Reinforcement learning for Security of a LDPC coded Cognitive Radio

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Abstract - *This paper aims to enhance the effectiveness of the present spectrum and efficiency of cognitive radio and use the reinforcement learning model to enhance its security. It incorporates a concept that detects presence of licensed primary users in a channel and assigns channels to secondary users automatically without the need for user intervention where the primary users are not present. An LDPC decoder used at the receiver's end allows for error detection and correction considering situations where noisy channels manipulate data. LDPC decoder and Software portion of Cognitive Radio are done using LabVIEW software and the Reinforcement learning model is developed using python.*

***KeyWords*: LabVIEW, LDPC decoder, Cognitive Radio, Python, Reinforcement Learning, TensorFlow, Spectrum Sensing, Energy Detection.**

1.INTRODUCTION

The accessibility of usable spectrum is very limited with growing demands in the mobile environment; hence it is crucial to utilize the spectrum frequency band efficiently such that all users can exist mutually without waste or misuse of it. Cognitive Radio is a well-versed technology in performing this task and allows for automatic allocation of required spectrums to Secondary users wherever licensed Primary Users are absent. Each individual block in the system has its own assigned responsibilities to enhance the working of the collective CR. Cognitive radio uses spectrum sensing which is the basic step in assigning channels to users.Spectrum sensing uses a definite algorithm (Energy Detection sensing algorithm used here) to observe the potentiality of licensed primary clients at a point in the channel. Once this is done, the secondary users are allocated the number of channels they require at instances where the principal user was absent. This minimizes interference between users and wastage of channel space.

The LDPC method implemented is the Min-Sum algorithm at the decoder end to detect and correct the errors that could have occurred during transmission in the channel. These errors could be caused due to AWGN noise or interferences in the channel which causes errors in the data. The application of this algorithm detects and automatically recalibrates and corrects the underlying glitches.

2. LOW DENSITY PARITY CHECK (LDPC)

LDPC coding involves error control coding technique that allows to modify the bit errors in the acquired message which has been modified due to noise and interference [1]. There are various algorithms available for the implementation of LDPC codes Min Sum Algorithm, Sum Product Algorithm, Log decoding algorithm etc. but the one used in this discussion is the Min Sum Algorithm as it is easier to construct and lesser calculations for similar performance as compared to SPA as it reduces complexity at check nodes. The Min-Sum Algorithm which is used is discussed here and a working model on LabVIEW is shown further.

2.1 ENCODING:

The traditional encoding method is used here where message vector 'm' is converted to code vector 'c' by multiplying it with generator matrix 'G' such that the product satisfies (c* Transpose(H))=0 [2]. The message vector, 'G' and 'H' matrix are all user defined, a 4 bit message vector is used in the given example with a 8*12 H matrix and 4*12 G matrix, but this can be changed according to requirements easily in LabVIEW.

2.2 DECODING – MIN SUM ALGORITHM:

The Min Sum algorithm is carried out as follows:

- Initialization from the received vector
- Horizontal transformation
- Vertical transformation
- Estimation
- Syndrome calculation

2.2.1 INITIALIZATION

In this step the **L (ci)** is obtained from the vector '**r**' using the given formula. The received data has noise added from the channel and this data is negated and assigned to L(c_i).

$$L\ (C_i) = -R_n$$

Subsequently, initialization is done. The **L(q_{ij})** is then obtained. This is done by multi- plying **L(c_i)** with each row of H matrix which is the same as the one.

2.2.2 HORIZONTAL TRANSFORMATION

Here, every node is changed by searching the smallest of all the nodes and is then multiplied by the sign obtained from the previous step and assigned to the check node. The least value is transferred to all check nodes in this step. From the ij matrices, **L(rij)** is obtained.

$$L\ (qij) = H.\ \square\ L\ (c_i)$$

2.2.3 VERTICAL TRANSFORMATION

Here, the given variable node is changed. L(qij) is obtained for the next cycle and the **L(Qi)** is generated [3]. This is done as shown below.

$$L\ (Q_i) = L(c_i) + j \in C_j L(r_{ij})$$

2.2.4 DECODING/ ESTIMATION

Here the decoded code vector is approximated based on values of **L(Qi)**. It is then verified in the next step.

