OPTIMIZATION OF PARALLEL COOPERATIVE SPECTRUM SENSING IN COGNITIVE RADIO NETWORKS

Avneet Kaur Anand*

Mrs.Inderdeep Kaur Aulakh**

***Abstract*—**

The limited available spectrum and the inefficiency in the spectrum usage necessitate a new communication paradigm to exploit the existing wireless spectrum opportunistically. This new networking paradigm is referred to as cognitive radio(CR) networks. In CR networks, one of the main challenges in open spectrum usage is the spectrum sensing before it is shared by different users. In this paper, we describe an optimization of an efficient sensing technique-Parallel Cooperative Spectrum Sensing.

Keywords- Cognitive Radio Networks;Spectrum sensing;Sensing Time; Throughput ; Randomness.

* Student,M.E,Information Technology,U.I.E.T,Panjab University,Chandigarh,India.

** Assistant Professor,U.I.E.T,Panjab University,Chandigarh,India.

INTRODUCTION

Before describing what actually Cognitive Radio networks are ,let us briefly discuss what is a Software Radio? It is basically a platform that evolves a fully configurable wireless black-box which changes automatically senses and adjust its communicating variables with respect to the network and its users. Now coming on to Cognitive radios, it can be viewed as a “step ahead up” of Software Radio. The concept of Cognitive radio was firstly introduces officially by Joseph Mitola III in a seminar at KTH, Royal Institute of Technology, in 1998. Technically, definition of cognitive radio is:” *A radio which is capable of sensing its operational environment and can adjust its parameters according to the environment dynamically*.” In cognitive radio networks (CRNs), cognitive secondary users (SUs) are allowed to access the spectrum licensed to primary users (PUs) as long as the interference caused by the secondary access is well managed. In this context, before transmitting, the SU senses and detects whether the spectrum is being used by PUs. Then, SUs opportunistically operate over the spectrum originally allocated to PUs only if PUs are idle or at least they seem to be idle. COGNITIVE radio is a promising technology aiming at better utilization of available channel resources.Cognitive radio prescribes the coexistence of licensed (or primary) and unlicensed (secondary or cognitive) radio nodes on the same bandwidth. While the first group is allowed to access the spectrum any time, the second seeks opportunities for transmission by exploiting the idle periods of primary nodes. The cognitive radio problem was investigated earlier from an information theoretic standpoint, where the cognitive transmitter is assumed to transmit at the same time and on the same bandwidth of the primary link, being able to mitigate its interference toward the primary through complex precoding techniques that are based on the perfect prior information about the signal transmitted by the primary. [1]

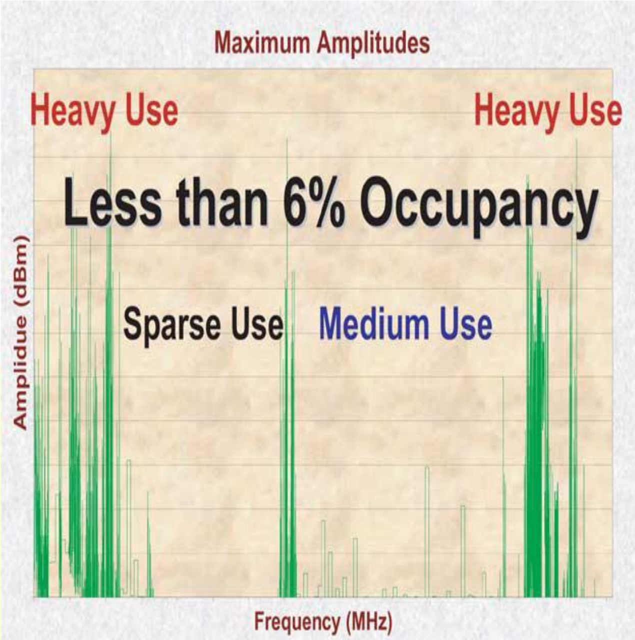

Figure1:Spectrum Usage[2]

In recent research it is found that less than 6% of the spectrum is utilized and rest of the spectrum remains unused. So, by using Cognitive Radio networks, this unused spectrum can be used efficiently. Cognitive Radio Networks have three significant tasks: Spectrum Sensing, Spectrum Management and Spectrum Allocation and Sharing. In Spectrum Sensing Spectrum is analyzed and sensing to check for its availability for the secondary users. Once the spectrum has been sensed the it is properly managed for efficient allocation of the spectrum. Lastly the spectrum is sharing among different secondary users without interfering with the streamline work of primary users.

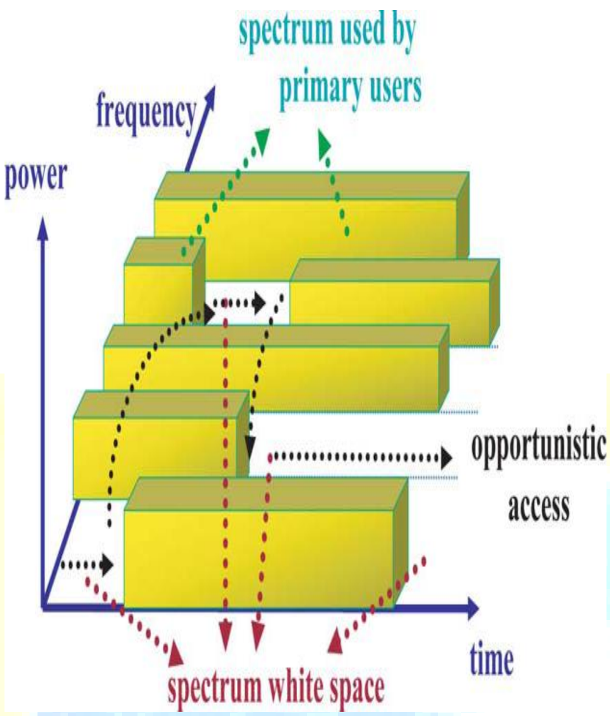

Figure2: Spectrum White spaces[2]

Through Spectrum Sensing, white spaces can be detected. Spectrum White Spaces are the portions of frequency band in the spectrum that are presently not being used by the primary users and can be temporarily utilized by the secondary users. The Spectrum is sensed with respect to various parameters: Frequency, Power, Time and white spaces are detected for being used by secondary users.

