RELIABLE SPECTRUM HOLE FINDING IN SPECTRUM-HETEROGENOUS MOBILE COGNITIVE RADIO NETWORKS IN PROGRESSIVE NON- PARAMETRIC ASSEMBLY

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Abstract

Cognitive Radio Networks (CRNs) are emerging as a solution for maximising cumulative spectrum usage in radio environments by using idle or underutilised airwaves. The fundamental idea is to provide unlicensed users access to permitted spectrum as long as disturbance to licenced users is kept to a minimum. To make better use of the spectrum and increase spectrum utilisation, new communication and networking technologies must be created. This means that a number of technological issues must be resolved before this technique can be used. Dynamic Spectrum Access (DSA), architectural problems (with a focus on network reconfigurability), the deployment of smaller cells, and security are the most pressing concerns. Given that 3G Long Term Evolution (LTE) pilots and 4G Long Term Evolution - Advanced (LTE-A) are now operational, Today, it appears that 5G will emphasis on architectural and networking features rather than faster carrier than 4G. Pervasive wireless computers and communications, cognitive radio technology, IPv6, wearable gadgets with Artificial Intelligence (AI) capabilities, and a uniform global standard are among the key 5G characteristics predicted. Wi-Fi and Bluetooth protocols are predicted to be available as radio applets by 2020, resulting in new technological advancements as well as new opportunities.

Index: Cognitive Radio Networks (CRNs), Dynamic Spectrum Access (DSA), Long Term Evolution - Advanced (LTE-A), IPv6, Artificial Intelligence (AI).

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1. INTRODUCTION

Given that 3G Long Term Evolution (LTE) pilots are presently underway and 4G Long Term Evolution - Advanced (LTE-A) pilots are anticipated for 2015, and given that each generation of wireless systems takes around a decade, 5G pilots are expected in 2025. Currently, it looks that 5G will prioritise architectural and networking characteristics above faster carrier than 4G. Among the primary 5G qualities projected are ubiquitous wireless computers and communications, cognitive radio technology, IPv6, wearable devices with Artificial Intelligence (AI) capabilities, and a unified worldwide standard. By 2020, Wi-Fi and Bluetooth protocols are expected to be available as radio applets, leading in new technical developments and opportunities.

System Model

Cognitive Radio Networks (CRNs) Probability of Detection Over Fading Channels with No Diversity

Statement of the Problem Identification

- To create an efficient framework for providing dynamic spectrum access for cloud-based cognitive radio vehicular users.
- To protect dynamic spectrum access in cognitive radio networks against location falsification attacks induced by GPS flaws.
- Why To decrease the likelihood of misdetection and false alarms caused by GPS measurement inaccuracies, hence enhancing overall performance and efficiency.
- Create the softwarization architecture to accomplish system energy efficiency.

