the Cognitive Radio (CR) concept is introduced.

The main motto of CR is to provide spectrum access to secondary users

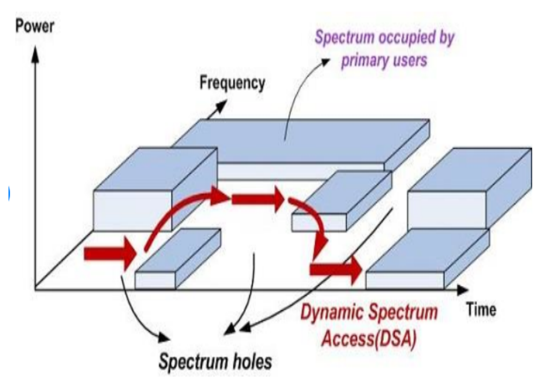


Figure 12: spectral holes

through dynamic spectrum access to improve spectrum efficiency. Secondary users are also licensed users who are given access to the spectrum whenever primary users are under-utilizing or not using it. In the Cognitive Radio concept, spectrum sensing plays a vital role in improving the spectrum efficiency by giving information on to what extent the spectrum is being utilized. Spectrum sensing is the most important part of Cognitive Radio system as it has to sense the spectrum in a fading environment.

CR can operate in 3 modes.They are

- Underlay

  Simultaneous cognitive and non cognitive transmissions are allowed as long as the interference level at the primary user side remains acceptable. Exceeding the predefined tolerable interference threshold may degrade dramatically the primary signal.

- Interweave

  This spectral coexistence approach has been proposed in the objective of enabling devices to occupy the spectrum rooms that has been left vacant by non cognitive users. The surrounding environment should be observed to be able to predict the state of each portion of the frequency spectrum, portions of spectrum that are considered as being under-utilized may be accessed by secondary users as long as the primary activity remains idle. In order to facilitate the coexistence of both primary and secondary traffics within the same network in an opportunistic transmission mode, spectrum opportunities should be actively identified and monitored.

- Overlay

  non cognitive users share knowledge of their signal codebooks and messages with the cognitive users. Thus, the cognitive devices may enhance and assist the non cognitive transmission rather than vying for spectrum access. More precisely, cognitive devices overhear the messages sent by non cognitive sources and use these messages either to eliminate the interference generated by the primary communication at the cognitive receiver side or to improve the performance of the primary transmission through relaying the accumulated messages to the primary receiver.

5.2 Spectrum Sensing in Cognitive Radio

To efficiently use the available radio frequency spectrum, the devices should be conscious of their respective surrounding Radio Frequency (RF) environment. Spectrum sensing is used to provide this information on the RF spectrum, i.e., whether the spectrum is free or occupied. Spectrum sensing regularly monitors the spectrum and finds out the underutilized spectrum to allocate it to a user. The licensed users are divided into Primary and Secondary users. The secondary users need to perform spectrum sensing to detect the primary user's signal in the licensed spectrum. If PU's signal is absent, then the secondary users can use that frequency band. If the signal is present, then the secondary users cannot use that frequency band as it results in signal interference. It is the most important and challenging process in cognitive radio as this needs to be done in a fading channel. For a fading wireless channel, the input and output relationship is given as

$$y(t) = hx(t) + n(t)$$

where $y(t)$ is the received signal, h is the channel fading co-efficient, $n(t)$ is additive white gaussian noise (AWGN) and $x(t)$ is the primary user (PU) signal. Spectrum sensing can be done using two methods. They are

- Matched filter Detector
- Energy detector

Matched filter detector uses the knowledge of channel state information (CSI) which is not available at all given times. Therefore, energy detector is mostly used to carryout spectrum sensing activity. Moreover, energy detector is very easy to implement without much complexity and it doesn't need CSI.

5.3 Spectrum Sensing using Energy Detector

The energy detector measures the energy of the received signal to detect the spectrum's availability in a particular frequency band. At the energy detector, a binary hypothesis test is used to formulate the received signal, $y(t)$. The hypothesis test is as follows

$$H_0 \Rightarrow y = n$$

$$H_1 \Rightarrow y = hx + n$$

Hypothesis 0 ($H0$) means the Primary User's signal is absent and Hypothesis 1 ($H1$) means the Primary User's signal is present.
At the energy detector, the received signal is multiplied by the factor $\frac{x^H}{||x||}$.
Therefore,

$$\text{for} H_0, \bar{y} = \frac{x^H}{||x||} y = \frac{x^H}{||x||} n = \bar{n}$$

$$\text{for} H_1, \bar{y} = \frac{x^H}{||x||} y = h||x|| + \bar{n}$$

Let $|\bar{y}|^2$ be the energy of the $\bar{y}$. This value is compared with the threshold value, E_t, to decide the outcome of the energy detector.

