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Survey Paper on Spectrum Sensing Algorithm for Cognitive Radio Applications

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***Abstract*— Spectrum sensing in CR is challenged by a number of uncertainties, which degrade the sensing performance and in turn require much more time to achieve the targeted sensing efficiency. Hence, this paper shows literature review & propose a spectrum sensing scheme which obtains reliable results with less mean detection time. First, the scheme determines a better matched filter, or a combination of energy and cyclostationary detectors based on the power and band of interest. In the combined energy and cyclostationary detector, an energy detector with a bi-threshold is used, and the cyclostationary detector is applied only if the energy of the signal lies between two thresholds. Second, sensing is performed by the selection choice resulting from the first step. To evaluate the scheme's performance, the results are compared with those where only an energy detector, matched filter, or cyclostationary detector are performed. The performance metrics are the probability of detection, probability of false alarm, and mean detection time.**

***Keywords*— Spectrum sensing; Energy detection; Cyclostationary detection; Matched filter**

I. INTRODUCTION

Technologies for wireless communication have advanced in recent years. The demand for radio spectrum increases proportionally with the number of users, and thus causes a significant increase in spectrum utilization. The major hurdle in the current spectrum scarcity is the fixed spectrum assignment. This spectrum shortage has a deep impact on research directions in the field of wireless communication.

Cognitive radio (CR) is a key technology for dealing with the current underutilization of spectrum[1]. The CR network allows CR users/secondary users (SUs) to access a spectrum which is not in use by a licensed user/primary user (PU). The most essential task of a CR network is to detect the presence or absence of a PU in order for the SU to use the licensed band efficiently and to avoid interference in the PU vicinity. The process of PU detection is called spectrum sensing. Currently, spectrum sensing techniques focus on PU transmitter detection. The local sensing techniques considered to be important are energy detection, matched filter detection, and cyclostationary detection [2]. Energy detection needs less sensing time but performs poorly under low signal-to-noise ratio (SNR) conditions. One of the well-known coherent detection techniques in the field of spectrum sensing is matched filter detection. Cyclostationary detection provides reliable detection but is computationally complex.

The probability of detection (*Pd*) and the probability of false alarm (*Pf*) are the metrics for the detection performance of spectrum sensing. The probability that an SU declares the presence of a PU when the spectrum is occupied by the PU is called the probability of detection, whereas the probability that an SU declares the presence of the PU when the spectrum is idle is called the probability of false alarm. The probability of miss detection (*Pm*) indicates the probability that an SU declares the absence of a PU when the spectrum is occupied. The probability of miss detection is simply, $Pm = 1 - Pd$. In view of the fact that false alarms reduce spectral efficiency and miss detection causes interference with the PU, generally it is vital for optimal detection performance so that the maximum probability of detection is achieved subject to the minimum probability of false alarm [3].

The matched filter is optimal if structure of PU waveform is known. If deployment of CR is limited to operate in few PU bands then matched filer is the best choice. However, the implementation cost and complexity will increase if more PU bands are considered because dedicated circuitry is required for each primary licensee to achieve synchronization [4]. Practically, it is not possible to devote circuitry for each PU licensee. However, matched filter can be considered for most frequent sensed channels to get optimal sensing results with minimum sensing time if PU waveform is known. This approach can be very healthy for CR applications for disaster management; smart grid, and so on to get reliable sensing results with minimum sensing time. Many improved local sensing schemes are proposed in [5–12], including our own fuzzy logic-based and SNR-based adaptive spectrum sensing for improved local sensing. In the proposed scheme, channels with known PU waveform will be sensed by matched filter detection and rest of the channels by the detectors which do not need dedicated circuitry and prior knowledge of PU waveform.

In this article, we propose an intelligent spectrum sensing scheme(I3S) based on the energy detection, matched filter detection, and cyclostationary detection. It is assumed that a CR network has to detect multiple PU systems and that the PU waveform for some of the PU systems is known. The SU analyzes based on the power and the band of interest regardless of whether the PU waveform is known or not. The SU then performs either the combination of energy detection and cyclostationary detection if the PU waveform is unknown, or matched filter detection if the PU waveform is known. The performance of the I3S is analyzed in terms of the probability of detection, the probability of false alarm, and the mean detection time to determine the occupancy of a channel.

