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Proposed Sensing -Transmission Model for Uncoordinated Cognitive Radios

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Abstract-The radio range accessible is a constrained asset and the quantity of devices with high information rates can't be suited in the present static range. The range detecting is the gauge on which the entire procedure of psychological radio works. To maintain a strategic distance from the impedance with the authorized clients and deciding the available range for expanding the range's use is the crucial errand of intellectual radio. Subjective radio developed to be a powerful technique to conquer this constraint by progressively getting to the information. In this paper, a strategy liable for detecting the range and after that transmitting on that range is proposed. FHSS-ED (Frequency Hoping Spread Spectrum- Energy Detection) is the methodology assessed. It has two phases; right off the detection is finished utilizing Vitality Identification Procedure and Transmission is finished by jumping on accessible channels derived from detecting stage by utilizing FHSS system. Comparison of the proposed strategy FHSS-ED is made with the current FHSS-OBRMB system and reenactment results demonstrate that proposed method has preferred outcomes over the leaving. Examination has additionally been made based on commotion vulnerability conditions.

Keywords – SS, CSS, Energy detection, FHSS, DSSS, threshold.

I. INTRODUCTION

The open radio range is constrained ordinary resource and the solicitations of creating number of high data rate gadgets can't be obliged by the present static range task plans [1], [2]. The static dispersion of range prompts underutilization of radio range. At present simply 15%-85% is the range resource use [4]. In like manner, the traditional method to manage range segment is invariable as independently every remote operant is given a specific license of certain repeat band [1], [3]. For long range of time the approved repeat gatherings are not used by heads and the entire range isn't Spectrum holes can be further classified on the basis of levels of interference: [9]

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used completely.Cognitive radio (CR) is another territory developed to control and deals with the radio spectrum insufficiency [3]. Joseph Mitola was the first to coin the expression "Cognitive Radio" [6]. In 1992, Joseph Mitola give idea about Software Defined Radio (SDR) radio primarily defined in Software support broad range of frequencies and configurations can be modified by the user. The properties of SDR are reconfigurability, easily upgradeable, low maintenance cost, run time reconfigurability. In 1999, Joseph Mitola enhances this idea by SDR combined with intelligence which is Cognitive Radio Network.

In Cognitive Radio Systems (CRNs), every framework can sense its environment, portray the surroundings and locate the best response procedure following the adjustment to new encompassing parameters bringing about better correspondence. A flexile and versatile physical (PHY) layer is required to execute the previously stated capacities. [7]. Spaces that are not utilized as a part of the designated recurrence band are called as "spectrum holes". With reference to the figure in [8] Fig 1.1 depicts the spectrum holes.

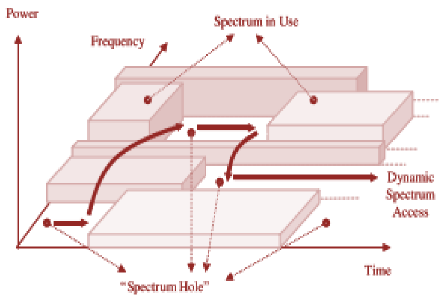

Fig 1.1 Spectrum Holes [8]

.*White Spaces*: no interference except the AWGN (Additive White Gaussian Noise).

- *Grey Spaces:* have low-power interference.
- *Black Spaces:* have high power interference at some instant of time.

From the above classification it can be deduced that SUs (Secondary Users or unlicensed users) can utilize the White and Grey spaces instead of the Black because the utilization of these spaces will lead to interference to the PU (Primary Users or licensed users). PUs has more priority over the SUs for assessing the particular band at same time. The main task of Cognitive Radio (CR) is to sense the spectrum band for the channels available and then share the unused channels/band with the SUs while not using the bands occupied by the PU.

Spectrum Sensing (SS) is defined as “action of a radio measuring signal feature” [10].

Spectrum Sensing (SS) is a key to efficiently utilize the unutilized spectrum. Fig 1.2 shows the classification of Spectrum Sensing techniques:[10-17]

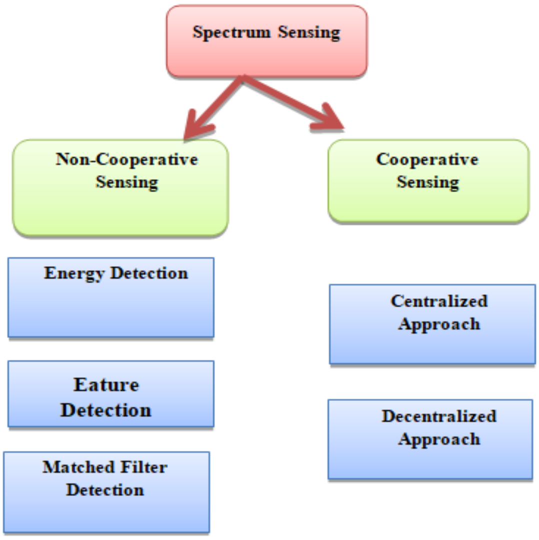

Fig 1.2 Spectrum Sensing Techniques

In *Non-Cooperative SS*technique every SU has the ability to autonomously detect the absence or presence of the PU signal in a particular band. Various techniques have been built such as energy detection, Matched filter detection and cyclostationary feature Detection [18]-[19]. Energy detection Technique measures the received energy from the signal and compares the value with the predefined threshold value[20].In Feature Detection approach works by comparing the features of the received signal with already known features of primary signal. Lastly Matched Filter Detection is done by matching the projected received signal towards the already known PU signal.