$$|\bar{y}|^2 < E_t \Rightarrow H_0$$

$$|\bar{y}|^2 \geq E_t \Rightarrow H_1$$

Practically to carry out energy detection process, energy detector uses a band pass filter to filter the received signal and let's say its bandwidth is B. To calculate the energy of the received signal, a magnitude squaring equipment is used. To increase the accuracy of the energy detector, the energy of the received signal is calculated over specific period of time (T). Then, this calculated energy is compared with the threshold value to determine whether the spectrum is occupied or not. The block diagram of energy detector is shown in the below figure.

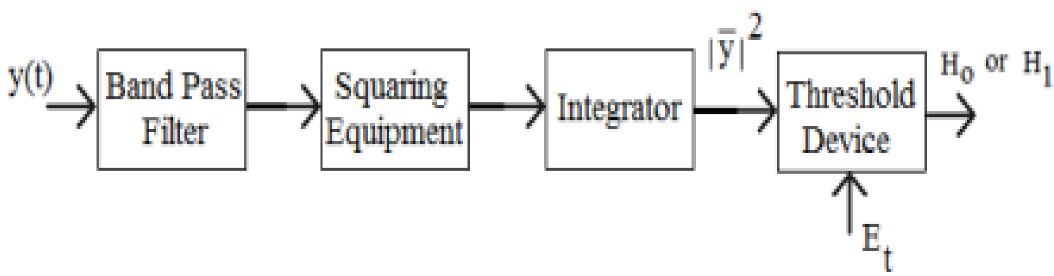


Figure 13: Block diagram of Energy Detector

5.4 Performance Parameters of Energy Detector

There are mainly two parameters which can effectively summarize the performance of energy detector. They are

- Probability of Detection (P_D)
- Probability of False Alarm (P_{FA})

1. Probability of Detection

   The probability of detection indicates the probability that the signal is detected by the energy detector when the spectrum actually contains the signal. It is the probability that H_1 is detected as H_1. The expression for P_D is written as

$$P_D = P(|\bar{y}|^2 \geq E_t|H_1)$$

$$P_D = Q_{X_2^2}\Big(\frac{2E_t}{||x||^2 + \sigma^2}\Big) = e^{-\frac{2E_t}{||x||^2+\sigma^2}}$$

where $Q_{X_2^2}$ is the complementary cumulative distribution function (CCDF) of X_2^2 and X_2^2 represents a central chi-squared random variable which is having two degrees of freedom.

2. Probability of False Alarm

   The probability of false alarm indicates the probability that the signal is detected by the energy detector when the spectrum is empty. It is the probability that H_0 is detected as H_1. The expression for P_{FA} is expressed as

$$P_{FA} = P(|y|^2 E_t|H_0)$$

$$P_{FA} = Q_{X_2^2}\Big(\frac{2E_t}{\sigma^2}\Big) = e^{-\frac{2E_t}{\sigma^2}}$$

From their respective expressions, the probability of false alarm is independent of $||x||^2$ and will not vary with respect to time. Therefore, it's average value will as same as P_{FA}. Let $\bar{P}_{FA}$ represents the average value of P_{FA}. Therefore,

$$\bar{P}_{FA} = P_{FA}$$

Contrary to this, the probability of detection is dependent on $||x||^2$. Therefore, it's average value, $\bar{P}_D$ will not be as same as P_D.

5.5 Simulation Results

To quantify the performance of energy detector, we have plotted Probability of False Alarm vs Probability of Detection curves for different cases. As we are dealing with the probabilities, the axes range from 0 to 1. In each figure, we compared simulation results with theoretical results. In figures, SNRdB represents the signal to noise ratio of the received signal in dB and

$$m = \frac{||x||^2}{\sigma^2 \mathrm{SNR}} \mathrm{where SNR} = 10^{\frac{\mathrm{SNRdB}}{10}}$$

In figure 15, we set m = 1 and SNRdB = 1. From the figure, it can be observed that the simulation results differ slightly from the theoretical results. But in the end, the simulation results curve follows theoretical results curve. In figure 16, we modified the value of SNRdB to 10 without changing the value of m. It is evident from the figure that the simulation results curve follows the theoretical results curve way better than the previous one. This indicates that if the SNRdB value is increased, the simulation results curve perfectly follows the theoretical results curve. But if we keep increasing the SNRdB value, the results are different. The probability of detection jumps nearly to 1 at the very beginning. The simulation results curve was way ahead of the theoretical results curve.