PREVIOUS WORK ON SPECTRUM SENSING

Multi-Dimensional Spectrum Awareness

By defining opportunity we describe the different ways of measuring and exploiting the spectrum space. Conventional sensing methods usually exploit the three main parameters: Frequency, Time and Space. However, there are other dimensions that need to be explored further for spectrum opportunity. For example, the code dimension of the spectrum space has not been explored well in the literature. Therefore, the conventional spectrum sensing algorithms do not know frequency hopping codes. As a result, these types of signals constitute a major problem in sensing the spectrum [3].

Hidden Primary User Problem

It can be caused by many factors including severe multipath fading or shadowing observed by secondary users while scanning for primary users' transmissions. Fig.3shows an illustration of a hidden node problem where the dashed circles show the operating ranges of the primary user and the cognitive radio device. Here, cognitive radio device causes unwanted interference to the primary user (receiver) as the primary transmitter's signal could not be detected because of the locations of devices. Cooperative sensing is proposed in the for handling hidden primary user problem.[3]

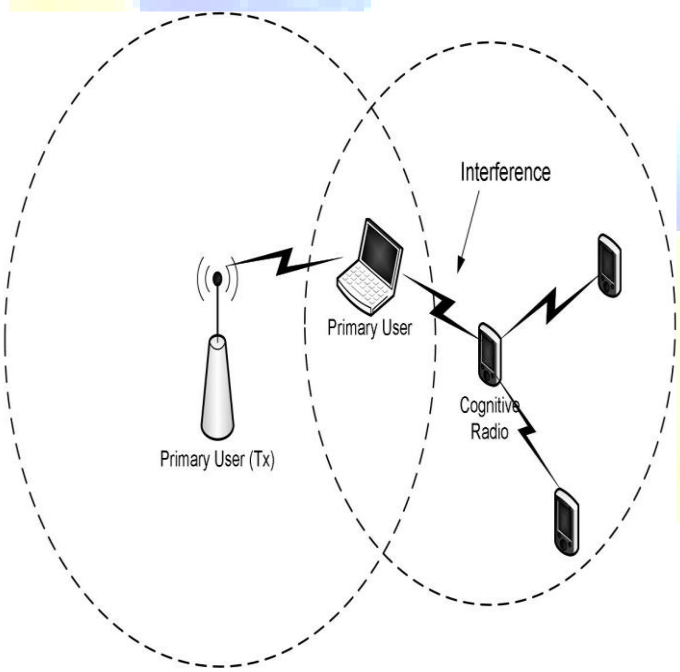

Figure3:Illustration of Hidden primary user problem.[3].

Traditional Spectrum Sensing Techniques

The main aim of Spectrum sensing is to find 'holes' in the spectrum so that they can be used by the secondary users until reclaimed by the primary users. There are some of the techniques used for spectrum sensing based on energy detector, matched filtering, Cyclostationary feature detection, waveform based. In *energy detector based*, signal is detected by comparing the output of the energy detector with a threshold which depends on the noise floor. The hypothesis used for performance evaluation in this method is:

$H0$: $y(n) = w(n)$, (3)

$H1$: $y(n) = s(n) + w(n)$.

The performance of the detection algorithm can be summarized with two probabilities: probability of detection PD and probability of false alarm PF . PD is the probability of detecting a signal on the considered frequency when it truly is present. Thus, a large detection probability is desired. [3].

Matched filtering requires demodulation of primary user signal for effective detection[4]. This implies that a separate receiver would be required for each class of primary users. The main advantage of matched filtering is the short time to achieve a certain probability of false alarm or probability of miss detection[3]. *Cyclostationary feature detection* taps the cyclic characteristics of a modulated signal to identify its presence in a low signal-to-noise ratio regime.[4]. It is a method for detecting primary user transmissions by exploiting the cyclostationarity features of the received signals. The cyclostationarity based detection algorithms can differentiate noise from primary users' signals.[3]. In *Matched-Filtering*,

In the presence of a known pattern, sensing can be performed by correlating the received signal with a known copy of itself . This method is only applicable to systems with known signal patterns, and it is termed as waveform-based sensing.[3].An enhanced technique has been developed:GLRT based Spectrum sensing. In this we describe the finite-sample optimality of the generalized likelihood ratio test (GLRT).The main aim of this method is to provide an optimal joint spectrum sensing and parameter estimation for cognitive radio networks given a small number of signal samples available at the secondary users by exploiting the prior knowledge on the channel statistics between the primary and the secondary users, the modulation schemes employed by the primary user, and the noise power at the cognitive receiver.[5]Another one to enhance spectrum utilization is Adaptive sensing. This scheme adaptively decides whether to sense the channel or to transmit the user data based on previous sensing results. By using this adaptive decision process, the CR can perform channel sensing only when it is needed, and therefore, unnecessary sensing can be avoided. The adaptive sensing CR makes each decision based on the previous sensing results. At a decision epoch after sensing, the CR can immediately stop sensing and transmit data if the sensing results strongly indicate that the channel is vacant. More sensing is required only when the sensing results are not conclusive. [6]