In *Cooperative SS* technique A group of SUs share the sensing information that they gather for detecting the PU signal. In centralized approach, a FC (Fusion Centre) is employed to which all the SUs share their sensing information. While on Decentralized approach all the SUs share the information of the sensing with each other [21],[22]

There are two Spread Spectrum techniques namely DSSS (Direct Sequence Spread Spectrum) and FHSS (Frequency Hopping Spread Spectrum) used for transmission. The original signal to be transmitted is modulated using a carrier signal which turns the original signal into a useful information in the form 0'sand 1's. This form of information is called as the Binary data and is understood by all the systems and the modulated wideband signal is sent on the channel. [7], [23]

Redundancy and Security are the two advantages provided by these techniques. Redundancy is achieved as data is sent on different frequencies and therefore can be again recovered in case of noise. Because the signal is sent on a wide band so each channel has lesser amount of energy which does not interfere the task of other receivers and hence detection becomes a difficult task.[24]

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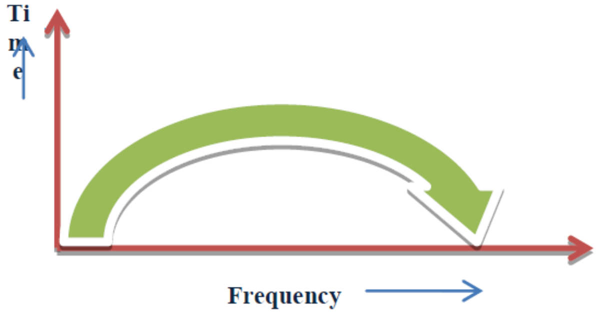


Fig 1.3 DSSS occupies the contiguous band

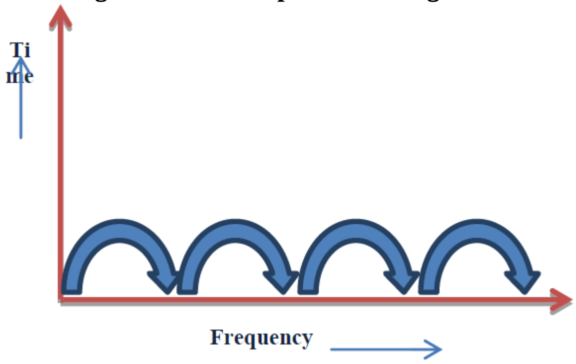


Fig 1.4 FHSS transmits in hop

FHSS and DSSS both have an unlicensed band of 2.4 GHz. FHSS and DSSS have been used in many scenarios. Adjustment of the spreading sequence can lead to better data rate results and less interference to the licensed users [25]. Cognitive Personal Area Network (CPAN) has been defined in [26], which dynamically chooses the hops for FHSS transmission. In [27] FHSS is used for opportunistically selecting a relevant carrier frequency from a separate spectrum band for the DSSS spectrum leading to high bit rates. DSSS have been used in [28] as a technique to exchange the sensing information between unlicensed users. DSSS is also used as a spreading technique in Zigbee [29]. In [30] DSSS in CRNs is proposed DSSS-OB in which to every one-bit query regarding the availability of channel has a one-bit reply allowing the unlicensed user to make decisions regarding transmission and in turn decreasing the data drop rate.

Section 2 provides with the extensive literature survey. Section 3 describes the work which has been done earlier followed by Section 4 which explains the proposed model. Section 5 gives the detailed Result analysis. Section 6 finally concludes the paper.

II. LITERATURE SURVEY

In [31], S. Jin et.al., has analyzed the performance Dynamic Spreading Spectrum approach of a spectrum sharing model in CRNs (Cognitive Radio Networks). This approach consists of two phases: (i) If after sensing the results show that PU (Primary User) is inactive, SU (Secondary User) can transmit on priority. (ii) If the sensing results show that PU (Primary User) is active, PU has the priority to transmit and SU using this dynamic spreading spectrum method can coexist with PU and continue its communication.

Comparison has also been done in this paper between the Opportunistic Spectrum Access and the proposed approach. Simulation results show that Dynamic Spreading Spectrum approach is much better than the OSA (Opportunistic Spectrum Access). The approach proposed by the authors not only protects PU from harmful interference but also maintain the QoS of the SU.

In [32] , Zhao et.al., have proposed two-stage CSS (Cooperative Spectrum Sensing) Process based on energy-efficient and time saving schemes. In first stage, they have proposed a new approach to eliminate or minimize the data loss, and based on various performance simulations authors justified it as the energy efficient technique. Also, one-bit decision sent by each cognitive user is added so as to minimize the overhead cost. In second stage, the proposed approach combines all the local decisions of the coarse detection, furthermore, leading to less energy consumption with its sensing ability somehow near to the approach used in first stage.

In [33] Z.Khalaf et.al., authors have proposed a sensing technique which is a combination of energy detection and cyclostationary feature detection mechanisms. These two mechanisms are used simultaneously i.e if the decision can't be made by the energy detector then the cyclostationary is used for estimating the level of noise and also corrects the energy value for energy detection.

In [34], J. Meng et.al., have proposed a technique to collaborately sense the unoccupied channels in wide range of spectrum by applying matrix completion and joint sparsity recovery. In this the linear combinations of multiple channel information are sensed and sent to FC (Fusion Center). Further, from the FC results are decoded using the aforementioned techniques of joint recovery and matrix completion. This technique reduces the number of sensing results sent by CR node to FC. Both of the decoding techniques have the ability to provide same information from incomplete information. They have proved by simulation that matrix completion approach works better in small-scale networks and joint sparsity recovery works best in large scale networks.

In [35] Umar, R. and Sheikh, A.U., have performed a deep survey of different SS (Spectrum Sensing) techniques and have also highlighted the key challenges and their possible solutions. Both Non-Cooperative and Cooperative techniques are discussed in detail.

In [36] ,B.Selim et.al., have studied the CSS over composite fading channels. Firstly, a Mixture of Gaussian distribution is used to derive a simple generic approximate value for the average probability of detection which can be efficiently applied onto any composite fading channel. Secondly, for hard combination in CSS an optimal voting rule has also been derived. At the end, for the optimal fusion rule a closed form expression has been derived by them. Performance analysis show that CRN's total error is reduced.

