Cognitive Radio Based Optimal Channel Sensing for Resource Allocation in Communications

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***Abstract*—Cognitive Radio (CR) is the cutting-edge wireless technology that is used to solve the spectrum saturation problem. In cognitive radio, Secondary Users (SUs) use Primary User's (PU's) spectrum (licensed band) during PU's absence. Cognitive radio provides more flexibility in terms of spectrum utilization but the spectrum sensing efficiency need to be improved to make sure that the PUs are not interrupted while they are active. This paper presents the test-bed development of a CR network using Android-based smartphones for optimal sensing and data transmission. An energy detector based sensing method is proposed and used here since the energy detector does not require the information of the PU. The CR features have been implemented in Android phone using the Eclipse Java programming. The test-bed experimental set up was done using Android-based smartphones and Wi-Fi Access Point (AP). Two spectrum, Wi-Fi and Bluetooth were used to verify the sensing and detection efficiency. Results show that the proposed sensing and detection scheme efficiency is about 83%.**

***Index Terms*—Bluetooth; Cognitive Radio Network; Cognitive Radio Test Bed; Spectrum Sensing and Detection; Wi-Fi.**

I. Introduction

Cognitive Radio (CR) is a type of technology that allows an unlicensed user (Secondary User (SU)) to use the spectrum that was given to licensed users (Primary User (PU)) [1-20]. This process was done so that SUs can use the spectrum while PUs are not using it. It is used to solve the spectrum shortage problem due to the inflexible spectrum allocation [1-20]. Cognitive radio is usually used to sense radio environment, to choose transmission parameters that improve efficiency and to avoid interfering with primary users [1-3].

Cognitive radio systems can be divided into five parts that consist of sensing, learning and reasoning, configuration database, reconfiguration radio, and policy database. Radio frequency is the input from radio component that can be accepted by the sensing engine. Input from this sensing engine is usually accepted by the reasoning engine. Configuration database maintains the current configuration of the radio components. Reconfiguration radio is used when a cognitive radio system has single reconfigurable radio component from local nodes and not from external data sources. Policy database is a database that determines which behavior is acceptable in various circumstances [19-21]. Cognitive radio can be named as the product of a multidisciplinary effort which involves in a wireless network, digital communication, system engineering, Artificial intelligence and other fields. As a result, it can provide greater flexibility and access to spectrum.

Spectrum sensing refers to CR users or SUs. The spectrum sensing is to detect unused spectrum that was allocated to the PUs for the usage of SUs without causing interference to Pus. This is needed to provide more spectrum access opportunities to CR users [4]. It identifies spectrum holes which match the data transmission. Spectrum sensing also involves in doing an estimation of the spatial directions of incoming interferes and signals classification. Matched filter based detection, energy-based detection, and cyclostationary-based feature detection are usually in use. Matched-filter based detection is the optimal detector for stationary Additive White Gaussian Noise (AWGN) environment as it maximizes the received Signal-to-Noise Ratio (SNR). Energy-based detection is the energy detector which requires knowledge of the AWGN power. Cyclostationary-based feature detection is detected by analyzing a spectral correlation function [5, 11]. Usually, the longer sensing time the better detection performance but the data transmission of the secondary user becomes shorter [6]. Resource allocation is involved in the scheduling of spectrum resource that includes frequency bands and time slots.

II. Previous Works

There are two types of cognitive radio spectrum sensing which are non-cooperative spectrum sensing and cooperative spectrum sensing. Non-cooperative spectrum sensing is when cognitive radio sense spectrum itself according to the signal and information it has. Non-cooperative spectrum sensing is such as Energy Detector (ED), Eigenvalue, Cyclostatinary, Match Filter (MF) and other types of spectrum sensing.

Energy detector based sensing is a type of spectrum sensing which measures the energy received on a primary and observe it. If measured energy is less than a properly set threshold, it declares a white space. It is simple and convenient to implement.

Cyclostationary based sensing is introduced by Gardner which use quadratic non-linearities to extract a sine-wave from a signal. Cyclostationary based sensing is the method that robust against noise variance uncertainty and at the same time, it will reject the effect of adjacent channel interference [7]. Hence, cyclostationary is mostly used in cognitive radio.

The match filter method detects the presence and absence of the signal with a minimum probability of error. It is a filter that will pick up the signal component and noise amplitude. Match filter mainly used to lower the noise and increase the signal. The matched filter was designed to fulfill the condition.

Cooperative spectrum sensing occurs when a group of cognitive radio shares the information together which they sense [8, 11-15, 18-20].