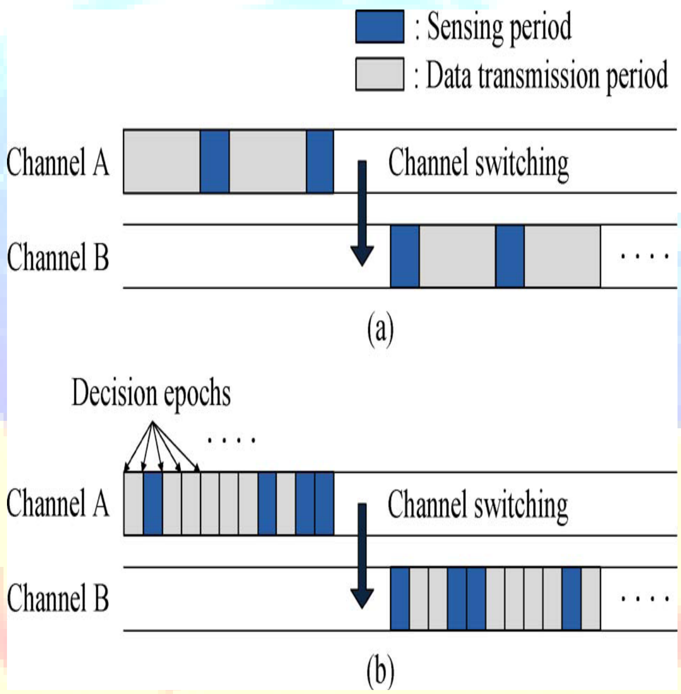

Figure4: Periodic sensing CR and adaptive sensing CR. (a) Periodic sensing CR.(b) Adaptive sensing CR.[6]

COOPERATIVE SPECTRUM SENSING

Cooperative spectrum sensing (CSS) is an environment where two or more spectrum sensing nodes, that form part of a CR network, combine their spectrum sensing capabilities leading to centralized or decentralized decision fusion. CSS allows individual nodes to gain a more global degree of awareness about spectrum occupancy . It also has the inherent advantages of increased levels of agility as well as greater accuracy due to the ability to detect a primary user (PU) that is obscured to a sub-set of sensing nodes due to channel behaviour. CSS has to be considered in the context of increased communication overhead . If the inherent advantages of CSS are more important as compared to the cost of overhead then it is a viable trade-off. In this scheme, during each sensing period, only one channel could be detected, and the detection of other channels is not allowed. The cooperation among several SUs is expected to improve the sensing accuracy of the sensed single channel. However, the strategy on sensing a single channel by one SU or several SUs simultaneously may largely limit the sensing efficiency. A study has introduced two novel cooperative sensing mechanisms, i.e., random sensing policy and negotiation-based sensing policy. The latter strategy assigns SUs to collaboratively sense different channels to improve the sensing efficiency [4]

Cooperative Spectrum Sensing in a Two User and Multi User network

CSS in a two user network allow the cognitive users operating in the same band to cooperate and hence helps in reducing the detection time and enhance the overall agility .In this scheme two cooperative protocols are used: *Amplify-and-forward* (AF) and 2) *Decode-and-forward* (DF)[7].It has been shown in [7] that two user single hop networks in which one of the user acts as a relay for the other, result in lower outage probabilities. A Detection Problem is shown in [8]. A network with two cognitive radio users *U*1 and *U*2 operating in a fixed TDMA mode for sending data to some common receiver is considered. If a primary (licensed) user starts using the band, then the two cognitive users need to vacate the band as soon as possible to make way for the primary user. However, the detection time becomes significant if one of the users, say *U*1, is far away from the primary user and the signal received from the primary user is so weak that the cognitive user *U*1 takes a long time to sense its presence .However, it is shown that cooperation between the cognitive users reduce the detection time of the weaker user and increase the overall agility.[8]

In Multi-User Networks, multiuser single carrier network is considered and sufficient conditions are developed for agility gain when the cognitive population is arbitrarily large. We then propose a practical algorithm is developed which allows cooperation between cognitive users in random networks. [9]

PARALLEL COOPERATIVE SPECTRUM SENSING

The traditional schemes of sensing has a major bottleneck that they use either one or multiple SUs to perform sensing on a single and the same channel in one sensing period. During each sensing period, only one channel could be detected, and the detection of other channels is not allowed. The cooperation among several SUs is expected to improve the sensing accuracy of the sensed single channel. Hence, Sensing in cooperation is proved to be more efficient .As a result a new and better cooperative sensing scheme has been proposed: Parallel Cooperative Spectrum sensing. In this scheme several SUs are optimally selected to perform sensing, and each of them senses a distinct channel in a parallel way. Thereby, a number of channels can be simultaneously monitored and sensed in each sensing period. The parallel sensing procedure has an inherent trade-off between the sensing efficiency and the sensing overhead. An SU may temporarily stop its own data transmission and help other SUs sense the spectrum opportunity. After the provision of help, the SU will continue its own data transmission. It is clear that more SUs are able to find more spectrum opportunities in one sensing period.[10]

The basic overall functioning in Parallel sensing is depicted in Fig.5

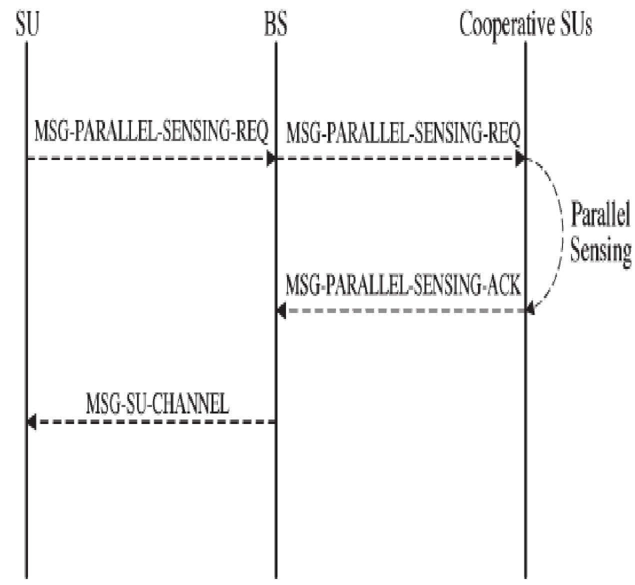

Figure5: Parallel Cooperative Sensing.[10]