5.6 Conclusion

A better insight into the need of the spectrum sensing process is given and the it's importance in Cognitive Radio is explained with the help of necessary images. Then, we have implemented the spectrum sensing process using the energy detector with the use of it's block diagram. The performance parameters of the energy detection are discussed and it's performance is quantified with the

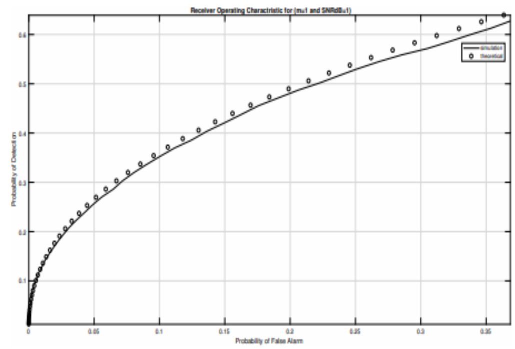


Figure 14: Characteristics of the energy detector for m=1 and SNRdB=1

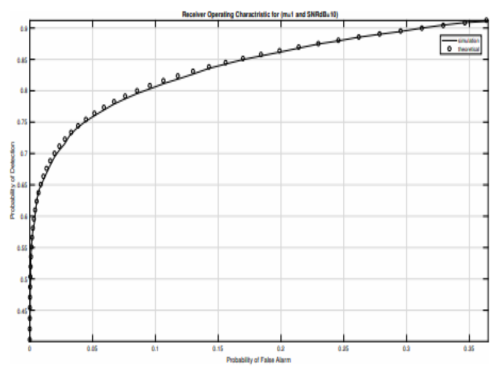


Figure 15: Characteristics of the energy detector for m=1 and SNRdB=10

help of simulation results. From the observation of simulation results, it can be concluded that the energy detector performs extremely good if the signal to noise ratio of the received signal is high. The energy detector correctly detects the spectrum if the SNR of the received signal is high.

5.7 Future Work

Generally, wireless communication channels are subjected to different types of fading. In these fading conditions, the signal will lose it's power considerably before reaching the destination. Performing energy detection on these received low power signals will yield wrong results about the spectrum. This, again leads to spectrum underutilization. So, to reduce the effects of fading on the signal, co-operative relaying techniques are employed. By using the co-operative relaying techniques, the SNR of the received signal can be increased significantly.

6 Reference

1. http://www.win-vector.com/blog/2012/01/six-fundamental-methods-to-generate-a-random-variable.

2. Mini-project course on MU-MIMO,Massive MIMO and OFDM Technologies for 5G networks-prof.Aditya K.jagannadham-IIT Kanpur.

3. Outage probability of diversity systems over generalized fading channels.

4.J. Abate and W. Whitt, “Numerical inversion of Laplace transforms of probability distribution”.

5. DSPlog

6. FCC, Spectrum Policy Task Force, 11/2002, ET Docket 02-135.

7. H. Urkowitz, Energy detection of unknown deterministic signals, in IEEE Proceedings, vol. 55, no. 4, April 1967, pp. 523531.

8. H. Sun, D. Laurenson, and C.-X. Wang, Computationally tractable model of energy detection performance over slow fading channels, IEEE Comm. Letters, vol. 14, no. 10, pp. 924 926, Oct. 2010.

9. Q. Chen, F. Gao, A. Nallanathan, and Y. Xin, Improved cooperative spectrum sensing in cognitive radio, in Proc. IEEE VTC 2008 Spring, 2008, pp. 1418 1422.

10. Q. Chen, M. Motani, W.-C. Wong, and A. Nallanathan, Cooperative spectrum sensing strategies for cognitive radio mesh networks, IEEE J-STSP, vol. 5, no. 1, pp. 56 67, Feb. 2011.

11. C.-X. Wang, H.-H. Chen, X. Hong, and M. Guizani, Cognitive radio network management: tuning in to real-time conditions, IEEE Vehicular Technology Magazine, vol. 3, no. 1, pp. 2835, Mar. 2008.

12. C.-X. Wang, X. Hong, H.-H. Chen, and J. S. Thompson, On capacity of cognitive radio networks with average interference power constraints, IEEE Trans. Wireless Comm., vol. 8, no. 4, pp. 1620 1625, Apr. 2009.