COGNITIVE RADIO NETWORK

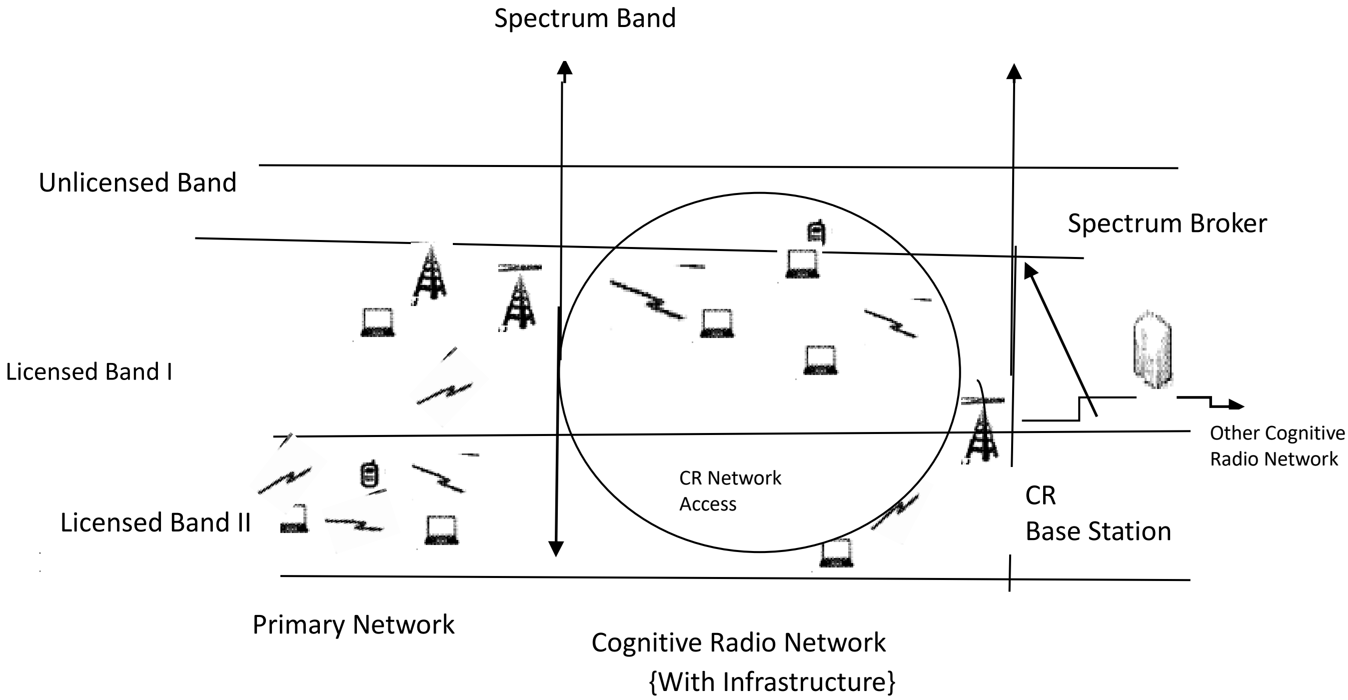

Fig.1: Infrastructure-Based CR Network Architecture

Primary base station: A primary base station is a fixed infrastructure network component that has a spectrum license, such as a base station transceiver system (BTS) in a cellular system. In principle, the primary base station does not have any CR capability for sharing spectrum with CR users.

CR base station: A CR base station is a piece of permanent infrastructure that has CR capabilities. It controls CR users within its transmission range by providing a single-hop connection without requiring spectrum access licences. A CR user can connect to other networks using this connection. It also aids in the synchronisation of sensing actions done by several CR users. The latter's observations and analysis are relayed to the central CR base station, which makes the decision on spectrum availability.

Spectrum broker: A spectrum broker (or scheduling server) is a central network element that helps distinct CR networks share spectrum resources. It does not directly sense the spectrum. It simply controls spectrum allocation among multiple networks based on sensing data provided by each network.

In order to evaluate the quality of the solution and the convergence speed of both PSO and GA algorithms, simulations for network selection in 5G heterogeneous networks are performed. The performance of both GA and PSO is determined on the parameters used. Figure 1 shows the settings used for the simulations of these algorithms after a first set of trials. Parameters for simulation. To evaluate the performance of GA and PSO, simulations are run under two situations with distinct data sets. To achieve the average performance of PSO and GA, we ran 20 runs on each scenario. The Poisson process is used to represent the PU arrival process and channel availability for each major network. A channel held by PU is regarded inaccessible to SUs; hence, if an SU attempts to access this channel, the repair procedure is launched. Figure 1 depicts the information received about the principal networks for both scenarios 1 and 2. When an SU enters the system, it declares its data rate needs as well as the amount it is prepared to pay to the CNO. Figure 2 depicts the information specified by the SU for situations 1 and 2.