In [37] , S. Althunibat et.al., have proposed a technique which is combination of both the Hard and Soft decision fusion rules, leading to high accuracy in sensing results. In this approach, every CR node reports only one-bit in a time slot allotted for its sensing results and the sensing result of the reporting CR node is the arrival time of this single bit. Performance evaluations show that the proposed technology performs better than hard and soft fusion decisions in terms of energy-efficient and detection accuracy.

In [38] Y. Liao et.al., have proposed a MAC protocol for efficient DSA, based on full-duplex Cognitive Radio Networks (CRNs). In full duplex CRNs, secondary users have ability to perform transmission and SS at same time and also can detect the collisions during transmission leading to increased network performance. Comparison has been done by them with the conventional half-duplex CRNs.

In [39] , A. Ali et.al., propose a low power UWB (Ultra Wide Band) SS scenario which makes use of one-bit quantization at CR receiver. The authors have proved that the proposed approach works better in low SNRs. Furthermore, this technique leads to less power consumption, complexity and period of sensing on the basis of acceptable range of performance degradation.

In [40], Y. Peng et.al., has proposed the combination of CR and Frequency Hopping to increase the spectrum utilization and improve the transmission quality. Transmitting information using frequency hopping is a kind of Spread Spectrum in transmission. It is an advantage over the random unequal jump to select channels for transmission. FHSS works better in jamming conditions, supports multi-users random access, has high resistance to interference and with many more abilities.

In[41], Spasojevicet.al., have analyzed the performance Spread Spectrum Techniques (FHSS and DSSS) using a software tool namely Monte Carlo tool. Authors have taken a scenario in which there is a single transmitter and receiver and interferences to the victim are assumed to come from three different types of interfering sources. Probability Density Function (PDF) and Cumulative Density Function (CDF) are the parameters on which the performance is measured. Results show that DSSS systems mostly cause more interference than FHSS.

In [42],Lu, R., Ye, G., Ma, J., Li, Y. and Huang, W., have proposed a normalized throughput of data approach and has done comparison on the basis of anti-jamming parameter between FHSS and DSSS. Normalized Throughput is defined as the ratio of received data with the effect of jamming signals to the received data without the effect of jamming signals. Simulations showed that FH signal has better resistance to jamming conditions than DSSS.

In [43] ,Javed, F., & Mahmood, A., have proposed a FHSS transmission approach in which there is no priori handshaking stage. Each CR node autonomously senses the white spaces and then sends or receives signals according to the pre-defined frequency hopping pattern. The proposed scheme is robust to large detection errors. Also using this approach the PUs can be optimized by adjusting the spreading gain.

Earlier, In [44], I.K Aulakh et.al. have proposed the energy efficient technique of SS (Spectrum Sensing) which makes use of one-bit exchange and leads to less number of control overheads. In this mechanism a pair of request and reply bit is used. The approach used in this aims to reduce an overhead cost of multiple bit exchanges. Cooperative Spectrum Sensing is used in this in addition to the Spread spectrum mechanism. DSSS and FHSS are combined individually with the scenario one by one and performances are measured and analyzed.

III. PREVIOUS WORK

Out the two sensing techniques namely Cooperative Spectrum Sensing and Non-Cooperative Spectrum Sensing, Non-Cooperative SS is the most suitable out of two, because of the fact that it does not require the prior knowledge of the PUs. Energy Detection is the most suitable technique for SS as it has low design complexity along with the aforementioned ability.

3.2FHSS-OBRMB:[44]

The scenario works in 4 phases:

3.2.1 CONNECTION ESTABLISHMENT

It consists of the initial setup to allow transmission between the sender and receiver. It is done, firstly, to ensure that whether the node on the receiver side is also a Cognitive User and secondly, to make sure that the Cognitive User is the intended receiver to which the transmission is to be made.

3.2.2 *AUTHENTICATION*

After the initial setup, authentication module starts up between the sender and receiver. To enable this authentication a seed mechanism is used. In this, sender and receiver independently generate a key from the seed value at both the sides. A seed bit is enabled, if the key matches and this seed helps to provide authentication between both the sender and the receiver.

3.3 SENSING PHASE

Earlier the OBRMB (One-Bit Replies Multiple Bits) technique is used in which CSS is used and the sensing module keeps a continuous check on the frequency band which can be used for transmission. In this, the sender sends a request to receiver for checking the channel availability. A Periodic Timer is installed on the receiver side which helps in achieving a periodicity in Spectrum Sensing. Such Sensing is not continuous for infinite times but the no. of channels to be sensed are predefined for which the receiver responses back to the request. Fig 3.1 depicts the scenario.

3.4 TRANSMISSION PHASE

After all these phases the sender and receiver have a predefined set of available frequencies. To transmit the data FHSS modulation technique has been implemented for modulating the data. Frequency Synthesizer and the Pseudo-random sequence is used to spread data on the frequency channels. Discussed and proved above that FHSS works better than DSSS in CRNs.

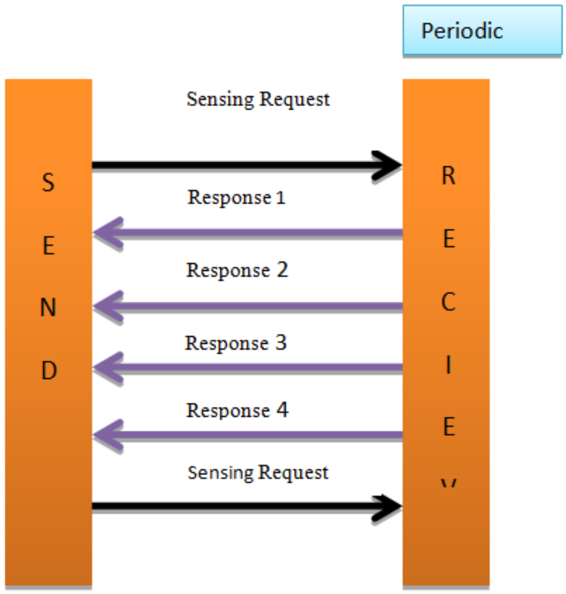


Fig 3.1 FHSS-OBRMB scenario

IV. PROPOSED MODEL

In earlier work there were following limitations which have been improved in this model:

1. The earlier technique used CSS (Cooperative Spectrum Sensing) in which sharing of information between the CR users is done which adds to the delay.
2. The previous technique is complex as it is based on the replies from the receiver side leading to increase in transmission time.
3. It has an overhead as the receiver replies periodically after a certain amount of time leading to more energy consumption.
4. There is no technique to measure the signal energy of the channel and so the receiver even replies on the channel having large amount of noise leading to increase in BER, data drop rate.