2.2.5 SYNDROME CALCULATION

Syndrome can be calculated to confirm the output of the decoder with the model data to be error free. This can be done by using the following equation [3].

$$S = C_i . H^T mod2$$

3. COGNITIVE RADIO SYSTEM

The CR is a very integral component of the system which allows the Secondary client to automatically be assigned a spectrum established on the basis of retention capability of PU and also based on the fundamental user preconditions [4]. Its functioning flow is shown below:

1. Spectrum Sensing refers to the detection of presence of any signals in the available set of channels so that the signal if present in any channel can be avoided and the traffic congestion on that channel can be reduced.
2. After the step of spectrum sensing the system identifies the various opportunistic points where the unlicensed user's signal can be transmitted along with avoiding congestion in the channel.
3. Adapting to the given surroundings is a very important requirement for any radio system. By analyzing the given constraints on the spectrum and amount of traffic being sent on a given channel CR system makes most efficient use of the provided conditions.
4. The assets accessible to a cognitive framework must be used by all the users. A various number of approaches can be utilized to achieve such an undertaking.

3.1 SPECTRUM SENSING ALGORITHM

A variety of algorithms are available to perform spectrum sensing (Matched Filter, Energy Detection, Cyclostationary etc.) but this approach deals with the Energy Detection algorithm as it provides least complexity as compared to other methods. Considerably other approaches provide a better SNR but usage of LDPC in this system eliminates this requirement [5].

3.2 ENERGY DETECTION FOR CR

1. There is a need to sample the received signal at specific intervals of time [6].
2. Next in order to measure the energy the samples got from the previous step are squared.
3. Next mean of the above squared samples is taken and analyzed, which is then compared to a predefined threshold.

The general flow diagram for energy detection algorithm is as shown in figure 1.

Equation for Received signal Rx at CR can be stated as X (t) is equal to n (t) when PU is not present and it is given as h (t)*s (t) +n (t) when PU is present.

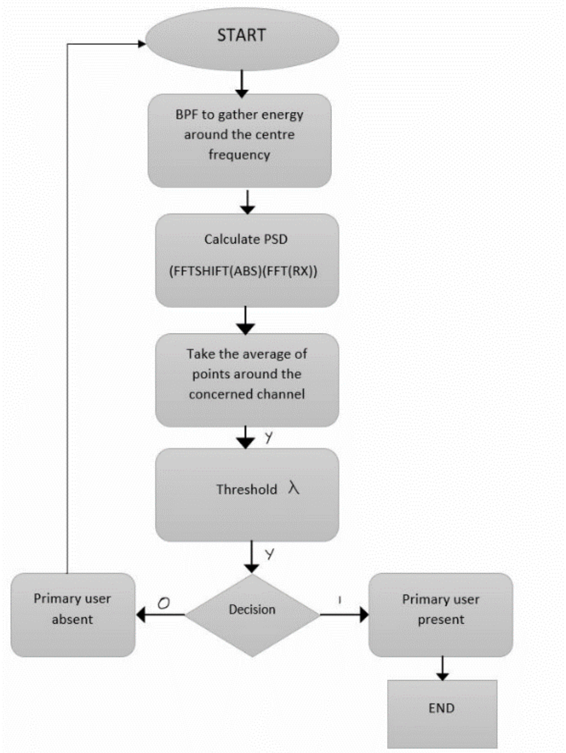

Fig 1: Energy Detection Model for Spectrum Sensing

4. FINAL INTEGRATION

Figure 2 shows the overview of the proposed cognitive radio system. Final Integration involves synchronization and correlation of CR with LDPC and transmission of data through the final model from sender to receiver [7]. Transmission of bit messages and texts were implemented successfully.