The major steps involved in this sensing are:

1. Each of the SU will sense its own channel for sensing period, let Ts.If it doesn't find any PU signal, it will send its own data for transmission. But if PU signal is detected, it will send a request to B.S indicating its parallel sensing requirement.
2. When B.S gets a request from the S.U, it will select a subgroup of S.Us deliberately and these S.Us would perform Parallel cooperative sensing. Each of these S.U would sense a different channel during same sensing time thereby performing sensing parallely. After the completion of sensing, these S.Us would send back an acknowledgement message along with the sensing results back to the B.S indicating availability or unavailability of the channel.
3. After getting the acknowledgement message and gathering all the required information ,B.S would allocate a specific channel to the requesting S.U and notify the S.U by send a message along with the channel index.

4. S.U would then transmit data over allocated channel and other cooperating S.Us would also continue with their own transmission after the completion of sensing.

OPTIMISATION OF PARALLEL COOPERATIVE SPECTRUM SENSING

Proposed Methodology

In the proposed, an environment has been created for parallel sensing by generating an OFDM spectrum and then dividing the channel into various sub-channels so that signals can be sent through these sub-channels in parallel manner and can be monitored simultaneously. For producing some variation in the signals some interference has been included in the signals in the form of noise and also by adding some randomness in the signals to investigate signal variations. Before transmission, the signals are modulated through BPSK modulation method. At the sender side FIR filters have been applied to the signal. Along with that Kalman Filtering has been applied to remove the noise and improve the signal quality and to analyze its effect on the performance. The signals are converted into digital form and are send in the form of 0’s and 1’s.Between the sending and receiving phase sensing is being performed at specified sensing time. At receiver side, the signals are received collectively as I-waveforms and Q-waveforms. The received signals are then analyzed on the basis of various parameter like sensing time, throughput. The achieved overall throughput of the proposed scheme is observed to be higher than the previous scheme. The main focus of this research is to identify an effective spectrum sensing technique and to optimize it further. The technique identified is Parallel Cooperative Spectrum Sensing. The objective of this thesis was to optimize Parallel Cooperative Spectrum Sensing Technique in order to enhance its efficiency. Simulations are done in Matlab.

Basic Equations

Hk (l) =h (l) exp (-j*2*pi*k (l/n))

where h (l): impulse response

Hk (l) represents FIR filter used to get linearity in signal.

A (n) = (1/sqrt(K))*(exp(j*2*pi*v*n)/N

A (n) is for signal retrieval in additive noise in multivariate (sample rate for each sub-carrier).This equation is defined in a loop to read each sample separately and to store sample rate for each sub-carrier.

B (n) = (exp (j*2*pi*n*k)/N)

B (n) is sample rate after inclusion of pilot symbol (for some diversity in signal, implementing CFO estimation). Pilot symbol is some value included for diversity in signal. Diversity can disturb or strengthen the signal.

yy (m)= exp(j*2*pi*v*1/J)

a (m)=exp(j*2*pi*v*m)/N)

These equations will estimate synchronization and channel sensing in terms of phase and signal.

Algorithm of the Proposed work

- Generation of the signal.
- Inclusion of Noise and Randomness in signal.
- Filtration of the signal.
- Performing Transmission.
- Sensing the Channel.
- Receiving the Signal.
- Analyzing the signal throughput

Simulation steps:

1. Generate the Signal: As OFDM spectrum has been used, first of all signals would be generated. For this, Channel Length, number of sub-carriers etc need to be described. Then the whole signal would be distributed among these sub-carriers for parallel transmission. The next step is to define the interference to be included in the form of noise, Channel noise etc. In our work we are randomly generating the Spectrum using rand () command of MATLAB.OFDM blocks are divided into J identical sub-blocks such that:

M=N/J

where N=no. of carriers

J=no. of sub-blocks

M=size of each sub-block

2. Inclusion of Noise and Randomness: In this work, two factors have been included: Noise and Randomness. Different intensities of noise would be included in different sub-carriers and would show the change in error rate as the signal passes through the channels. Another factor included for variation is randomness. By adding randomness the variation occurring in the signal that can lead to distortion can be analyzed. And in this case channel sensing becomes desirable. For showing randomness factor Crammer Rao Bound method has been used. In this method after modulation signal from different sub-carriers is verified against calculated MSE(Mean Square Error).In this way signal from each sub-carrier is verified w.r.t noise and the result shows parallel output for all the sub-carriers(gradually).

3. Filter the Signal: Next step is to filter the signal using low pass filter and Kalman filtering method to improve the signal quality.

4. Perform the Transmission: Here, Firstly the number of Primary users and Secondary users for the scheme would be described. 5 Primary users and 16 Secondary users per channel have been used in this work. For transmission signals from different sub-carriers are converted into digital form before transmission and are send in the combination of 0's and 1's (bits) simultaneously. In digital form, these are represented as I-Waveform and Q-Waveform where I-waveform represents odd bits and Q-waveform represent even bits. I/Q waveforms show any change in magnitude or phase of the signal being send. These are more prevalent in Radio Frequency communication system and mainly where signal modulation is involved because of its efficient way of signal modulation while transmitting the signal. Carrier sine waves are being converted into I/Q waveforms because signal modulator that manipulates amplitude and phase is much expensive and less flexible in sine waveforms as compared to circuit used for I/Q waveforms.