4.1CONNECTION ESTABLISHMENT

This establishment is made to securely establish the connections between the two communication ends. The sender’s end always enquires the receiver’s end, because the sender’s end is giving up the data towards the receiver’s end. It is done, firstly, to ensure that whether the node on the receiver side is also a Cognitive User and secondly, to make sure that the Cognitive User is the intended receiver to which the transmission is to be made.

4.2 SENSING PHASE

Spectrum Sensing is the process of distinguishing the unused portions of spectrum from the used ones. It is the ability of Cognitive Radio to measure, sense and be aware of the parameters related to the radio channel characteristics, availability of spectrum, transmit power, interference and noise, radio’s operating environment etc.

The availability of spectrum is determined usually by identifying the presence or absence of any signal in a particular channel. Absence of any signal indicates that the particular channel can be used by cognitive user to transmit data over it. Sensing results are transmitted to cognitive users in the form or bits, where multiple bits can be used to provide additional information about the present signal's characteristics. In our model, Energy Detection method which is transmitter- initiated detection technique is used for sensing phase.

Energy Detection is the most suitable technique for SS as it has low design complexity along with the aforementioned ability.The received signal X_j of the j^{th}SU can be defined in Eq 4.1:

$$X_j = \begin{cases} N_j, & H_0 \\ H_j P_j + N_j H_1 \end{cases} \quad \text{-- (4.1)}$$

In the above equation, H_0 depicts the scenario without PU's signal and H_1 depicts the scenario with PU's signal. $H_j$is the gain in the channel, P_j is the PU signal. N_j is the AWGN (Additive White Gaussian Noise).

Over an interval of 'q' channels, every SU measures the summary statistic Y_j defined in Eq. 4.2:

$$Y_j = \sum_0^{q-1} |X_j|^2 \quad \text{-- (4.2)}$$

Y_j is test statistic of every j^{th} SU in the AWGN measurement channels. Y_j is defined as the Sum of the Squares of 'q' Gaussian random variables.[34-40]Eq 4.3 gives the formula used for threshold, with which the signal energy is to be compared.

$$\lambda = \sqrt{2 \times Total\ data \times \frac{1}{SNR}^4} \times Q^{-1}(P_f) + \left[N + \left(\frac{1}{SNR}\right)^2\right] \quad \text{--(4.3)}$$

A Spectrum Sensing Approach FHSS-ED in Fig 4.1 is proposed, which will be utilizing the Non-Cooperative Spectrum Sensing based upon the Energy Detection technique. Unlike, the previous mechanism of one-way spectrum acknowledgements, the proposed mechanism is based upon the ED mechanism, where after establishing the connection; node on the sender side senses the channels using energy detection technique. It then marks the channels available if the signal energy is < threshold (λ), and further transfers the selected channels to the hopping list 'HS'. The frequencies with high signal strength are eliminated from the final frequency group for data propagation, in order to minimize the chances of the data drop, the bit error rate and the energy consumption and to maximize the throughput. The information is then sent through the channel using the FHSS technique. Following are the algorithms of Sender and Receiver nodes.

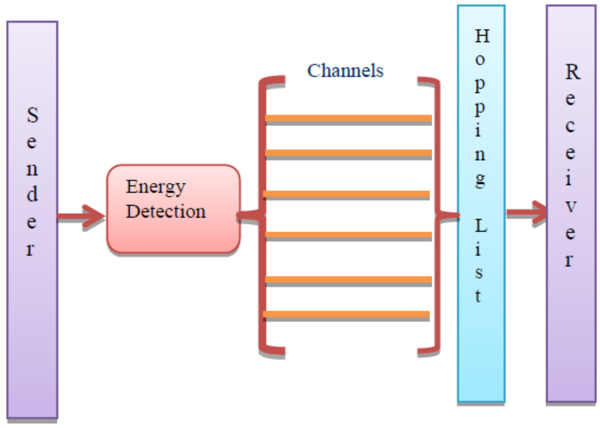


Fig. 4.1 Proposed Model FHSS-ED

Sender's algorithm

1. Input status value.
2. Case 1: (Status = 1)
   a. Request Pre-shared key.
3. Case 2: (Status = 2)
   a. If the reply acknowledgment contains the value [1 1], which represents the two bits.
      i. Set up the connection between two ends.
      ii. Otherwise, stop.

Receiver's algorithm

1. Input status value.
2. Case 1: (Status = 1)
   Return Pre-shared key.
3. Case 2: (Status = 2)
   a. Reply with the acknowledgment containing two bits with value 1, represented as [1 1] bit data.
   b. The two bits depict the approval for connection setup between the two nodes.

4.3 TRANSMISSION PHASE:

FHSS is used for spreading the information over the available channels as FHSS has better jamming conditions than DSSS and also, in Frequency Hopping channel selection, let the given set of frequencies in the spectrum be defined as Eq. 4.4 below:

$FH_n = \{FH_1, FH_2, FH_3, FH_4, FH_5, \ldots\ldots\ldots FH_n\}$

-- (4.4)

On these frequencies no information is made to transmit. Furthermore, let the list of available frequencies be defined as Eq. 4.5:

$AF_n = \{(FH_1, k), (FH_2, k), (FH_3, k), (FH_4, k), \ldots\ldots\ldots (FH_n, k)\}$ -- (4.5),

where value of 'k' can be 0 or 1.

If the value of 'k' is 1 i.e the cannel is available and if the value of 'k' is 0 then it depicts that the channel is unavailabledue to presence of noise
or some other uncertainty.