II. LITERATURE SURVEY : SURVEY OF SIMILAR SYSTEMS ALONG WITH PROS AND CONS

Spectrum sensing is fundamental for the successful deployment of CRs. The main focus of current spectrum sensing schemes for CRs is divided into two main streams: the first is to improve local sensing performance, and the second is to improve performance by having cooperation between SUs. In local sensing, each SU performs spectrum sensing on the received signal and makes a decision about the presence or absence of a PU. In cooperative spectrum sensing, SUs perform local sensing and send their sensed information to the fusion center, and a final cooperative decision is taken at the fusion center. Therefore, in order to improve cooperative performance, it is necessary to improve local sensing. Many two-stage spectrum sensing schemes are proposed in literature to improve local spectrum sensing.

In [5], a two-stage fuzzy logic-based detection (FLD) scheme is proposed. In the first stage, each CR performs existing spectrum sensing techniques, i.e., energy detection, matched filter detection, and cyclostationary detection. While in the second stage, the output from each technique employed in the first stage is combined using fuzzy logic to ultimately decide about the presence or absence of a PU.

A low power discrete Fourier transform (DFT) filter bank-based two-stage spectrum sensing is proposed in [6]. Energy detector is used for the first stage course sensing and then in the second stage fine sensing it is complemented by the cyclostationary detection. Authors exploited the fact that power of sensing operation depends on the sampling rate. Therefore, polyphase DFT filter bank is used to choose appropriate sampling rate.

SNR-based two-stage adaptive spectrum sensing is proposed in [7]. In the first stage, the SNR is estimated in advance for available channels. The SU then performs either energy detection or cyclostationary detection based on the SNR estimated in the first stage of PU detection.

A novel high-speed two-stage detector is proposed in [8] that effectively decreased the sensing time by satisfying the required detection capabilities. Energy detector is used in the coarse sensing stage and if the measured energy is greater than threshold then it declares PU present, else it computes the SNR of device. If the computed SNR is greater than theoretical SNR, then the result of energy detector is reliable. If computed SNR is less than theoretical SNR then second stage for fine sensing is performed in which covariance absolute value is used.

In [9], another two-stage sensing scheme is proposed in which, at the first stage, the energy detector is used, and if required, cyclostationary detection is used at the second stage. The second stage will run only if a channel is declared unoccupied in the first stage. In this case, the second stage will give a final decision about the presence or absence of a PU. If a channel is declared occupied, the first stage will provide the final decision.

An improved version of [9] in terms of mean detection time is proposed in [10]. It achieves the same probability of detection and false alarm with much less mean detection time. The first stage will run in the same way as previously discussed, but before the second stage, it estimates the SNR of the received signal and determines the credibility of the energy detector. If the energy detector is credible, it declares the absence of a PU at the first stage, otherwise it will run the second stage in order to get an accurate decision about the presence or absence of a PU.

A two-stage spectrum sensing scheme is also proposed in [11], in which the energy detector is used at the first stage to sort channels in ascending order based on the power of each channel. The one-order cyclostationary detector is used on the channel with the lowest power to detect weak signals in the second stage.

A two-stage dynamic spectrum access approach, which consists of preliminary coarse resolution sensing (CRS) followed by fine resolution sensing (FRS), is proposed in [12]. In CRS, the whole spectrum is divided into equal-sized coarse sensing blocks (CSB) of equal bandwidth, and an energy detector of bandwidth equal to that of the CSB is applied on randomly selected CSB and checked for at least one idle channel. FRS is then applied on the same CSB, using the energy detector equal to the bandwidth of the channel to determine its unused channel.

In our proposed scheme, based on the power and band of interest, we first determine information about the PU waveform. The distinction of the proposed scheme is that it deals with multiple types of primary systems, i.e., for primary systems with known and unknown waveforms. Whereas all the existing two-stage detection schemes in the literature only considered single type of primary system. Most of the useful spectrum is allocated to licensed users (eg. mobile carriers, TV broacasting companies) that do not transmit at all the geographical locations all the time.