5. Channel Sensing: In between transmission and receiving of the signal, channel sensing would be done. For this purpose an array of clock timer for sensing purpose has been generated.

6. Receive the Signal: At receiver side, signal is received as combination of even and odd waveforms collectively and parallel.

7. Analysis of the Signal: The signal is then analyzed w.r.t sensing time and throughput (with Filtration and without Filtration).

RESULTS AND DISCUSSIONS

RESULTS

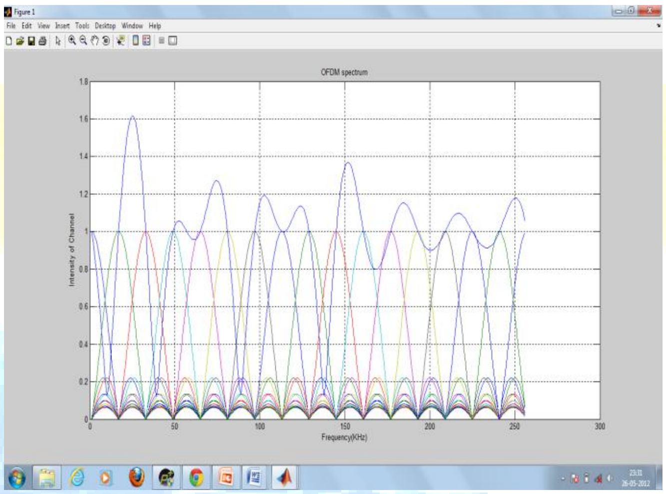

Figure6: OFDM Spectrum Generation

OFDM (Orthogonal Frequency Division Multiplexing) Spectrum is being generated in Figure6. The sub-channel spacing in this spectrum helps in maintaining the orthogonality. OFDM Spectrum has been generated randomly. It is showing waves of different frequencies present on the channel.

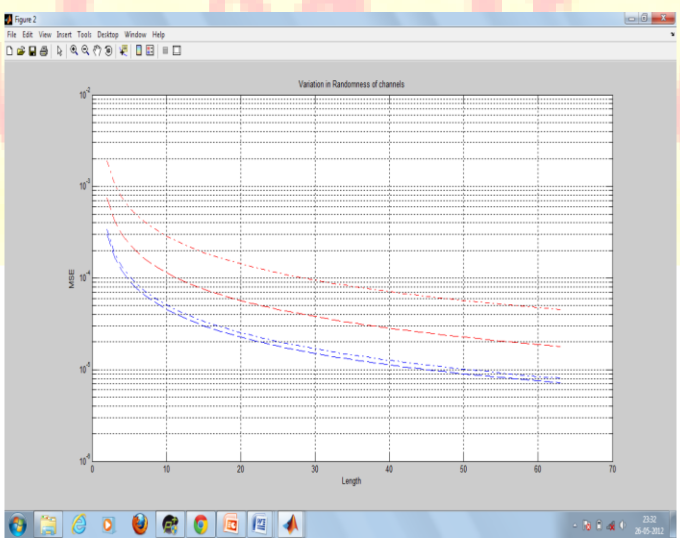

Figure 7: Inclusion of Randomness

In Figure7, Crammer Rao Bound method has been used to include randomness and analyze the signal variation in different sub-channels simultaneously. In this method, after signal modulation different signal outputs are verified w.r.t noise (MSE) .As the error goes down the signals are eventually becoming parallel. It is used to sense randomness in signals. Randomness is being included to analyze the signal variation as these are passed through the various sub-channels.

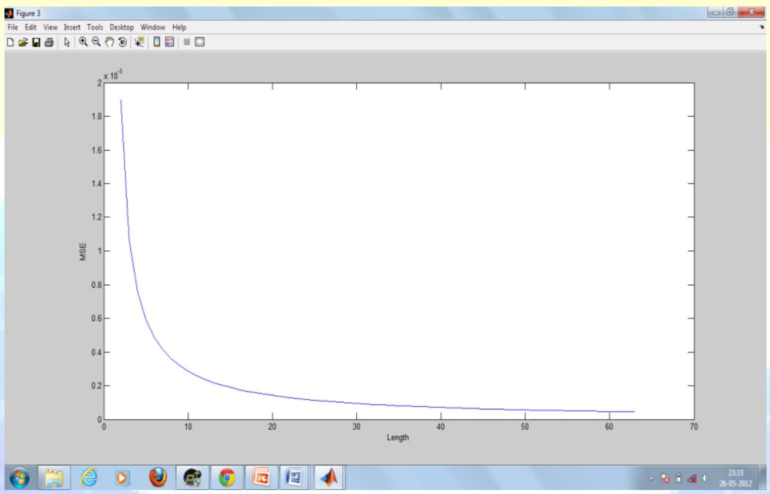

Figure 8. a.Inclusion of Error(Ratio1)

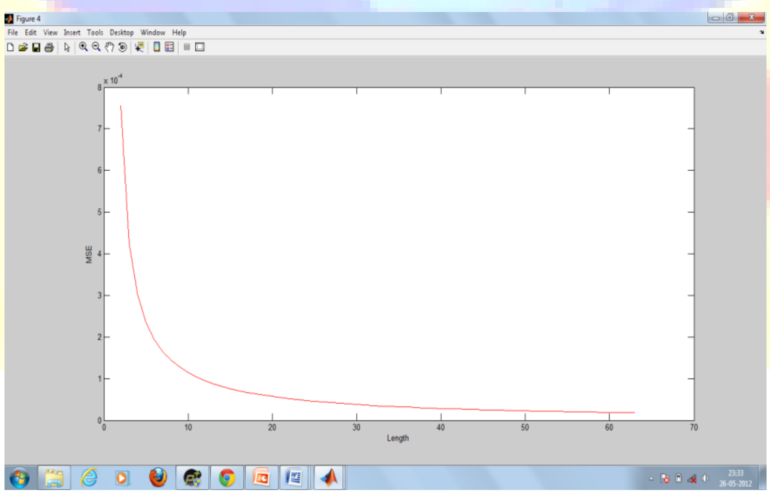

Figure 8. b.Inclusion of Error(Ratio2)