A sub-band is provided to the FHSS which is the set of frequencies joined together to allow transmission of data between the two ends. The set of frequencies can be static or variable. For Static frequency set;

$$S_n = \text{constant}$$

predefined no. of channels that can be used for transmission

For Variable frequency set,

$$V_n = \int_1^n fx(AF_n) \quad \text{-- (4.6)}$$

where k=1

The available frequencies for the static frequency set are stored in 'AF_{ns}' can be equated as in Eq. 4.7. 'id' is the identity given to each frequency due to the fact that in FHSS the frequencies are not used consecutively as in the case of DSSS. '$\frac{S_e}{S_{en}}$' value is also stored in 'id.'.

The hopping sequence depends on the list of available frequencies and the list L_f can be defined as Eq. 4.8, where 'sk' is the sequence taken from the combination of list of available frequencies 'L_f'and the set of available frequencies 'AF_{nS}'. The hopping sequence 'HS' for transmission is denoted as in Eq. 4.9. Fig. 4.2 depicts the flowchart for the transmission using FHSS.

$$AF_{nS} = \int_1^n fx\left(AF_n, id, \left[\frac{S_e}{S_{en}}\right]\right) \quad \text{-- (4.7)}$$

where, k=1

$$L_f = \int_1^n AF_n\{fx(AF_n)\} \quad \text{-- (4.8)}$$

where k=1 ……..3.10

$$HS = fx(D[sk, AF_{nS}]) \quad \text{-(4.9)}$$

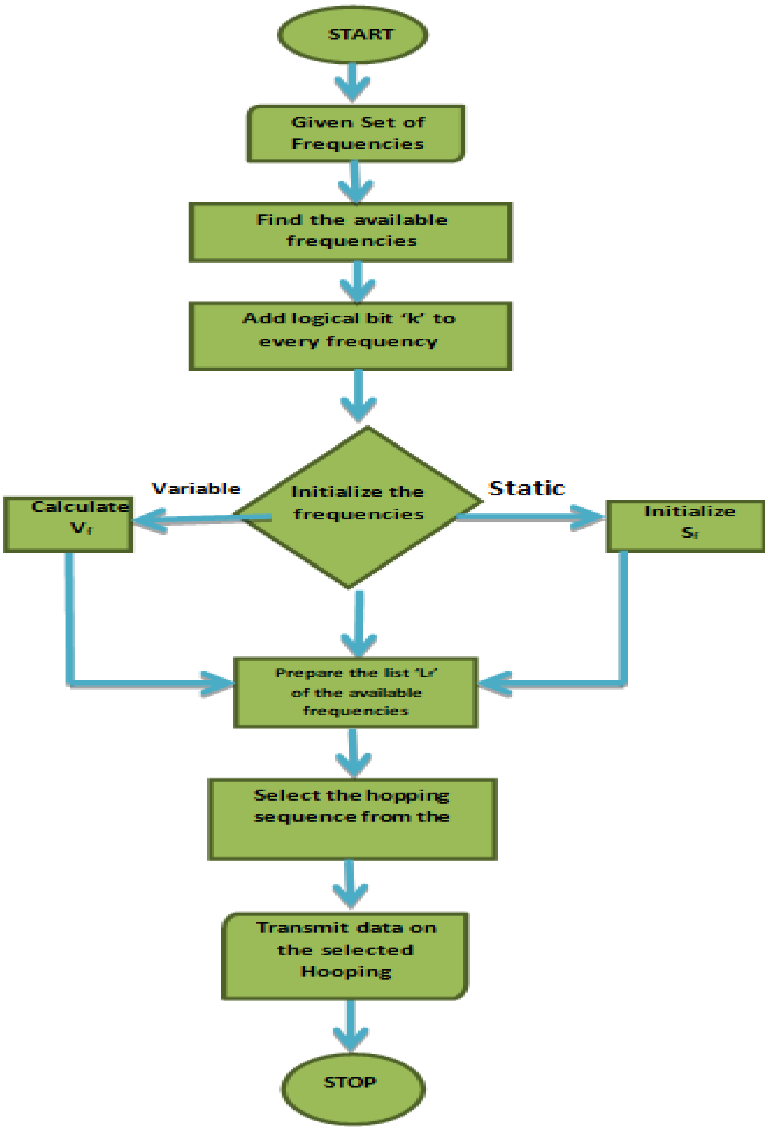


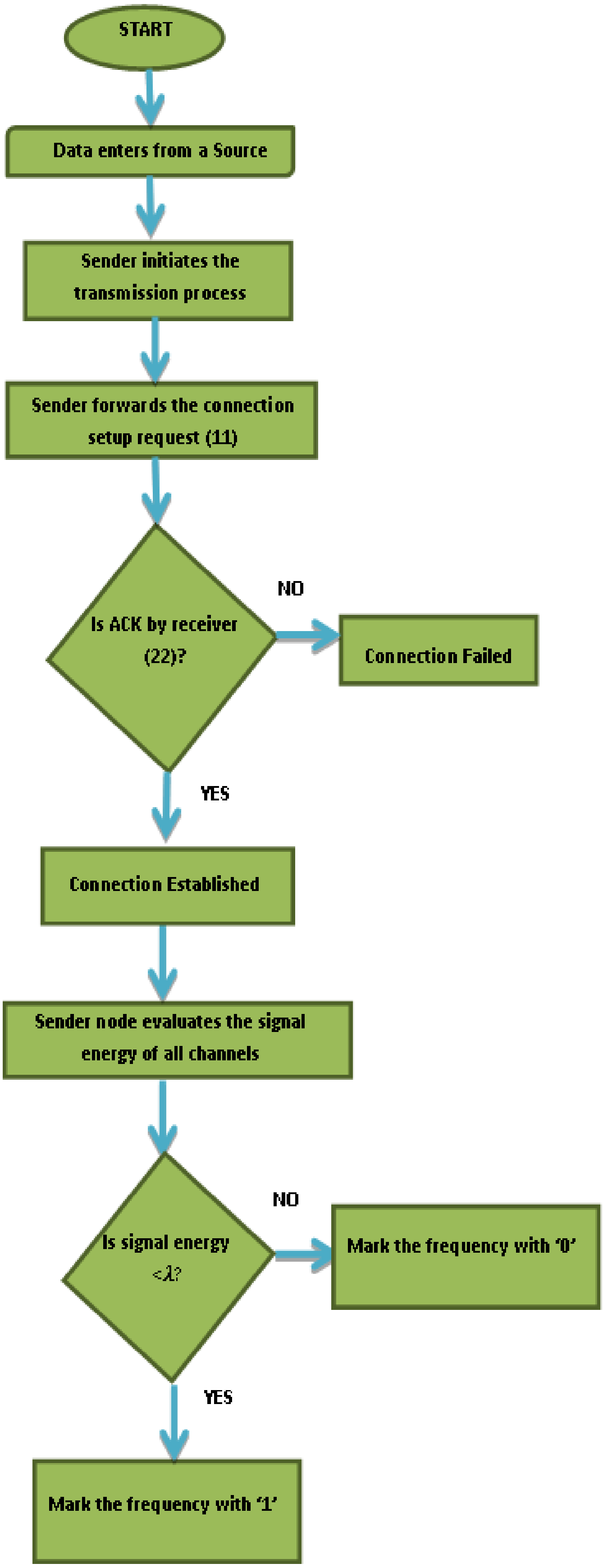
Fig 4.2 Workflow of the Transmission Phase.

MODEL IMPLEMENTATION

Combining all the previous phases the proposed model implementation follows the algorithm depicted below followed by the flowchart:

Spectrum Sensing and Transmission Algorithm

1. Sender firstly receives the data from a source.
2. Then the Sender initiates the data transmission process towards the other end.
3. Sender forwards the connection setup request containing the value 11.
4. Receiver acknowledges with a value 22 in the acknowledgment for a successful connection request acceptance; otherwise any other value.
5. Sender replies with the connection setup confirmation after receiving the value 22 from receiver.
6. If the data index is set to 1, sender requests for Pre-shared key from receiver.
7. Receiver replies with the Pre-shared key requested by sender.