If this spectrum is opened for unlicensed use (eg. private users, short range networks, ...) it is highly likely that a vast array of new services will appear. One example of this is for example the huge innovation that has occurred in WiFi and Bluetooth operating in unlicensed bands, even though these two standards share just scraps of undesirable spectrum with many other technologies.

However, before opening the licensed spectrum to new users in a Dynamic Spectrum Access (DSA) basis it is necessary to guarantee to the primary users, that own the rights over these bands, that they will not be interfered. **Cognitive radios** (CR), first proposed by Mitola in his landmark paper, have been chosen as an enabling platform in realizing such dynamic spectrum sharing due to their built-in cognition capabilities. A cognitive radio system is a 'smart' network that can observe, learn from, and adjust to changing environment conditions.

A common assumption in cognitive radio systems is that the licensed users which own the spectrum rights are unaware of the presence of secondary users. Hence the burden of interference management relies mainly on the secondary system. In particular, either (i) there is a maximum interference level that the primary system is willing to tolerate, and the secondary powers/activity are to be adjusted within this constraint, hence both primary and secondary users transmit in the same band, or (ii) secondary users are allowed to opportunistically access the spectrum on the basis of no-interference to the primary (licensed) users. These two paradigms fit into what is commonly known as *hierarchical-access schemes*, refering to the fact that secondary users need to fulfill the constraints imposed by the primary user.

Primary user : airtel,reliance,tata sky,dish tv.etc
Secondary : wifi, Bluetooth ,local FM generator, talkie walkie user

A. Walkie-talkies are battery-powered **transceivers**, meaning they can both send and receive radio messages. They have a **half-duplex** channel, which indicates that only one walkie-talkie on a channel can transmit a signal at one time, although many radios can receive that same signal. In other words, unlike your phone, in which both parties can interrupt or add to the conversation in a ceaseless flow of sound, walkie-talkies use a push-to-talk (PTT) system -- you have to press a button in order to speak, and you have to release that button to hear sound coming from other units.

B. Because you don't have to dial a number each time you want to transmit, walkie-talkies are quick and easy to use. And best of all, they don't rely on finicky cell phone signals. The handsets transmit directly to each other, so they still work when cell networks fail during natural disasters or power outages. They're designed primarily for short-range communications, in which groups of people are within a few miles of each other.

C. Businesses use walkie-talkies so that employees can chat efficiently in and around their indoor and outdoor structures. Wilderness lovers tote walkie-talkies so that they can keep in touch during hiking or hunting trips out where cell phone cover age is non-existent. Even baby monitors employ one-way walkie-talkie technology, so that you know if Junior is sleeping peacefully or attempting escape.

Devices with cognitive capabilities can be networked to create Cognitive Radio Networks (CRNs), which are recently gaining momentum as viable architectural solutions to address the limited spectrum availability and the inefficiency in the spectrum usage.

The most general scenario of CRNs distinguishes two types of users sharing a common spectrum portion with different rules: Primary (or licensed) Users (PUs) have priority in spectrum utilization within the band they have licensed. Secondary Users (SUs) must access the spectrum in a non-intrusive manner. Primary Users use traditional wireless communication systems with static spectrum allocation. Secondary Users are equipped with CRs and exploit Spectrum Opportunities (SOPs) to sustain their communication activities without interfering with PU transmissions.

The reference network model reported in Fig. 1 features secondary devices which share different spectrum bands (or SOPs) with primary users. Several spectrum bands (1, . . . , M) may exist with different capacities C1, C2, CM, and the SUs may have different views of the available spectrum bands due to inherent locality of the spectrum sensing process. Typically the PUs are assumed motionless while the SUs may vary their position before and during a transmission. In this scenario, the problem of routing in multi-hop CRNs targets the creation and the maintenance of wireless multi-hop paths among SUs by deciding both the relay nodes and the spectrum to be used on each link of the path. Such problem exhibits similarities with routing in multi- channel, multi-hop ad hoc networks and mesh networks, but with the additional challenge of having to deal with the simultaneous transmissions of the PUs which dynamically change the SOPs availability.