Parameters	Value
Number of iterations	3000
Number of SU in CRN	12
Number of Primary Network	7
Number of channels in each network (p)	7
PSO	
Population Size	12
Acceleration constants c1, c2	2
Inertial Weight (w)	0.2
V min	-7
V max	7
GA:	
Population Size	12
Crossover rate	0.5
Mutation rate	0.03

Our integrated circuits and reference designs help you quickly create multi-access edge computing (MEC) designs with higher energy efficiency, density and fast data computing. Our power management and signal chain ICs support the need to improve 5G network latency performance as well as emerging technologies like artificial intelligence and machine learning. CPUs, FPGAs, ASICs and even peripherals are growing increasingly complex and, consequently, so do their power delivery requirements. To handle the higher demands, multiphase regulators are becoming increasingly common on motherboards in many areas of computing. Designing with these regulators is more challenging than using conventional switchers and linear regulators, but the benefits of multiphase outweigh the complexity for high-performance power applications. Our multiphase buck portfolio includes Intel CPU core regulators, as well as other ASIC/Processor/FPGA multiphase buck regulators, with or without interfaces to the processor. This training series is designed to provide the necessary equations and guidance to get a new multiphase design up and running and ready for validation. After an overview of multiphase benefits, an in-depth design example of a multiphase buck regulator for an ASIC core rail is presented.

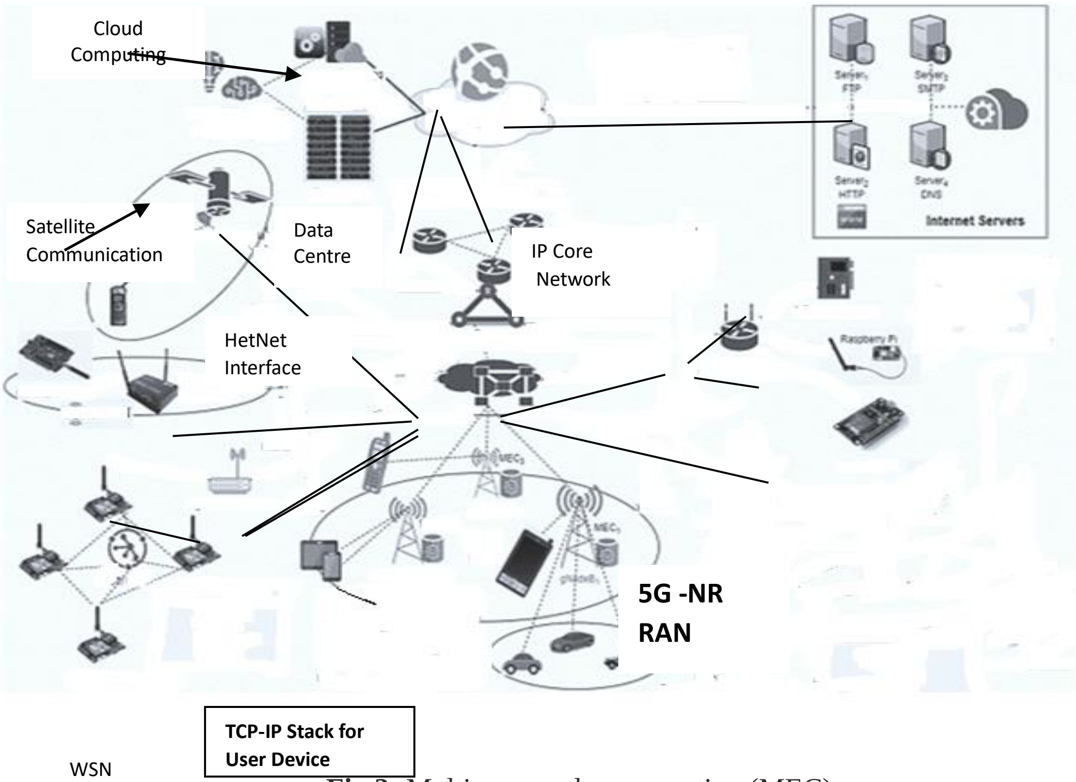

Fig.2: Multiaccess edge computing (MEC)

Multiaccess edge computing (MEC) is creating a technology impact in distributing the computation to the edge of the radio access network (RAN). The MEC offers large bandwidth, low latency, highly efficient network operation and host of services to the end user. This property of MEC is going to benefit in handling the computation of voluminous data traffic created in fifth-generation (5G) network. However, MEC acts as a key technology to provide the concept of architecture of evolution of 5G from previous generation by transforming the mobile broadband network into advanced programmable and computational infrastructure for satisfying the requirements of 5G such as throughput, scalability, latency and automation. Therefore, to fulfil the requirements of new compute-intense applications of 5G IoT, it is intuitive to converge with MEC for smooth processing of large data traffic to offload the cloud especially in the era of artificial intelligence and machine learning. This chapter deals with an overview of the convergence of 5G with MEC technology and enlightens technical aspects, which are crucial for any IoT-based smart healthcare system with a special focus on Convergence between 5G and MEC in the purview of IoT applications.