8. If the Pre-shared key sent by the receiver matches with the one stored with the sender;
   a. Communication begins;
   b. Else, communication terminates.
9. If initial connection establishment is successful;
   a. The FHSS-ED mechanism takes place over the given spectrum.
10. The sender node evaluates the signal strength over all of the available frequencies in the given spectrum by using the Energy Detection mechanism.
11. The sender node autonomously senses the spectrum and follows the Weighted Average Sum mechanism for combining the sensing results.
12. Every channel is marked with the Energy level calculated from the combining mechanism.
13. The channels with energy level > λ (threshold) are marked as '0'and other channels are marked as '1' and added to the 'AF_n', which shows the available list of frequencies.
14. The frequencies with signal energy > λ are eliminated, and the other frequencies are added to the hopping list 'HS'.
15. Sender sends the information on the frequencies in the hopping list to the receiver side.



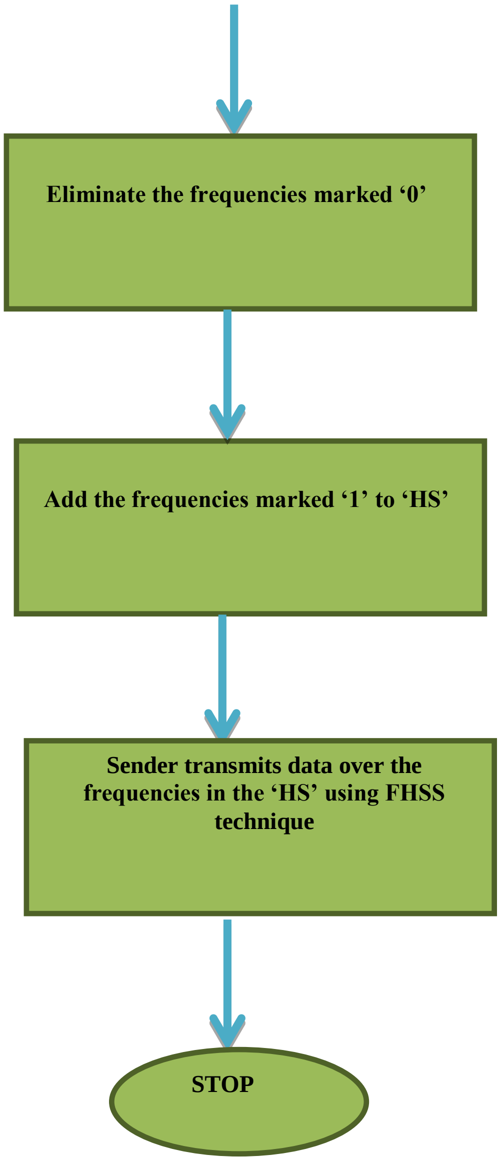


Fig 4.3 Work Flow of FHSS-ED

V. ANALYSIS OF SIMULATION RESULTS

The transmission approach named as *FHSS-ED* based on Energy Detection technique for sensing and FHSS for selecting the accurate channel with maximum energy and hopping from one channel to another for transmitting the information is built, keeping the number of channels for simulation more than required by the system due to fact that for communication in real-time scenario, the network can have a large spectrum band.

A. *Parameters for Simulation*

Table 5.1 depicts the parameters and their values taken for simulation.

PARAMETER	VALUE
No. of channels	*60*
No. of channels having Signal energy <λ	*5*
Sender transmission time	*80ms*
Transmission time	*10ms*
Spectrum Sensing	*Energy Detection*
Channel Selection approach	*FHSS*
Range of Frequency Hopping	*1:60*

Table 5.1 List of Parameters for Simulation

B. *Analysis of Results*

Probability of Detection and Probability of False Alarm [45]

The detection probability or the probability of detection is the parameter which signifies the detection accuracy or detection rate on the given spectrum. The probability of detection parameter gives the robustness and accuracy of the spectrum sensing approach.