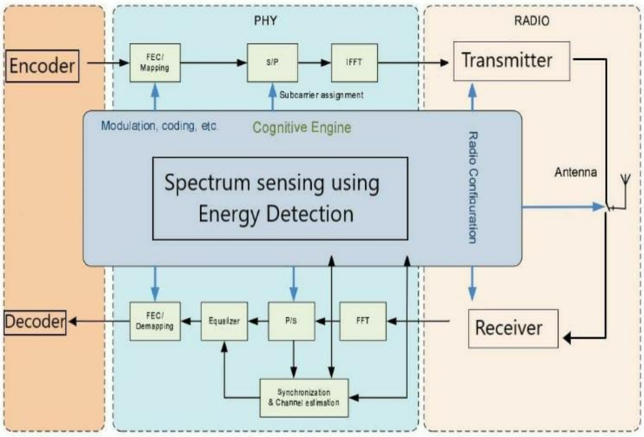

Fig. 2. An overview of the Cognitive radio system

The LabVIEW implementation of the proposed Cognitive radio system was made and the result is as shown in the absence of secondary users in Figure 3 and presence of Secondary Users in Figure 4. Here an entire string is transmitted by converting it to ASCII characters first and then transmitted on the free channel as a secondary user.

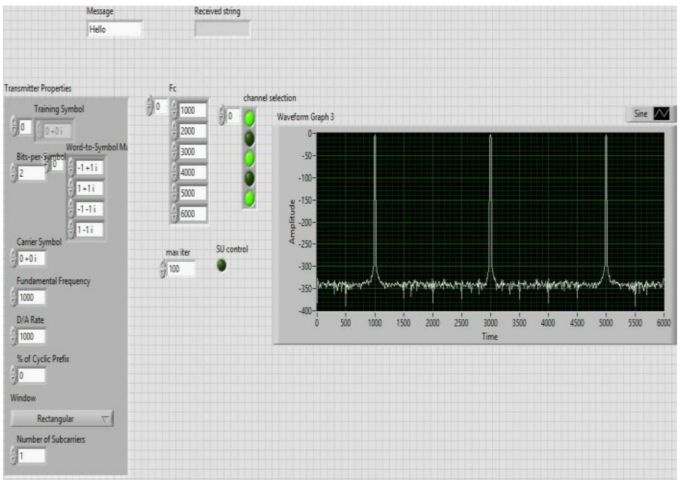

Fig 3: Final transmission of data without SU with selected PU present

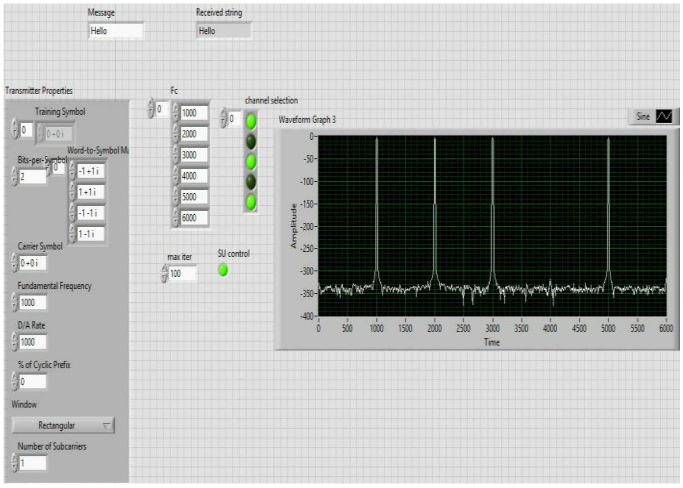

Fig 4: Final transmission of data as SU with selected PU present

5. TYPES OF SPECTRUM SENSING METHODS: A COMPARISON

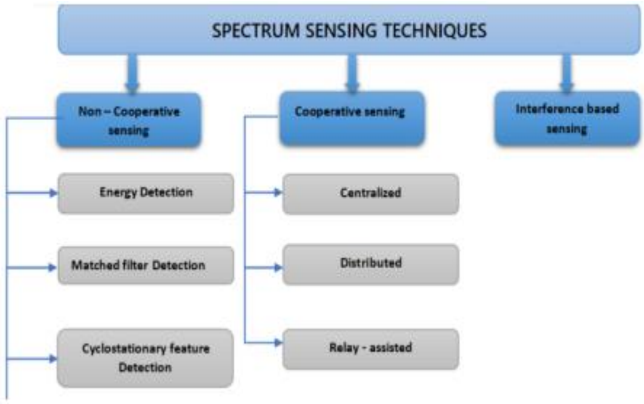

Fig 5: Types of Spectrum Sensing methods

Sensing is a vital part of CR in which primary users are detected so that Secondary unlicensed users can occupy vacant channels to prevent undesirable interference. Hence the choice of the correct sensing technique applied on the spectrum will aid in giving the best required performance for the system. As seen above in figure 14, there are a variety of SS techniques available to use [8]. The most suitable SS technique after a thorough study is chosen to be an energy detection method, the reasoning for which is stated below Interference based sensing deals with accommodation of more than one user mutually in a single channel selection. This is useful only in high traffic situations and deviates from the goal of a general-purpose cognitive radio I.e. to occupy vacant spectrum with secondary users (SU). Cooperative sensing involves a method of sensing in which all the SU together combine and communicate to mutually discover gaps in spectrum which can be occupied by them. The drawback of this method is that Cognitive Radios are usually real time, I.e. secondary users are allocated free spaces on request individually without depending on other users. Hence the radio need not wait for all secondary users to arrive to allocate channels and can do so on the fly. This type can also be used for specific application CR's but is not implemented here between the 3 Non-Cooperative sensing methods which are the most used methods as they are the most general purpose methods available [8].