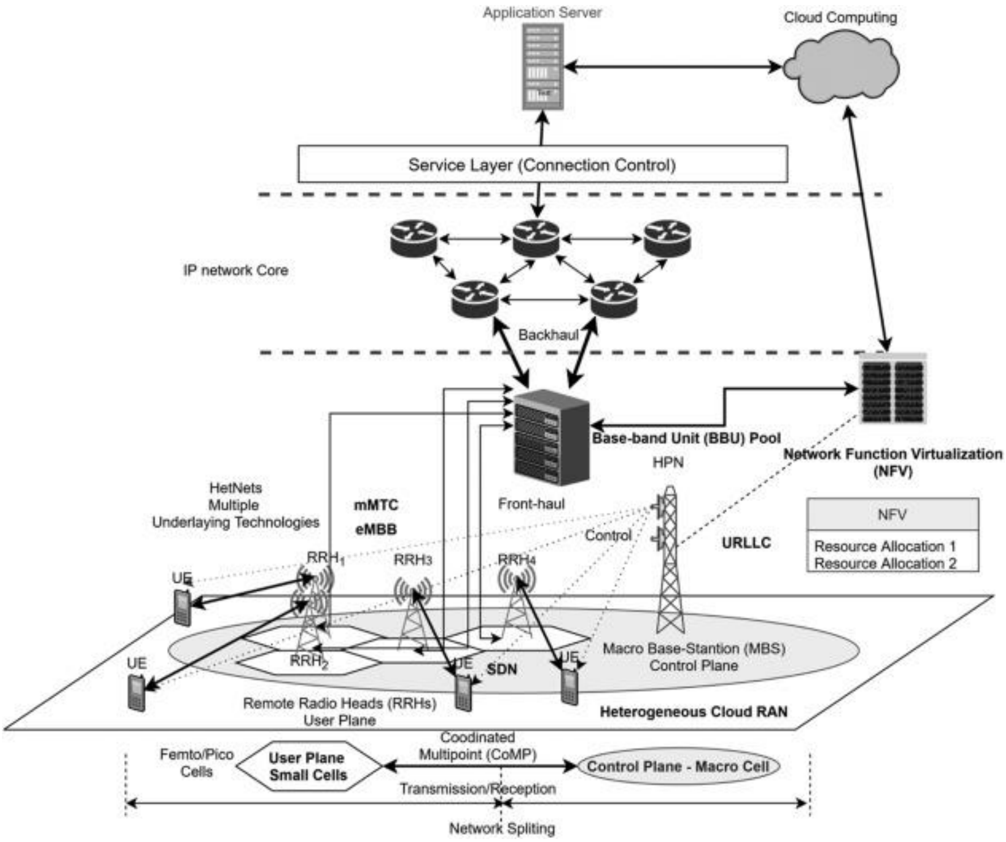

Fig.3: high-data rate/enhanced Mobile Broad-band (eMBB), ultrareliable low latency communication (URLLC), and massive Machine-Type Communication (mMTC)