In order to calculate probability of detection and probability of false alarm, a threshold based testing method is used. A threshold value (λ) is imposed on the output signal to determine the probability of detection and false alarm. Probability of detection signifies that the output signal or sample is larger than the threshold whenever the signal to be detected is present. Thus, mathematically, Eq 5.1 gives the probability of detection is the integral of signal and noise probability density function above the threshold value.

$$P_d = \int_{\lambda}^{\infty} p_{signal+noise}(x)\, dx \qquad \text{-- (5.1)}$$

Similarly, probability of false alarm in Eq. 5.2, signifies that the output signal or sample is larger than the threshold whenever the signal to be detected is absent. Thus, it is the integral of only noise probability density function above the threshold value.

$$P_f = \int_{\lambda}^{\infty} p_{noise}(x)\, dx \qquad \text{-- (5.2)}$$

Value of threshold is already defined in Eq. 4.5. Threshold is computed from the probability of false alarm and the noise level in the channel.Q^{-1} is the inverse Q-function. Q-functions are commonly used in statistics and $Q(x)$ give the probability that a normal (Gaussian) random variable will obtain a value larger than x standard deviations above the mean. Q-functions are calculated automatically in MATLAB but it can be mathematically represented as Eq 5.3:

$$Q(x) = \frac{1}{\sqrt{2\pi}} \int \exp\left({-t^2}/{2}\right) dt \qquad \text{-- (5.3)}$$

Consequently, Probability of detection is calculated from the threshold as Eq.5.4;

$$P_d = Q\left(\frac{\lambda-(L\times R_S)}{R_S\times\sqrt{2L}}\right) \qquad \text{-- (5.4)}$$

Where, $R_s = p_{signal+noise}$ indicates the received signal. Also, probability of false alarm can be calculated as Eq 5.5 in the similar fashion by using noise signal in place of the received signal;

$$P_f = Q\left(\frac{\lambda-(L\times p_{noise})}{p_{noise}\times\sqrt{2L}}\right) \text{-- (5.5)}$$

In Figure 5.1, shows the probability of detection v/s Probability of False alarm of the PU"s signal and these two parameters are compared for the two proposed models namely FHSS-ED and DSSS-ED with existing models. It can be analyzed from the graph that the Probability of Detection of FHSS-OBRMB for every false-alarm probability is more than any of the three models because conventionally Cooperative Spectrum Sensing includes the sharing of sensing results between the CR users, making results more accurate. While ED (Energy Detection) technique is a form of Non-Cooperative Spectrum Sensing in which the CR user autonomously senses the spectrum leading to less accurate results.

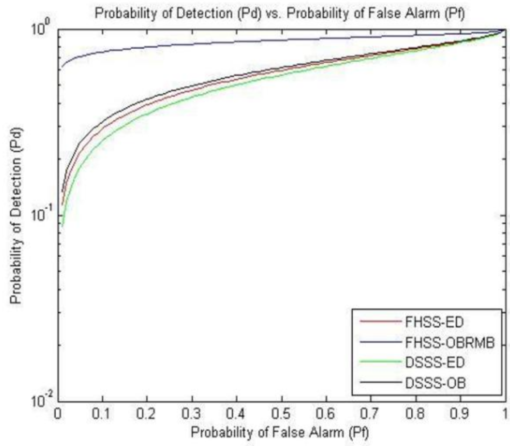


Figure 5.1: Comparision of Pd and Pf for the proposed models FHSS-ED and DSSS-ED with the previous models FHSS-OBRMB and DSSS-OB

5.1Time Complexity

Time complexity measures the time taken by the technique for sensing and then transmitting the data on the channels selected using FHSS or DSSS technique. Figure 5.2 shows that the time taken by the proposed models FHSS-ED and DSSS-ED is less than the existing models because the sensing technique used in proposed models takes less time to sense the channels as it is sender- initiated sensing technique and the previous models used for sensing techniques initiated by the receiver.Sensing: DSSS-ED takes more time than FHSS-ED because sensing channels along with DSSS channel selection approach; a constant value has to be provided so as to consider the static number of consecutive channels for transmission. While in FHSS-ED channels are not selected consecutively.

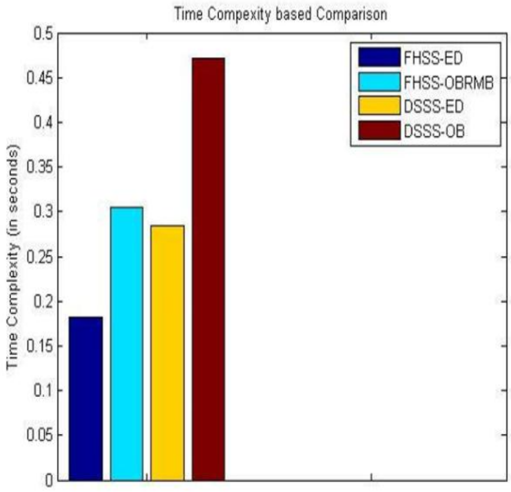


Figure 5.2: Time based Comparision of the proposed models FHSS-ED and DSSS-ED with the previous models FHSS-OBRMB and DSSS-OB

5.3 Energy Consumption

Energy in this model is assumed to be consumed under two scenarios while establishing connection and secondly while sensing the spectrum. In Figure 6.3, the graph shows the energy consumption for DSSS-OB and FHSS-OBRMB is more than the proposed models, FHSS-ED and DSSS-ED.

Energy consumed by FHSS-ED is less than the previous models because the CR user autonomously senses the spectrum without sharing any results with other CR user and also in FHSS-ED no request is sent from the sender side to the receiver side for receiving the sensing results which leads to less energy consumption.