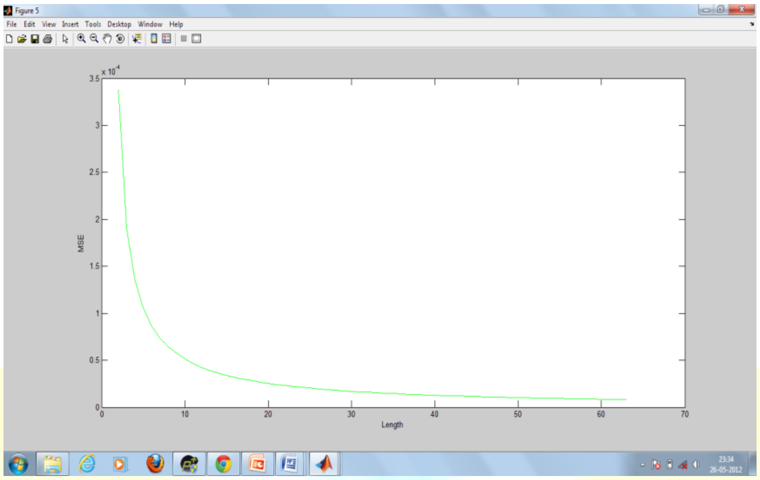

Figure 8. c. Inclusion of Error(Ratio3)

Figure 8 a,b,c depicts variation in signal due to error. Initially error is included and as the signal pass on through the sub-channels the error goes down(due to FIR low pass filtersand Kalman Filters being used). The three figures are showing errors with different intensities(ratio). There is gradual decline in error rate as the signal is passing through the sub-channels,making the signal more strong for transmission over the network.

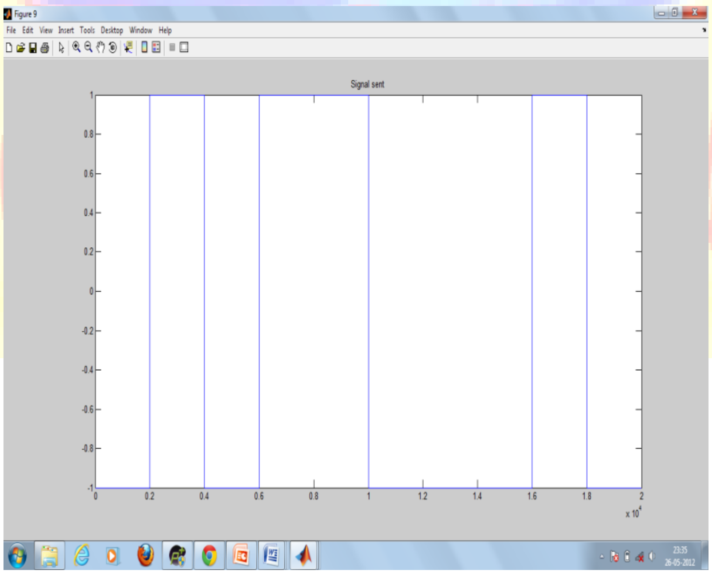

Figure 9 Signal Transmission

In Figure9, signals are being converted into digital form before transmission and are send in the combination of 0's and 1's (bits) simultaneously. In digital form, these are represented as I-Waveform and Q-Waveform where I-waveform represent odd(1) bits and Q-waveform represent even (0) bits. These waveforms show any change in magnitude or phase of the signal being send. Signal is converted into from carrier cosine waveforms into I/Q waveforms because I/Q waveforms are more flexible and use less expensive modulation circuits.

Channel sensing is performed while transmission of the signal. Sensing is performed in between transmission and receiving phase. For this an array (tt[]) of clock timer is generated for sensing purpose as shown below on Command Window of MATLAB.

```
tt = [.001 .0015 .00175 .002 .00225 .0025 .00255 .0027 .003 .0035 .004 .0045];
```

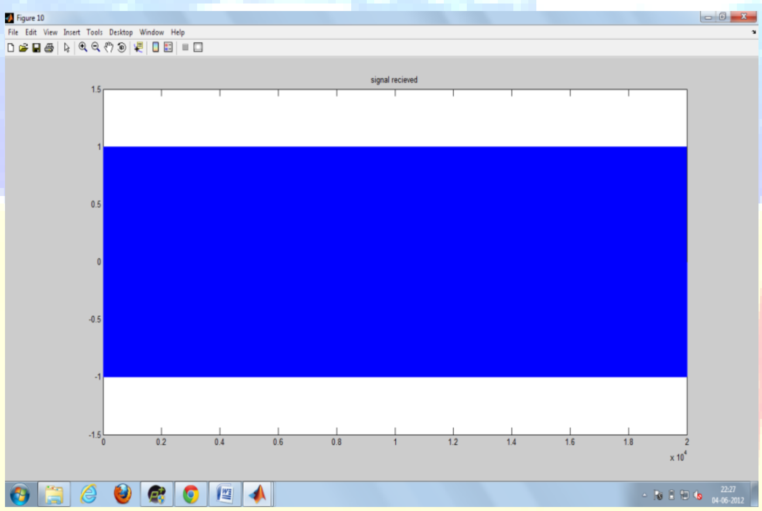

Figure 10 a. Signal Receiving (Without Filtration)

In Figure10 a., Signal has been received, in combination of I/Q waveforms, without doing any filtration; as a result there is no differentiation between the received bits (in form of 0's and 1's) and the noise bits. In this case noise is also being transmitted along with the relevant information making the signal weaker and less efficient.