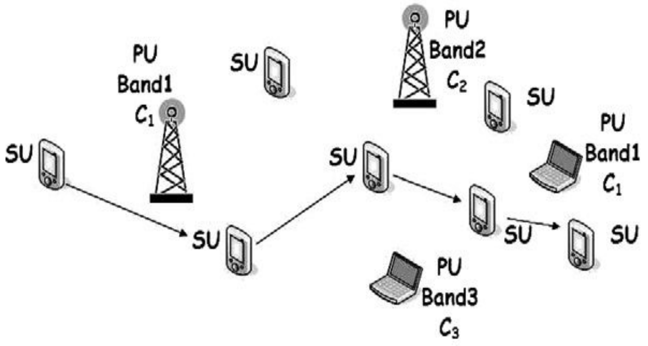


FIG 1: Information routing in multi-hop CRNs.

Routing Challenges in CRNs

1. Challenge 1: The spectrum-awareness; designing efficient routing solutions for multi-hop
CRNs requires a tight coupling between the routing module(s) and the spectrum management functionalities such that the routing module(s) can be continuously aware of the surrounding physical environment to take more accurate decisions. Within this field, three scenarios may be possible: the information on the spectrum occupancy is provided to the routing engine by external entities (e.g., SUs may have access to a data base of white spaces of TV towers); the information on spectrum occupancy is to be gathered locally by each SU through local and distributed sensing mechanisms; a mixture of the previous two. In any case, any routing solution designed for multi-hop CRNs must be highly coupled to the entire cognitive cycle of spectrum management.

2. Challenge 2: The set up of quality routes in dynamic variable environment; the very same
concept of route quality is to be re-defined under CRN scenario. Indeed, the actual topology

of multi- hop CRNs is highly influenced by PUs behavior, and classical ways of measuring/ assessing the quality of end-to-end routes (nominal bandwidth, throughput, delay, energy efficiency and fairness) should be coupled with novel measures on path stability, spectrum availability/PU presence. As an example, if the PU activity is moderate- to-low, the topology of the secondary users network is almost static, and classical routing metrics adopted for wireless mesh networks could be leveraged. On the other hand, if PUs become active very frequently, routing techniques for disconnected networks could be favorable.

3. Challenge 3: The route maintenance/reparation; the sudden appearance of a PU in a given location may render a given channel unusable in a given area, thus resulting in unpredictable route failures, which may require frequent path rerouting either in terms of nodes or used channels. In this scenario, effective signalling procedures are required to restore broken paths with minimal effect on the perceived quality.

III. SYSTEM MODEL AND FRAMEWORK

There are 3 conventional methods which can be used for detection of spectrum:

Match Filtering :

A number of detection techniques exist for spectrum sensing from coherent matched filter detection where the signal structure of the primary user is almost completely known

Energy Detection:

Energy detection (ED) is a widely used spectrum sensing scheme for cognitive radio networks since it is veryeasy to implement and does not require any knowledge of the primary signal. However, ED requires accurate noise power to perform the detection and its performance is very sensitive to noise uncertainty.

Cyclostationary Method:

Consequently, a matched filter is not practical. Cycle-stationary feature detection maybe a much better way[5], but it needs a large amount of complicated calculations, about two times of FFT(Fast Fourier Transform) in fact.

But different method can been applied, depending on variety signal-noise situations[4]. For examples, if we have got the signal expressions, then we can use a matched filter to get back the signal from noise environments. If the signal received has periodical statistical features, then we can use cycle-stationary feature detection. But in fact, the signals are being transmitted in an extremely complex environment. A signal emitted will be reflected, scattered, absorbed and interfered, then reaches the receiver with low signal-noise ratio.

A binary hypothesis model for transmitter detection, i.e., the model of signals received by the SU, is defined as

$$r\left(t\right) = \begin{cases} n(t), & \text{if } H_0 \\ n(t) + hs(t), & \text{if } H_1 \end{cases}$$

where $r(t)$ is the signal received by the C R, $s(t)$ is the transmitted signal of the PU, $n(t)$ is additive white Gaussian noise (AWGN), and h is the amplitude gain of the channel. $H0$ indicates only noise, and $H1$ indicates the presence of PU.