Two types of approaches to cooperative spectrum sensing are centralized approach and distributed approach. In the centralized approach, there is a master node in a network. This node analyses the sensing information from all the nodes within the network to find whether a frequency/channel is absent or present. The advantage of this method, it can take different sensing actions in multiple numbers. In the distributed approach, there is no master node that controls the network but the different sense nodes can share their information together. This approach requires a higher level of autonomy and an ad-hoc network. Each of them can make a decision itself.

For this paper, we have used Energy Detection technique due to its simplicity to implement. Unlicensed 2.4 GHz Wireless Local Area Network (WLAN) (commonly known as Wi-Fi) channels and Bluetooth are used to perform optimal sensing and detection using an Android-based smartphone for resource allocation for smart cities or villages.

III. The System Model

We considered N (= 10) number of stationary primary users (PUs), who are fixed in their specific location and the SU can change their locations as per need. The PUs' has 13 specified 2.4 GHz dedicated channels for their own use. The Android-based smartphones and tablets are considered as SUs.

We assumed the Access Points (APs) as PUs, which are fixed at their locations and using non-identical channels to avoid inter-channel interference. SUs are also not moving during the period of channel detection and the APs are located at various distances from the SUs. Smartphones have different types of WLAN sensors (Broadcom, Qualcomm-Atheros (Qcom), Texas Instruments etc.), the reception sensitivity may differ. But the basic principles of received SNR measurement are same for all sensors. For our experiments, we assumed noise floor between -95 dBm to -100 dBm, which is usual for a clean sunny weather. Figure 1 shows the basic experimental setup scenario, whereas Figure 2 shows the CR sensing scenario.

The WLAN 802.11g can provide data rate up to 54Mbps and the previous version 802.11b can provide data rate up to 11Mbps. The latest 802.11n offers a data rate of up to 150Mbps per channel or up to 600Mbps in total. It uses 2.4 GHz or 5 GHz frequency bands, and a receiver needs to have dual-band antenna to operate.

Android is a smartphone Operating System (OS) based on Linux Kernel developed by Google [9]. The smartphone chips are usually integrated with Bluetooth and some have FM 100 MHz channel reception capability. The minimum reception sensitivity of the chips varies from –98.3dBm to –94dBm depending on their model and specification.

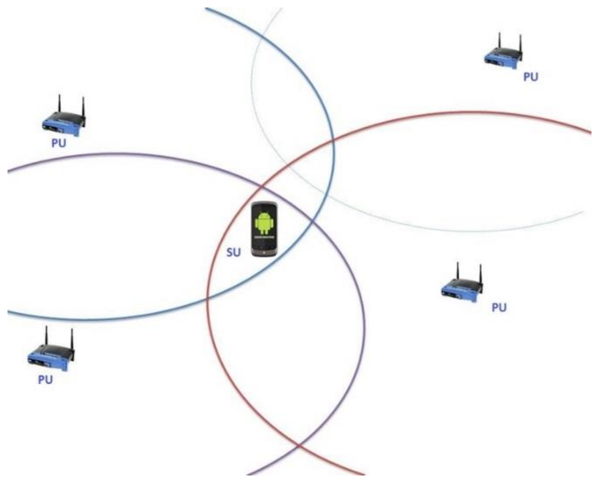

Figure 1: Experimental setup scenario

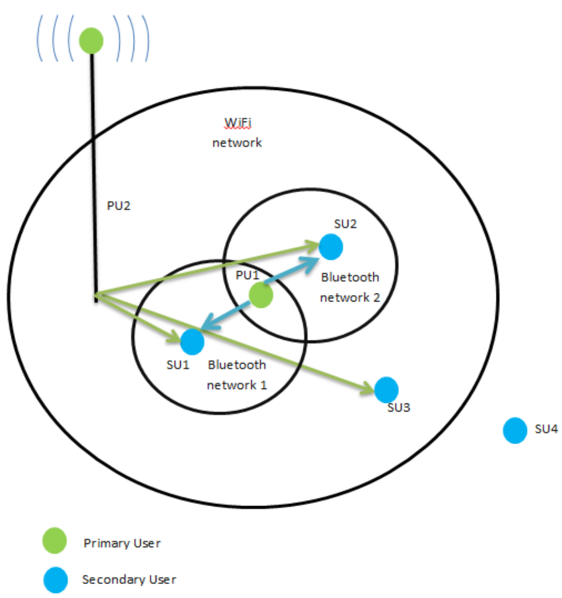

Figure 2: Cognitive radio system scenario

IV. Experiments and Measurements

Cognitive channel detection refers to the action of monitoring the characteristics of received signals which may include Radio Frequency (RF) energy levels if a particular band is occupied by a PU. The presence or absence of PU is detected from the following criteria shows in Equation (1) [10].

$$x(t) = \begin{cases} w(t), & H_0 \\ h(t).s(t) + w(t), & H_1 \end{cases} \qquad (1)$$

Where, $x(t)$ = Received signal power by SU,
$w(t)$ = Noise power,
$h(t)$ = Channel gain,
$s(t)$ = Received PU signal.