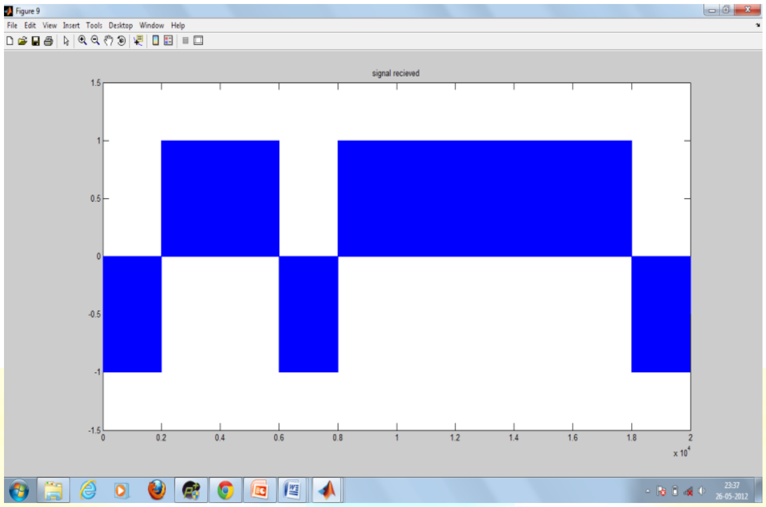

Figure 10 b. Signal Receiving (With Filtration)

In Figure 10 b., Signal has been received, in combination of I/Q waveforms, after performing filtration; Kalman Filtering has been applied. As a result, noise has been filtered and signal is received clearly in combination of 0's and 1's.As seen in the figure the received bits can be clearly identified due to removal of noise.

At receiver side combination of even (Q-waveform) and odd (I-Waveform) bits are received collectively. It is shown as below on Command Window of MATLAB:

```
transmitted_data_bits =

   0   0   1   1   0   1   1   0   1   1   0   1   0   1   0   1   1   1   0   0


Recoutput =

   0   0   1   1   0   1   1   0   1   1   0   1   0   1   0   1   1   1   0   0
```

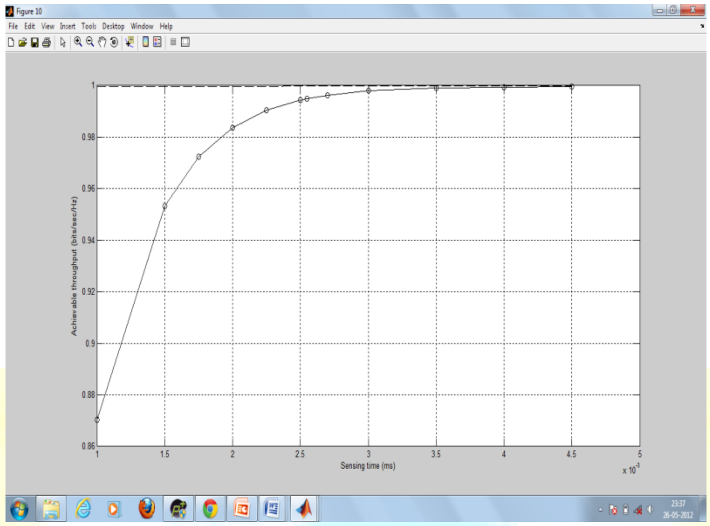

Figure11.Throughput (bits per second per Hz)

In Figure11, throughput (bits per second) has been analyzed with respect to sensing time (in msec). Throughput is taken as frames received per second. It reveals that maximum throughput point is achieved at about 3ms after which it is stabilized. It clearly describe that maximum throughput is being achieved at much lower sensing time.

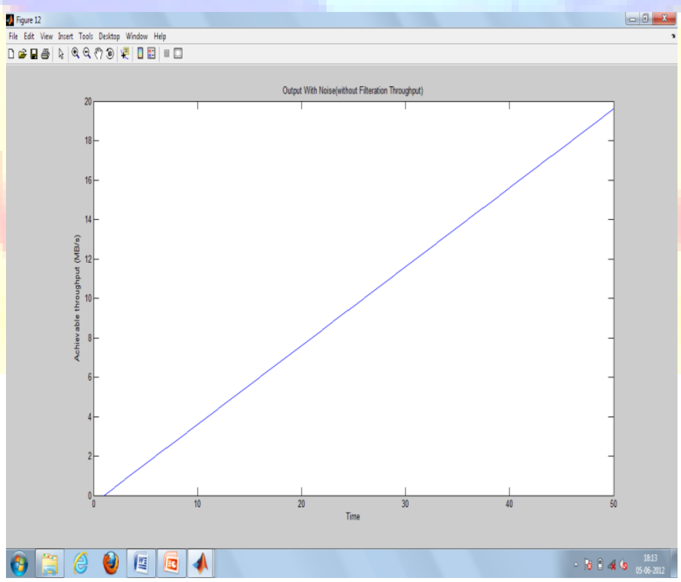

Figure12 a. Overall Throughput (Without Filtration)

Figure12a. shows overall throughput achieved without applying Filtering. It comes out to be between 18 and 20 MB/s which is not much efficient. In this case sensing is also not done much effectively due to presence of noise. So, we consider the case where filtration is performed.