The Legal User generates an OFDM signal with QPSK modulation. Noise is combined with the signal, and the corresponding signal is the received signal. The energy detection values are then calculated from the received signal and later compared with a threshold, at a probability of FA. To improve performance of detector 10000 iterations are performed.

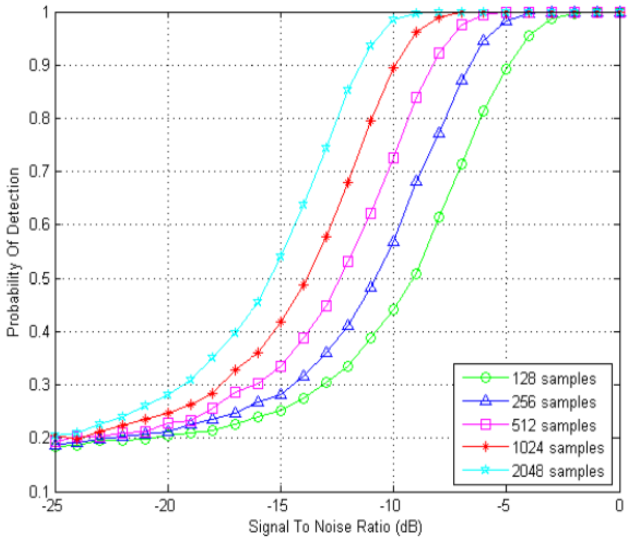

Fig 6: Energy Detection for various SNR

Energy detection method out of the various spectrum sensing methods, is the simplest and most cost effective method which uses a simple squaring algorithm to detect the presence of the primary user in the spectrum [9].A plot of probability of detection for various SNR values is as shown above in the figure 6.

Cyclostationary and Matched filter techniques are somewhat costlier techniques in which cyclostationary method involves studying PU signal characteristics to observe its periodicity and separate it from noise whereas matched filter requires prior knowledge of the presence of PU to project the SU's in direction of vacant spaces using a pilot signal[10].

Since Cyclostationary method bets on autocorrelated statistics of a signal, it cannot be applied for all types of signals and is hence not used here. Matched filter method being too expensive and complex, is not preferred here. Energy detection on the other hand provides a simple technique and the detection does not need to worry about SNR due to the presence of OFDM and LDPC combination which targets and fixes errors present in the received signal.

A matched filter requires prior knowledge about the primary user's waveform but in comparison with an energy detector it is still better under noisy environments [11]. The major drawback of the energy detector is that it is unable to differentiate between sources of received energy that means it cannot distinguish between noise and licensed users. So, this makes it a susceptible technique when there are uncertainties in background noise power, especially at low SNR. Cyclostationary Feature Detector is a good technique under noisy environments as it is able to distinguish between noise energy and signal energy [12].

Figure 7 shows comparison of transmitter detection techniques when the primary user is present under different SNRs.