H_0 and H_1 are considered as absence and presence of primary user respectively. To declare one channel to a white space, we must have to be confirmed that $s(t)$ is not present in the detected signal by SU.

For experiments, we fixed one WLAN AP in one corner of an open playground and measure the Received Signal Strength (RSS) repeatedly after a certain period. The measurements were conducted on three different days with different weather conditions and recorded the entire successful detection rate for different trials as shown in Table 1. Finally, we calculated the average for all values to compare for the different attempt and to determine the related threshold values.

Table 1
Real-Time Experimental RSS Values for Various Distances and Conditions

Distance (meter)	Received Signal Strength (RSS) in dBm			
	Day 1 (cloudy noon)	Day 2 (sunny afternoon)	Day 3 (clean evening)	Average Value
20	-35	-36	-34	-35.00
40	-47	-46	-48	-47.00
60	-57	-56	-58	-57.00
80	-64	-63	-67	-64.67
100	-68	-70	-71	-69.67
130	-74	-77	-76	-75.67
160	-80	-82	-79	-80.33
200	-85	-82	-84	-83.67
250	-89	-89	-87	-88.33
300	-94	-97	-95	-95.33
350	-100	-97	-98	-98.33
370	fail	-100	-100	-100.50
400	fail	fail	fail	fail

V. PERFORMANCE ANALYSIS

The application was developed using Android Development Tools (ADT) with Eclipse software and initially tested on the ADT emulator as shown in Figure 3.

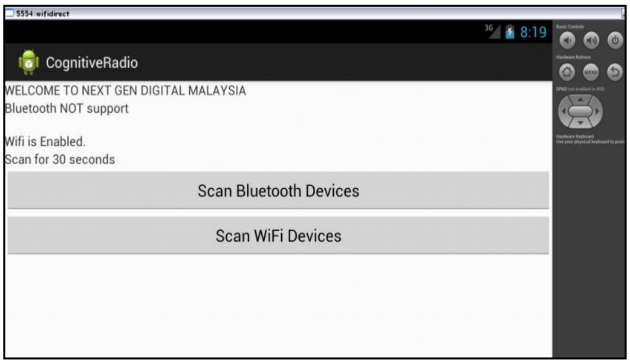

Figure 3: Emulation scenario on eclipse virtual emulator

Eclipse is basically a compiler for Java application development. Android is a mobile smartphone operating system based on Linux Kernel. Most of the mobile phone applications support Java and Android. So, the Java language is chosen for the application development. The application file was installed in Android smartphone and tested as shown in Figures 4 and 5.

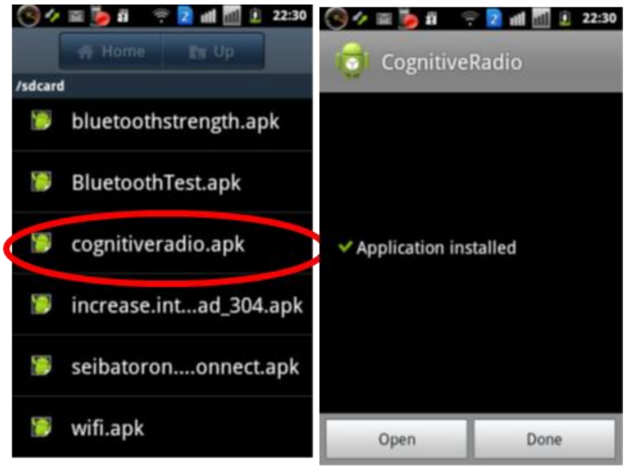

Figure 4: APK file installation in Android phone

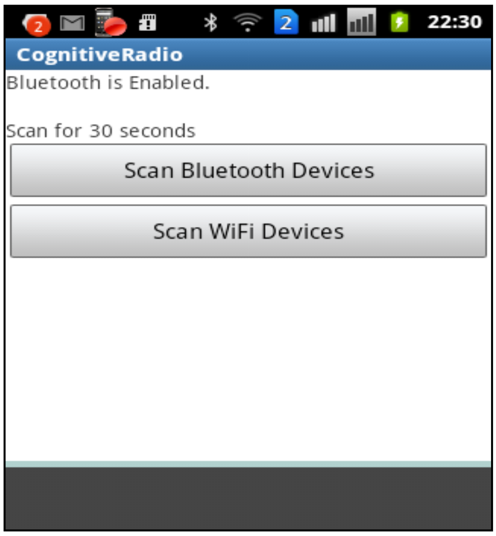

Figure 5: Cognitive radio application layout in Android phone

After completed the installation process, turned on both the Bluetooth and Wi-Fi, this main screen popped up as shown in Figure 5. Bluetooth and Wi-Fi icons can be seen on top of the Android phone. It showed that this system was waiting for the user to click either Scan Bluetooth Device button or Scan Wi-Fi signal button to process.