In today's era of connected intelligent systems, 5G is the key technology enabler toward achieving high-data rate/enhanced Mobile Broad-band (eMBB), ultrareliable low latency communication (URLLC), and massive Machine-Type Communication (mMTC) for enhancing the legacy data network. 5G-enabled heterogenous networks (HetNets) are necessary for modern-day communication for several game changing applications like Internet of Things (IoT), Device-to-Device (D2D), and Machine to Machine (M2M) communication. These applications have tremendous business potential to have a significant impact on the socioeconomical strata of modern world. However, the heterogeneity in several fronts of technologies to deploy such 5G HetNet based systems are considered to be an opportunity, while having challenges associated with it. Heterogeneity in network, protocol, communication standards, and even cross-platform operations has some functional advantage of modularity in 5G HetNet implementation. Heterogenous Networks (HetNets) with functional modularity are best harnessed by scenario-specific system requirement. 5G-HetNets fronthaul is an agile Heterogenous-Cloud-Radio Access Network (H-CRAN) using technologies like Software Defined Network (SDN) and Network Functions Virtualization, and at the same time a Time Wavelength Division Multiplexing-Passive Optical Network (TWDM-PON) backhaul network to provide ultrahigh data-rate/bandwidth to 5G HetNets as traffic aggregation is needed from large numbers of mMTC devices. M2M and D2D frameworks provide communication between mMTC devices for various IoT applications. Smart home/city/grid, industrial automation and the healthcare sector to name a few. In 2012, OneM2M was the new de-facto standard by a consortium of ICT standards development organization to create one platform compatible with all to provide interoperability to HetNets. In 2016, One M2M standard was adapted by 3GPP (R-13) and several amendments in 3GPP R-15/16 toward 5G support for M2M and HetNets (*ui.vk*).

T The angle(γ_k) can be obtained from the dot product between unit vector

$$\Upsilon_{ik} = \cos^{-1}\frac{ui.vk}{[\![ui]\!].[\![vk]\!]}$$

$$\gamma_{ik} = \left(\frac{(\cos\varphi_i a_x\, sin\, \varphi_i a_y).(\cos\phi_k \sin\theta_k a_x + \sin\phi_k \sin\theta_{\ k} a_{\ y}}{\|vi\|\|uk\|}\right)$$

$$\Upsilon_{ik}=\left(\frac{(\cos\varphi_i.\cos\phi_k sin\ \theta_k\ )+(\sin\varphi_i.sin\theta_k.\sin\theta_k}{\|v_i\|.\|u_k\|}\right)$$

$$\gamma_{ik} = \left(\frac{(\cos \phi_k \cos (\theta_k \ - \phi_{k)}}{\|vi\| \|uk\|} \right)$$

$$\gamma_k = \cos^{-1}(\sin \theta_k \cos(\emptyset_k - \varphi_i)$$

$$\varphi = |\varphi_1, \varphi_2, \dots \dots \dots . \varphi_M|$$

$$\gamma_k = \begin{bmatrix} \gamma_{11} & \gamma_{12} & \cdots & \gamma_{1D} \\ \gamma_{21} & \gamma_{22} & \vdots & \gamma_{2D} \\ \vdots & \vdots & \ddots & \vdots \\ \gamma_{M1} & \gamma_{M2} & \cdots & \gamma_{MD} \end{bmatrix}$$

2. MATERIAL METHOD AND HYPOTHESIS H_0 and H_1

The breadth of research questions and technologies involved in building CRN systems calls for considering innovative approaches to organizing a CRN research program. There are four aspects to consider when setting up a CRN research program:

1. CRN research and development requires a multidisciplinary approach involving researchers in the areas of radio frequency circuit design, signal processing, networking, adaptive systems and learning, spectrum policy, economics, and social sciences.
2. CRN research requires a structure that insures wide participation in developing CR technologies.
3. CRN research must be built on a foundation of field measurements (testbeds) and repeatable experiments.
4. CRN research must be connected with emerging applications and radio communications needs. Point (1) argues for a few (2-3), significant efforts to organize and maintain solid engineering teams to address the breadth of CRN technologies. These efforts might involve single or multiple institutions, but should be funded at a level to support locally developed technologies as well as the ability to integrate technologies from other research groups. These efforts should be able to widely disseminate CR experimental platforms to others. Point (2) argues for a collaborative effort to collect and disseminate information and CRN measurements and models to a wide range of institutions. Many research groups can contribute to CRN research but do not have the infrastructure to begin from scratch. Organizing a cooperative, collaborative effort is important. CRN research must be grounded in the physical world. Radios work in the physical world, not in models.