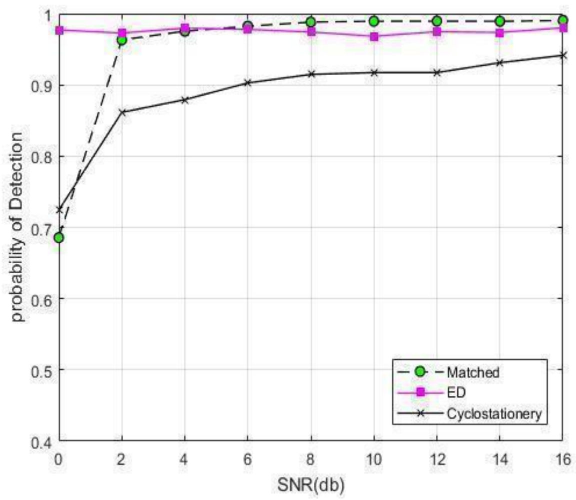

Fig 7: Comparison of various Spectrum sensing methods

6. REINFORCEMENT LEARNING

Reinforcement Learning is an AI learning method that is online and unsupervised. In many instances, using simple modeling it has proved to enhance performance of the systems considerably. The term Unsupervised learning means that the system runs without the presence of a teacher/teacher to oversee. This essentially means that the agent learns the system all by itself. With no need of any empirical data or pre derived results, the agent while performing its usual functioning, at the same time also learns about the system. This is through the process of online learning, To enhance channel characteristics with no environmental analysis, RL proves to be the trick. Figure 8 shows a simplified version of a RL model. To learn the environment, the learning agent actively observes the operating environment for every instance of time. Once it learns the environment, the agent then makes a decision and implements action accordingly.

State refers to the factors learnt from the environment by the observer that affect rewards (network performance) negatively.

Action refers to the action implemented by the agent. The reward and state (operating environment) may be subjected to change as a result of this action.

Reward refers to the effect we see in the environment as a consequence of an agent's action at a previous instant of time, in other words a previous operation. it is the consequence of the earlier operation on the operating environment in the form of network performance (e.g., throughput).

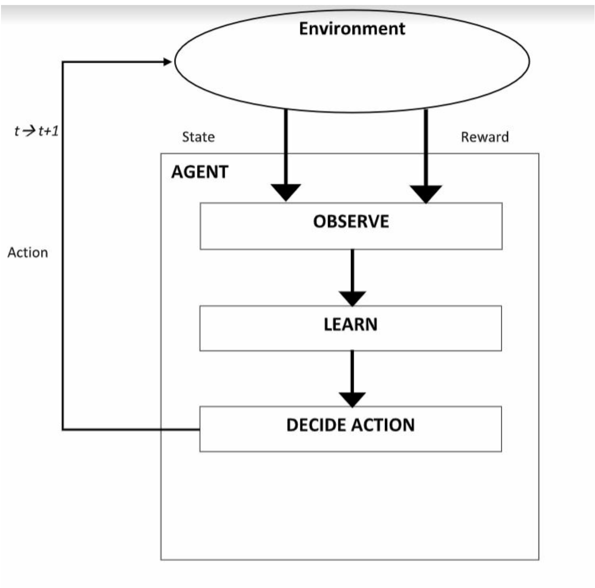

Fig 8: Basic Reinforcement learning model Issues Addressed

The rapidly increasing numbers of wireless devices has caused the spectrum to be very crowded. Majority of the spectrum that is usable is occupied. Research and analytics on usage of spectrum have demonstrated that at any time, a big chunk of licensed spectrum is unused. Despite this, collisions and errors in spectrum sensing take place in the OSA network.

The primary goal of this paper is to effectively use Reinforcement learning to create a distributed learning algorithm such that it actively monitors spectrum to keep check of vacant spectrum time slots, This is also commonly referred to as white space hunting

Q learning and Deep Reinforcement learning are RL methods. These methods are crucial in finding good policies for dynamic programming problems. The most important feature of these methods is the capability of gauging the utility amongst all available actions without any previous information about the system model [13].

6.1 MODEL IMPLEMENTATION

[1] Python and Tensorflow have been used to design the model used with the CR system. The model has been built in Python and trained using Tensorflow. The requirements that were satisfied in order to create this model are as follows.

- **To Create the environment:** The variable action stores information regarding channel characteristics. If action = [1 0 3 4], this translates to the following: user 1 uses channel 1, channel 2 is unused. channel 3 is used by user 3, channel 4 is used by user 4. In the subsequent code, these actions are passed to the environment created. once we commit the action. we see that the channels are acknowledged, the code returns immediate reward. We also see that the code outputs the remaining capacity of the channel.