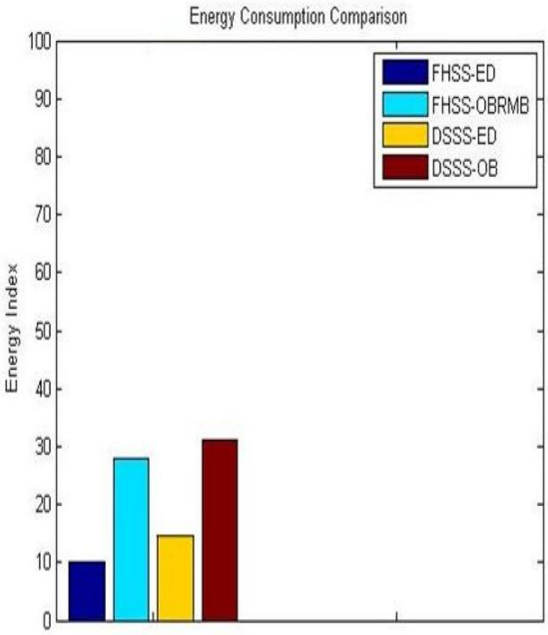


Figure 5.3: Energy based comparision of the proposed models FHSS-ED and DSSS-ED with the previous models FHSS-OBRMB and DSSS-OB

5.4 Throughput

Throughput is defined as the ratio of number of received packets to the total no of sent bits. It is usually measured in Kbps, Mbps, and Gbps. Analyzing graph in Figure 5.4, it can be deduced that the throughput of FHSS-ED is more than FHSS-OBRMB, DSSS-ED and DSSSOB. A cyclic prefix of T/16 is assumed in our model so that there is no intersymbol interference while transmission.

$$Throughput = \frac{No.of\ recieved\ bits}{Total\ no.of\ sent\ bits}$$

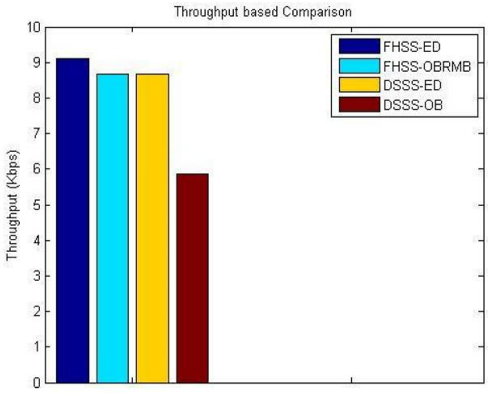


Figure 5.4: Throughput based Comparision of the proposed models FHSS-ED and DSSS-ED with the previous models FHSS-OBRMB and DSSS-OB

Figure 5.4 depicts that FHSS-ED and DSSS-ED has maximum throughput than FHSSOBRMB and DSSS-OB leading to least data drop rate as in the proposed models the data is initiated by the sender only if the channel energy less than threshold depicting that channel has acceptable level of noise and data can be sent on it. While in FHSS-OBRMB and DSSS-OB receiver has to send a one bit reply to the sender and a bit is little amount of data which can be transferred even on channel having unacceptable noise thereby allowing sender to transmit on that particular channel leading to high data drop rate. DSSS-ED has less throughput than FHSSED due to the fact that, in DSSS based transmission consecutive channels are required, but the free detected channels cannot be utilized even if their channel energy less than threshold.

VI. CONCLUSION AND FUTURE RESEARCH WORK

The radio spectrum available is a limited resource and large number of gadgets with high data rates cannot be accommodated in the present static allocation of spectrum. The spectrum sensing is the base line on which the whole process of cognitive radio works. The pivotal task of cognitive radio is to avoid the interference with the licensed users and determining the accessible spectrum for increasing the spectrum"s usage. Cognitive radio has evolved to be an effective method to overcome this limitation by dynamically accessing the data. The existing scheme DSSS-OB was using CSS (Cooperative Spectrum Sensing) in which communication between the CR users added to the delay in sensing as the receiver replies to the sender for the availability of each channel on request by the sender for that channel. Further in FHSS-OBRMB, for each request by the sender the receiver replies with the availability or non-availability status of some predefined number of channels or the same channel, but a number of times depending on a timer.

In the previous mechanisms there was an overhead of seed exchange for transmission and receiver replies for every channel at periodic intervals. Even in FHSS-OBRMB the signal energy is not calculated and receiver replies even on channels with high noise interference making it available for transmission and leading to high data drop rate and more energy consumption due to periodic replies. The proposed mechanism FHSS-ED and DSSS-ED overcomes the limitations of the existing models by using Non-Cooperative Spectrum Sensing technique in which no periodic timer is installed on either ends of transmission and sensing is initiated by the sender and the channel energy is calculated and if it less than the threshold then only the transmission is made otherwise that channel is not used for transmission. Energy consumed in this technique is less as it is consumed only during the connection establishment phase and not on receiving replies from the sender side. The results above show that the proposed techniques are more robust as time taken for sensing is less and provide more throughputs by decreasing the Data Drop Rate and the Energy Consumed. Further, work in this can lead to provide security in the existing FHSS-ED, thus making it secure from the attackers. Although a lot of research has been carried out in this field, yet there is no true spectrum sensing method which is unarguably agreed upon by majority of researchers as to be the best. There has always been a difference in opinion as no method is unconditionally applicable in every scenario. On the other hand, it gives hope for further advancements in this field. Some areas of spectrum sensing definitely need more modifications above this research. Apart from these, there are some other design issues which can be researched extensively. These include power management problems discussed in [54] and security issues extensively discussed in [55]. There is also an issue of safeguarding PU"s transmission while maximizing access for SUs. This issue has been studied in [56][57] and an approach for determination of the optimal balance between SU access and PU contention has been provided. Collision costs and rewards are optimized to address this issue. The PU can regulate the collision cost and SU can regulate the Reward to control the aggressiveness of SU access. So, it can be concluded that the research in cognitive radio networks is still far from completion and there are abundant unexplored dimensions and issues to be resolved. It can be said that once these issues are rectified, cognitive radio networks will be infinitely beneficial.

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