A CRN research program must develop the tools and techniques to easily move information from field experiments (testbeds) to abstract models and move questions from the models to experiments in the field. A range of capabilities is required. First, we need experimental testbeds to gather physical world experience. We cannot improve our science without measurements in the real world. Second, we need facilities for controlled experiments. We cannot move the technology forward if there are too many unknowns in an experiment. We must be able to repeat experiments. Third, we need techniques to abstract field experiment measurements into simpler models. This enables us to consider larger CRN systems before extensive deployment. At the same time, we need to learn how to extract questions fromour models to design new and worthwhile field experiments. We see this as a continuum from simulation models, to emulation, to controlled laboratory experiments, to field experiments. Point (4) argues for grounding CRN research in current or foreseeable user needs. A balance is required here. We must understand the emerging needs and incorporate those needs into the motivation for our CRN research. However, we do not attempt to use a CR networking research program to solve a specific application requirement. There are three possible research structures:

1. The first is the standard NSF program. A research program is announced. Investigators submit proposals. The best is selected by a review panel and funded. The problem with this approach is that without significant NSF Program Director involvement over the long term, there is little coordination across the funded research efforts.
2. A second approach, used in the Gigabits testbeds and, to some extent, in the current GENI GPO, is to issue a large grant to a single institution, in the case of the Gigabits testbeds it was CNRI and in GENI it is BBN. The outside institution solicits proposals, reviews them and issues grants/contracts. This can lead to a coordinated endeavour. A task of the coordinating entity is to ensure collaboration among funded investigators and ensure collection and dissemination of work.
3. A third approach would be one or a small number of large collaborative grants supporting a consortium of university partners to move this endeavour forward in a coordinated fashion. Given that one of the major research challenges is how to integrate the many CRN components into a larger, stable, and deployable system, the panel felt that the 2nd and 3rd approaches were worth considering, and that there are important lessons

to be learnt from the Gigabit Testbeds and GENI project structure.

However, the 1st approach is also feasible, if accompanied by mechanisms to coordinate the selected projects, as is done in the recent Cyber-Physical Systems program (NSF 08-611). Putting a program together is however a significant and possibly lengthy process and the panel felt that there is an opportunity for an immediate, focused effort that would have a significant impact on the CRN community. The lack of shared CRN testbeds is a serious impediment to continued research progress in the field. It leads to heavy reliance on simulation or small-scale experiments in lab environments that are non-repeatable and often not realistic. Given our improved understanding on how to deploy and manage shared wireless testbed, there is an opportunity for a focused research effort in the area of CR networking testbeds, including testbeds that support controlled, partially controlled, and in-the-wild testbeds. This testbed effort should be coupled with a development of a shared community infrastructure for CR networks that can be used by other researchers for their experiments. The results of such a focused effort would of great value to the CRN research community and it would also provide a solid starting point for, accelerate, and reduce the risk of any future program in the CRN area. Note that because of the unique features of CR networks, the development of CRN testbeds requires a research effort – it is not an infrastructure project.

3. SYSTEM AND CHANNEL MODELS

Spectrum utilisation by licenced Primary Users (PUs) is inefficient, according to measurements [1]. Cognitive radio [2], [3] is a system that has the intrinsic capacity of improving the efficiency of inefficient spectrum utilisation by allowing unlicensed Secondary Users (SUs) to access the frequency band during idle time. As soon as the PU is operational, the Cognitive Radio Network (CRN) and all SUs must release the spectrum band. It means that the SUs do not interfere with the PU and that the SUs use the spectrum band in an opportunistic manner. Spectrum sensing is required to identify spectrum gaps, or idle licenced spectrum sub-bands, in order to prevent SUs from interfering with the principal network, the PU network. Several ways for perceiving the spectrum have been proposed. Among them Matching filter detection [4, 5], cyclostationary detection [6, 7], energy detection [8, 9], and covariance-based detection [10] are examples. Because of its simplicity, energy detection is the most commonly used practical detection technique for spectrum sensing. Due to fading, shadowing, and the buried node problem, the instantaneous Signal-to-Noise Ratio (SNR) of the received signal with a single SU may become too low to produce the sensing result. To tackle this difficulty, a collaborative strategy has been implemented. Several different SUs cooperatively detects the spectrum holes. As the number of involved SUs increases, the probability that all of the cooperating SUs are simultaneously in a deep shadowing or fading is reduced [11]. