Study on Spectrum Sensing Techniques

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Abstract
Cognitive radio is a recent emerging technology for effective use of spectrum. To provide newer opportunities in advanced wireless communication system. Spectrum sensing and security are the key issues of Cognitive Radio (CR). The main aim of Cognitive Radio (CR) is to detect unused or idle frequencies of cellular spectrum, not used by Primary User (PU’s). Practically PU’s frequencies can be idle or busy. The goal is to investigate spectrum sensing predictive methods. These methods find idle or busy states of frequencies at discrete interval of time periods. The decision is made to assign these free frequencies to Secondary Users (SU’s). For this we use Machine Learning (ML) techniques to improve its performance, usability and efficiency. A machine learning system includes pre-processing, feature extraction and decision making classifier.

This paper lists recent research activities and co-operative spectrum sensing. Identification of CR terminals is done by predictive spectrum sensing methods. Machine learning algorithm are used for classification.

Keywords
Cognitive Radio (CR), Primary User (PU’s), Secondary Users (SU’s), Machine Learning (ML), Software Defined Radio (SDR), Low Noise Amplifier (LNA).

Introduction
Now a day’s requirement of bandwidth has increased a lot. This forced research community to find new better techniques for radio spectrum utilization. To achieve this goal the dynamic usage of cellular spectrum is required. Spectrum sharing capability results to higher spectral efficiency. Cognitive Radio recognizes spectrum white spaces which are idle & can be reused by secondary users (SU’s).

A main role of a CR is to detect white spaces and based on priority allocate to SUs. This increases the spectral efficiency and the channel capacity. The ‘Shannon Channel Capacity’ is given by $C = \log(1 + SNR)$. Where C is channel capacity, B is Bandwidth and SNR is signal to noise ratio. To fulfill the user requirement spectrum needs to be managed effectively. This adaptive spectral efficiency of 4G network is reaching to Shannon limit. Thus Cognitive radio enables next generation networks to utilize the spectrum more efficiently.

A nut shell CR gathers information regarding transmission frequency, BW, power, modulation of the serving area. Using this information SU’s can identify the idle or unused spectrum. To achieve the optimal performance SDR re-configurable device can be used to meet the CR requirements. Dynamic channel allocation between PU’s & SU’s are to be done in seamless manner.

Figure 1 shows basic concept of sensing CR spectrum of cellular systems. It consists of three basic task; (1) Radio Environment: In the available cellular spectrum SU’s need to identify unused frequencies dynamically among PU’s. (2) Adaptive spectrum management: Spectrum Sharing, Decision & Allocation all together is referred as adaptive spectrum management. CR selects the best available bands for other cellular service (viz white TV, Wireless LAN, Wireless sensor network etc.) and (3) Spectrum Mobility: Reconfigurable device like SDR (SU’s) can adaptively change its transmission parameters (carrier frequency, power level, channels BW etc.).

Sensing
It is a continuous process where in information about cellular network behavior is gathered for allocation SU’s for real time application. Many research community has discussed different sensing techniques such as radio identification based sensing, cyclo-stationary feature detection, energy detection and cooperative spectrum sensing, matched filter detection, waveform based sensing.

Radio-Scene Analysis
The process of radio environment is to identify unused or idle frequencies & allocate it to SU’s dynamically

Decision
The probabilistic models are used for cooperative decision in allocating SU’s by soft & hard process.

Action
Statistical models are used to predict the radio environment parameters for mutual allocation among many SU’s.
Learning
Stochastic information for geographically based activity are monitored by ML algorithms for real time CR implementation.

Radio Environment
Reconfigurable Transmitter & Receiver cellular unit.

Materials and Methods
Spectrum Sensing Setup
The figure 2 shows the experimental setup that is to be used for our research. The antenna is used to receive particular wideband spectrum & it is followed by Low Noise amplifier (LNA). The Fast Fourier Transformer (FFT) analyzer is used to measure frequency components at discrete intervals of time. The real time data is collected from different cellular network at different time interval & geographical location. This helps us to analyze the spectrum usage of PU’s on hourly, daily basis at different geographical locations. Furthermore, detail experimental analysis can be carried out for cooperative, non-cooperative predictive statistical models. ML approach may help us to allocate SU’s to access unused or idle frequency slots.

Matched Filter
Matched filter is an optimum filter widely used for gathering spectrum information of PU’s. It also detects presence and absence of PU’s. Advantage of matched filter is, it requires less time for high processing gain. Disadvantage is CR needs a dedicated receiver for every PU’s. [1-4]. Refer figure-4
Energy Detection
For fading environment matched filter is not an optimal choice to sense CR. To measure random received signal strength squaring method is used to detect PU’s. Furthermore, probability of detection (Pd) and probability of false (Pf) alarm are used in detection of PU’s. A low value of Pd indicates an absence of PU’s thereby CR can use that spectrum with higher chance. A high value of Pf indicates lesser use of spectrum [5-7]. Refer fig-5 for energy detection.

Cyclo-stationary Feature Detection
Auto correlation method is used to extract the signal information of PU’s such as mean, autocorrelation and periodicity. These parameters help to identify type of modulation scheme, symbol order and presence of signal interference. The correlation coefficient is used to decide the presence and absence of PU’s in CR network. To find these parameter computational time is more this degrades the performance of CR [8-9]. Refer figure 6

Cooperative Based Detection
Artificial intelligence is used learn the spectrum activity. However many challenges are faced while applying ML techniques [10-22].
The taxonomy of ML techniques is shown in figure 7.