The proposed I3S system model is shown in Figure 1 .

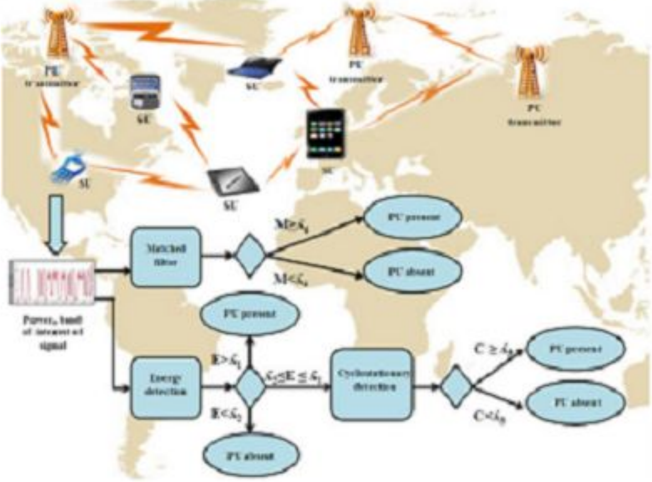


FIG 2: Block diagram of I3S

Multiple PU systems are considered for detection. It is assumed that, for some PU systems, the signal structure is unknown, while for the others, enough information is known about the PU waveform to perform the matched filter as an optimal detector. It is assumed that there are N channels to be sensed. The SU will scan the whole spectrum and detect whether or not there is a spectrum hole available. The SU identifies that a PU waveform is known (or not) on the basis of the power and band of interest, and then selects either a combined energy and cyclostationary detector, or a matched filter detector.

A. Combined energy and cyclostationary detector:

If the PU waveform is unknown, the energy detector is applied on the received signal $r(t)$. An energy detector with bi-thresholds is used for detection in which two thresholds $\lambda1$ and $\lambda2$ are used. The received energy is given by

$$E = \sum_{k=0}^{j-1} |r(k)|^2$$

where j is determined from the time bandwidth product. If the received energy E is greater than $\lambda1$, then the presence of a PU is declared. Similarly, if the received signal is less than

$\lambda 2$, then the absence of a PU is declared. If the received signal energy is between $\lambda 1$ and $\lambda 2$, it is in the region of uncertainty (RU), and the energy detector is not reliable for PU detection, which is evaluated as

$$\text{Decision} = \begin{cases} 1, & \text{if } E > \lambda_1 \\ \text{RU}, & \text{if } \lambda_2 \le E \le \lambda_1 \\ 0, & \text{if } E < \lambda_2 \end{cases}$$

Therefore, the cyclostationary detector is applied for a reliable decision of sensing accuracy. Researchers suggest that cyclostationary feature detection is more suitable than the energy detector technique when the noise uncertainties are unknown [2]. Although the energy detector, as a non-coherent detection method, does not require any prior knowledge of a PU's waveform and so is easy to implement, it is highly susceptible to in-band interference and changing noise levels [14], and cannot differentiate between signal and noise power.

Commonly, the primary modulated waveforms are coupled with patterns also characterized as cyclostationary features, like sine wave carriers, pulse trains, repeating spreading, hopping sequences, and cyclic prefixes inducing periodicity [15]. An SU can detect a random signal with a specific modulation type in the presence of random stochastic noise by exploiting periodic statistics like the mean and auto-correlation of a PU waveform. Features like autocorrelation and mean are estimated by analyzing spectral correlation functions (SC Fs). A block diagram of cyclostationary detection using the SC F is shown in Figure 2.

FIG 3: Block diagram of cyclostationary detection

The overall probability of detection and false alarm of the combined energy and cyclostationary detector is given as

$$P_{d,\mathrm{EC}} = P_{d,\mathrm{E}} - P_0(1 - P_{d,\mathrm{C}})$$

$$P_{f,\mathrm{EC}} = P_{f,\mathrm{E}} - P_1(1 - P_{f,\mathrm{C}})$$

where $P0$ is the probability that the received energy is between $\lambda 1$ and $\lambda 2$ when a PU is present, and $P1$ is the probability that the received energy is between $\lambda 1$ and $\lambda 2$ when a PU is absent. In the I3S, when the received energy is between $\lambda 1$ and $\lambda 2$, channels are sensed by the cyclostationary detector. Thus, $P = P1 + P2$ is the same as the probability that channels are sensed by the cyclostationary detector.

B. Matched filter detection:

One of the well-known techniques of spectrum sensing for a known PU waveform is matched filter detection. The intuition behind the matched filter relies on the prior knowledge of a PU waveform, such as modulation type, order, the pulse shape, and the packet format. To meet such a stringent condition, C Rs need to have a cache for the pattern information in their memory and to satisfy synchronization. The matched filter is an optimal linear filter for maximizing the SNR in the presence of additive stochastic noise [18].

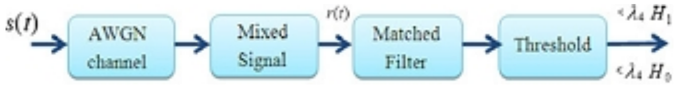


FIG 4. Block diagram of matched filter.

In this section, we compare the I3S with matched filter detection, energy detection, and cyclostationary detection. The sensing performance of each detection scheme is quantified by the receiver operating characteristic (ROC), such as *Pf* versus *Pd* and the mean sensing time.

NS2 simulator was used for the experimentation under the following system settings:

- NS – Simulator
- NAM – Network AniMator
  - visual demonstration of NS output
- Preprocessing
  - Handwritten TCL or
  - Topology generator
- Post analysis
  - Trace analysis using Perl/TCL/AWK/MATLAB
  -

ns (from **network simulator**) is a name for series of discrete event network simulators, specifically **ns-1**, **ns-2** and **ns-3**. All of them are discrete-event network simulator, primarily used in research and teaching. In 1996-97, ns version 2 (ns-2) was initiated based on a refactoring by Steve McCanne. Use of Tcl was replaced by MIT's Object Tcl (OTcl), an object-oriented dialect of Tcl. The core of ns-2 is also written in C++, but the C++ simulation objects are linked to shadow objects in OTcl and variables can be linked between both language realms. Simulation scripts are written in the OTcl language, an extension of the Tcl scripting language.

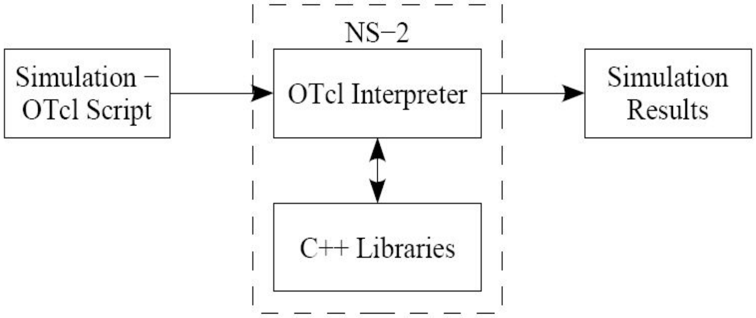
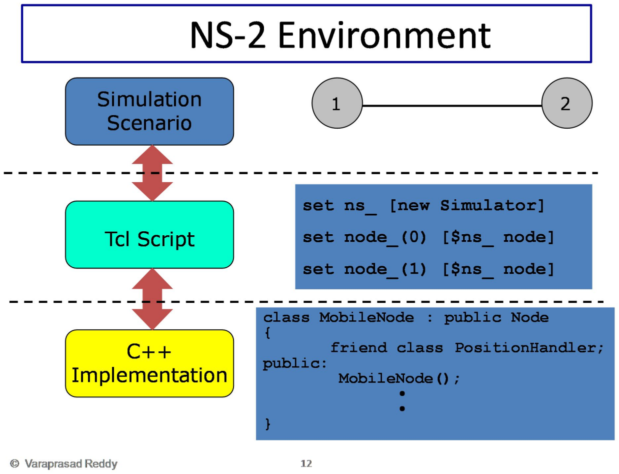


FIG 5. BLOCK DIAGRAM OF USERS PERSPECTIVE

- Network Simulator
- A package of tools that simulates behavior of networks
  - Create Network Topologies
  - Log events that happen under any load