- **To Generate States:** The first step in this process is to create a state for each user with regard to other users and the environment. To make the state generation more efficient, we use one-hot vectors. Every vector represents a user's parameters in the environment. These states are subsequently fed into the Deep Q Learning algorithm.

- **To Generate Algorithm of Clustering for WSN:**

The following is a brief description of the working of this algorithm. A random node is first picked from a set. This node is connected to its n closest neighbours. The virtual distance between these nodes is set as infinity. This process is repeated until all nodes are assigned. DFS or BFS graph traversal algorithms can be used to achieve this.

6.2 TRAINING THE MODEL

To train the built Python model, we use the following two Python files.

- **Training File:** This file accounts for the fundamental training structure we follow. First, required inputs of number of channels, count of time slots, figure of users and ALOHA properties are set. Required libraries are imported. Next, one hot vectors are generated. These vectors are used to create action from observation. The parameters of the training algorithm could be any of Learning rate, rate of exponential decay, discount factor etc. The DQN and environment are also created and initialized by this file. The actions are generated by observing activity, status, states generated. This data is sampled from users. The next part of the code results specific rewards and cumulative results. The main code proceeds after this which uses the learning algorithm. The graphs are then plotted for the results of the learning code and rewards.

- **DRQN File:** This file contains the DRQN code that essentially gives the model self learning and acting properties which are used to enchance the security.

7. EXPERIMENTAL RESULTS

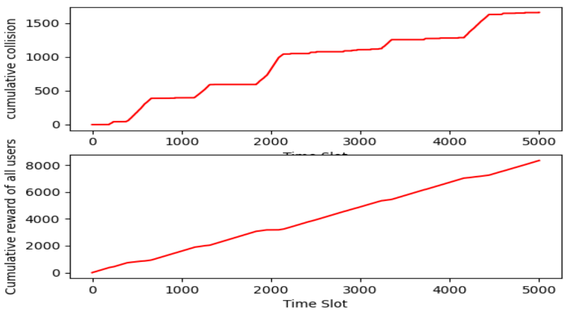

Figure 9: Cumulative collision and reward plots

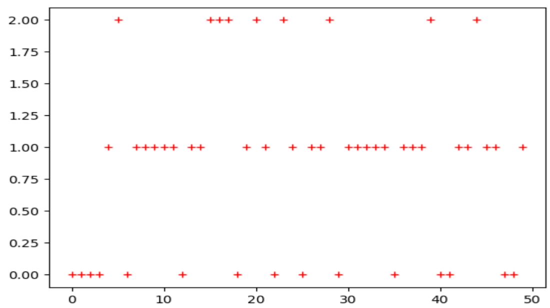

Fig 10: Cumulative rewards plot

(Note : Here 0.0 means no user was using the channels which were otherwise free whereas 2.0 means both channels were being used without collision where 1 user was not sending packets)

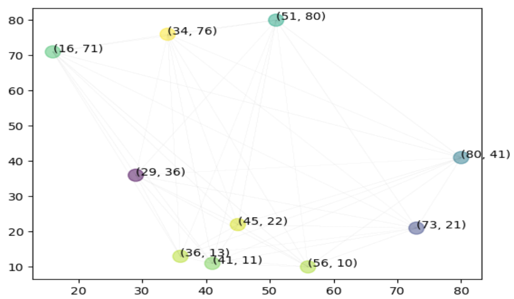

Fig 11: Nodes plot with BFS method.

8. CONCLUSIONS

Reinforcement learning (RL) has been applied in cognitive radio (CR) networks to achieve context awareness and intelligence. The usual CR systems under study and in practice work at a significant amount of efficiency and moreover, are more complex and harder to maintain. The proposed approach not only provides a simpler method by incorporating the Energy Detection method for spectrum sensing but also various concepts of LDPC which greatly reduces the errors caused by AWGN noise during transmission and also helps to reduce the interference. The proposed system is also scalable for a large value of data in the form of bits or text. A significant comparison has also been made among different types of spectrum sensing methods to show how energy detection methods are highly efficient and less complex. The proposed CR system when used along with LDPC decoder was able to overcome many of the problems faced by a usual CR system by reducing bit errors and interference in the signal by a considerable amount. The proposed approach not only provides a simpler method by incorporating the concepts of LDPC and but provides desired security to the modelled system with the aid of Deep Reinforcement learning.

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