Figures 6 and 7 show the process of Wi-Fi scanning and one of the successful detection performances respectively.

Figure 6: Scanning Wi-Fi devices

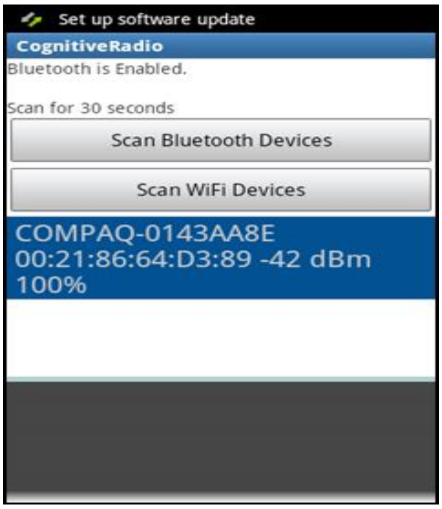

Figure 7: One successful detection performance

The free channel (white-space) detection algorithm works base on Equation 1 with pseudo-code as shown in Figure 8. It uses the RSS and threshold values from Table 1.

```
{
int Threshold = -98 dBm // Noise floore level
 if (Signal.level <= Threshold)
          percentage = 0;            // Under H0
 else if (Signal.level >= -50 dBm)
              percentage = 100; // Under H1
 else
           percentage = 2 * (Signal.level + 100);
        }
freeChannelDetection% = 100 - percentage;
```

Figure 8: Pseudo-code for Successful Free Channel Detection

The application based on the algorithm was tested on an Android phone in the CR test-bed for ten times to check the efficiency of the system, also repeated for three different days with time variations.

If a channel for SU (white-space) is detected, successful communication among paired SUs can be performed. Hence, communication solely depends on white-space (or PUs absence) detection efficiency. Figure 9 shows the percentage of successful communication (along with detection) efficiency for the cognitive radio network test-bed with Android smartphones. The communication with detection was successful for most of the cases, with variation from 50% to 100% efficiency. The average system performance efficiency was around 83%. The worst-case scenario was the presence of PU (active suddenly) in a channel, while it was used (on-going communication) by a pair of SUs. This problem can be avoided by the detection (PU's absence/presence) and automatic channel selection efficiency of the system. Besides, the error in detection occurred due to the noise level in the surrounding test-bed environment and for various weather conditions (which is consistent with Table 1).

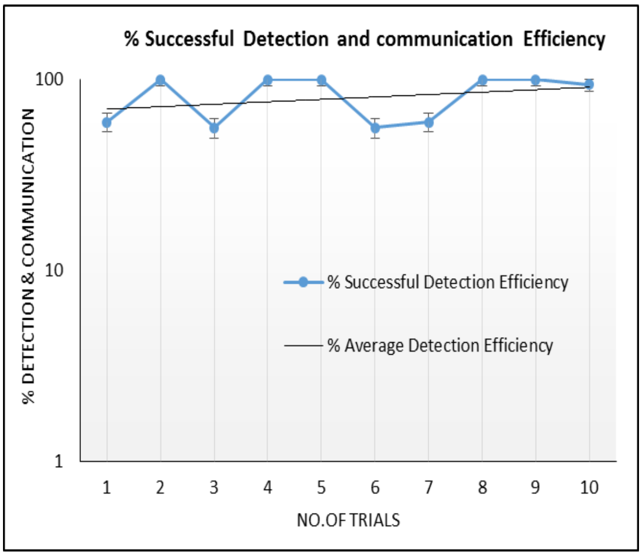

Figure 9: Successful detection and communication efficiency

VI. Conclusion & Future Works

Cognitive radio network implementation has been done with successful channel detection and secondary user's communication without affecting the primary user. Java Eclipse program has been developed to test the efficiency of the proposed CR sensing and detection using smartphones. The efficiency of CR network environment has been verified and validated numerically and experimentally through test-bed using Android-based smartphones and Wi-Fi access points. The developed CR system can scan all available devices within the coverage area, find the device with strongest RSSI, communicate with the specified device, and finally save the detected devices as log file in the sd card of the phone. The efficiency of the cognitive radio network is satisfactory in the developed test-bed environment.

Upgrading the application detection of Bluetooth devices and WI-FI devices can be done automatically in future. This system can also be upgraded by considering multi-hop CR communications.

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