  - Analyze events to understand the network behavior



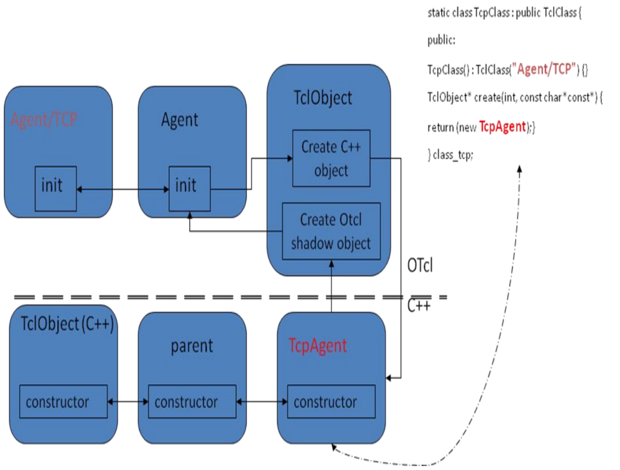
```
set ns_ [new Simulator]
set node_(0) [$ns_ node]
set node_(1) [$ns_ node]
```

```
class MobileNode : public Node
{
        friend class PositionHandler;
public:
         MobileNode();
                 •
                 •
}
```

FIG 6. Block diagram of NS2 Environment

IV. RESULTS

- NS-2 Code contains two sets of languages, namely C++ and OTcl.
- C++ is used for the creation of objects because of speed and efficiency.
- OTcl is used as a front-end to setup the simulator, configure objects and schedule events because of its ease of use



```
static class TcpClass : public TclClass {
public:
TcpClass() : TclClass("Agent/TCP") {}
TclObject* create(int, const char*const*) {
return (new TcpAgent);}
} class_tcp;
```

FIG 6. OTCL LINKAGE

Why two languages? (Tcl & C++)

- C++: Detailed protocol simulations require systems programming language
  - byte manipulation, packet processing, algorithm implementation
  - Run time speed is important
  - Turn around time (run simulation, find bug, fix bug, recompile, re-run) is slower
- Tcl: Simulation of slightly varying parameters or configurations
  - quickly exploring a number of scenarios
  - iteration time (change the model and re-run) is more important

- Define Network topology, load, output files in Tcl Script
- To run,

$ ns simple_network.tcl

- Internally, NS2 instantiates C++ classes based on the tcl scripts
- Output is in form of trace files

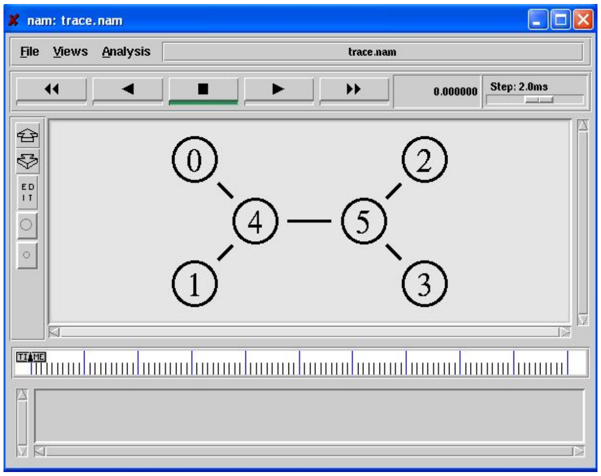


FIG 8. Expected output of node creation

This study is different from all existing improvements in two ways:

• The proposed scheme intelligently decides the detection algorithm based on the power and band of interest, thus increasing accuracy and reducing mean detection time for the known PU waveforms. According to the author's best knowledge, none of the existing approaches have incorporated the information of the band for the selection of the detector.

• All other schemes consider multiple detectors working sequentially.

V. CONCLUSION

In this paper we have compared with the existing transmitter detection techniques In this paper, a new local spectrum sensing scheme, namely, I3S, was proposed to improve the utilization efficiency of the radio spectrum by increasing detection reliability and decreasing sensing time. The proposed scheme chooses either the combined energy and cyclostationary detector, or the matched filter detection based on the power and band of interest.

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