Supervised Learning
It’s guided by a teacher. It needs to be trained. It is task driven. This algorithm builds a mathematical model of a set of data that contains both input & target. Here we first train the model with the lots of training data (input & target). Using new data we get the output we predict. Exact output may not be obtained but it will be very close to it. Variation in output depends upon the training data & algorithm. Classification & regression algorithms are used in supervised learning.

Unsupervised Learning
It is self-sufficient in learning. It is data driven. Here training data is not structured. This algorithm builds a mathematical model of a set of data which contains only input & no desired output. The training data doesn’t include the target. Here we don’t tell the system where to go. The system has to understand itself from the data we give. Hence called an unsupervised learning. Clustering & anomaly detection are used for unsupervised learning. As its bit difficult to implement it’s not widely used as supervised.
Comparison between supervised & unsupervised learning methods are listed in table-I & between few algorithm are listed in table-II
### Table 1: Comparison between Supervised & Unsupervised Learning.

<table>
<thead>
<tr>
<th>Supervised Learning</th>
<th>Unsupervised Learning</th>
</tr>
</thead>
<tbody>
<tr>
<td>Output data is known</td>
<td>Output data is unknown</td>
</tr>
<tr>
<td>Very complex computational complexity</td>
<td>Less complex computational complexity</td>
</tr>
<tr>
<td>Does off-line analysis of data</td>
<td>Does real time analysis of data</td>
</tr>
<tr>
<td>Results are more accurate &amp; reliable</td>
<td>Results are moderate accurate &amp; reliable</td>
</tr>
<tr>
<td>Needs a teacher to train</td>
<td>Self-sufficient in learning</td>
</tr>
<tr>
<td>Task driven</td>
<td>Data driven</td>
</tr>
<tr>
<td>Model consists of both input &amp; target</td>
<td>Model consists of only input &amp; no desired output</td>
</tr>
<tr>
<td>Training data is structured</td>
<td>Training data is not structured</td>
</tr>
</tbody>
</table>

### Table 2: Comparison of Algorithms

<table>
<thead>
<tr>
<th>Techniques</th>
<th>Advantages</th>
<th>Disadvantages</th>
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<tbody>
<tr>
<td>Reinforcement learning (RL)</td>
<td>1. Gives optimal solution for MDP’s 2. Groups on off-policy &amp; on-policy</td>
<td>1. for discrete number of states is more</td>
</tr>
<tr>
<td>Non-parametric Learning</td>
<td>1. Deals with random variables having probability distributions 2. Provides solid decision theoretical framework</td>
<td>1. Selection of priory information is difficult, this may leads error in generating results. 2. Computational time is more for large number of variables</td>
</tr>
<tr>
<td>Game theory</td>
<td>1. Uses scientific quantitative technique to arrive at an optimal strategy for multi-players. 2. Develops a framework for analyzing decision making</td>
<td>1. Not able to analyse all the competitive problems. 2. Requires knowledge of parameters which is not possible all the time.</td>
</tr>
<tr>
<td>Artificial Neural Network (ANN) [23]</td>
<td>1. Ability to produce approximated results for incomplete information 2. This has memory, hence training is easy and produces accurate result 3. It has entire network information</td>
<td>1. Can be over trained 2. If not trained properly, it can lead to wrong class label 3. More computational time 4. Hardware dependant 5. No specific rule for structure of ANN</td>
</tr>
</tbody>
</table>

### Characteristics of Efficient ML [21]:
1. Learning methods to observe CR networks.
2. Cooperative method in distributed CR network.
Spectrum Sensing Challenges [21-22]:
1. Channel Uncertainty: Cellular system network have lot of uncertainty. This is due to channel fading. At most care will be taken while allocating SU’s under such channels.
2. Noise uncertainty: CR should detect minimum SNR of PU’s so that SU’s can be allocated for unused frequency of PU’s.
3. Aggregate uncertainty: Cooperative spectrum sensing techniques are required to avoid wrong selection of PU’s. This is due to increase in SU’s; this creates more interference among them.
4. Sense interference limit: The prime epitome of sensing spectrum is to identify unused frequency bands effectively in a cellular band.
5. Hardware requirements: For real time dynamic spectrum sensing the experimental setup requires high dynamic range and higher sampling rate Analog to Digital convertor. Low noise amplifier with high speed processor for recording spectrum activity.
6. Detection capability: In multi user CR network PU’s are to be identified in minimum time to serve more number of SU’s
7. Security: Due to non-cooperative operation of SU’s may improper usages of PU’s spectrum.
8. Spread spectrum primary user detection: In wide band network it is difficult to detect PU’s as power is distributed over wide frequency range.

Expected Outcome of the Proposed Project
1. Creation of different cellular spectrum data base for different geo-locations
2. Novel model to identify and to classify PU activities
3. Result validation of system
4. Contribution to the society as a new technology

Conclusion
In cognitive radio network spectrum sensing is key process. We have studied different technique and challenge to sense the spectrum and details are discussed in this paper.

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References