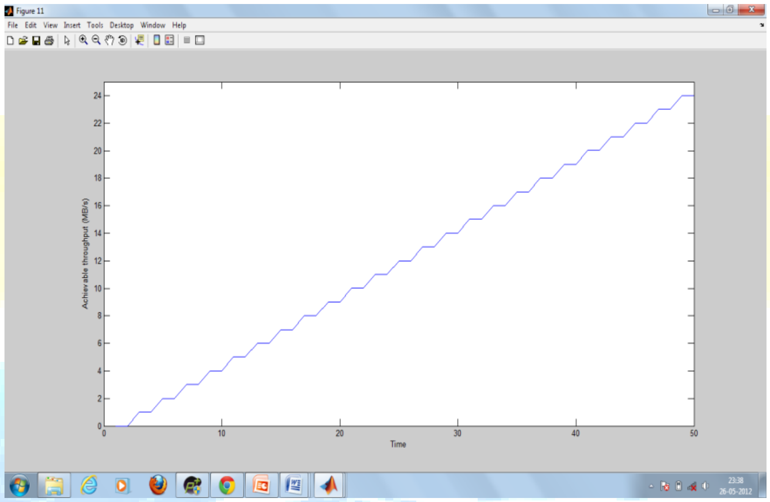

Figure 12 b. Overall Throughput (With Filtration)

Figure12b. shows overall Throughput achieved after performing Filtering. And the result shows much efficient throughput of around 24 MB/s.In this case the Time axis include both sensing time and transmission time and sensing is being performed much effectively due to removal of noise.

DISCUSSIONS

In this work, results with and without Filtration have been shown and results shows that filtration results are much efficient as compared to non-filtered results. Also, the filtration result can be compared to the previous performance results shown in [10].As compared to a reference figure from [10] shown below it can be clearly analyzed that the overall throughput of our work with filtration is much efficient than the previous work done in this respect.

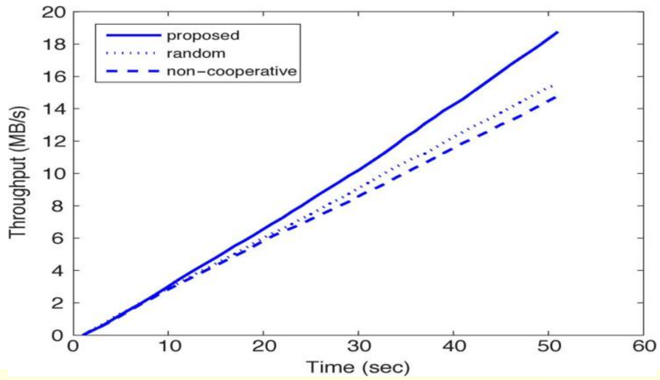

Figure 13 Throughput Results of Previous work [10]

Although the parameters used in previous approach are different but the results of proposed work comes out to be more significant. As a result, it can be concluded that the results of this thesis work are relevant and comparative with the previous scheme.

CONCLUSION

An OFDM is always affected from some kind of impurities over the channel including some noise, instrumentation problem, non linearity etc. These kinds of impurities affect the overall communication and throughput reliability over the channel. In this present work a channel sensing mechanism has been defined that can estimate the channel impurities in an early stage efficiently. This research deal with the same to estimate channel sensing and to remove these impurities effectively and efficiently so that the network throughput is increased. Here three kinds of impurities have been included over the channel, these are: Randomness, Gaussian noise and the instrumentation noise. In first stage of work the channel has been analyzed with respective to these impurities and in next stage these impurities have been resolved effectively by using Kalman Filtering approach. The results are presented in terms of effective sensing time and the effective throughput driven from the network.

REFERENCES

[1] Insook Kim and Dongwoo Kim,” Optimal Allocation of Sensing Time Between Two Primary Channels in Cognitive Radio Networks”,IEEE Communication letters, VOL. 14, NO. 4, April 2010.

[2] Beibei Wang and K. J. Ray Liu,” Advances in Cognitive Radio Networks: A Survey”, IEEE JOURNAL OF SELECTED TOPICS IN SIGNAL PROCESSING, VOL. 5, NO. 1, FEBRUARY 2011

[3] Tevfik Y¨ucek and H¨useyin Arslan,”A Survey of Spectrum Sensing Algorithms for Cognitive Radio Applications”, IEEE COMMUNICATIONS SURVEYS & TUTORIALS, VOL. 11, NO. 1, FIRST QUARTER 2009

[4] Rizwan Akhtar, Adnan Rashdi and Abdul Ghafoor,” Grouping Technique for Cooperative Spectrum Sensing in Cognitive Radios”,IEEE,2009

[5]] Font-Segura Josep and Wang Xiaodong,” GLRT-Based Spectrum Sensing for Cognitive Radio with Prior Information”,IEEE Transactions on Communications, VOL. 58, NO. 7, JULY 2010

[6] Kae Won Choi,” Adaptive Sensing Technique to Maximize Spectrum Utilization in Cognitive Radio”, IEEE TRANSACTIONS ON VEHICULAR TECHNOLOGY, VOL. 59, NO. 2, FEBRUARY 2010

[7] .J. N. Laneman and D. N. C. Tse, “Cooperative diversity in wirelessnetworks: efficient protocols and outage behaviour,” *IEEE Trans. Inf. Theory*, vol. 50, pp. 3062–3080, Dec. 2004.

[8] Ghurumuruhan Ganesan and Ye (Geoffrey) Li,” Cooperative Spectrum Sensing in Cognitive Radio, Part I: Two User Networks”, IEEE TRANSACTIONS ON WIRELESS COMMUNICATIONS, VOL. 6, NO. 6, JUNE 2007

[9] Ghurumuruhan Ganesan and Ye (Geoffrey) Li, Cooperative Spectrum Sensing in Cognitive Radio,Part II: Multiuser Networks, IEEE TRANSACTIONS ON WIRELESS COMMUNICATIONS, VOL. 6, NO. 6, JUNE 2007

[10] Shengli Xie, Yi Liu, Yan Zhang,Rong Yu, “A Parallel Cooperative Spectrum Sensing in Cognitive Radio Networks”, *IEEE Transactions on vehicular technology*, vol. 59, no. 8, October.2010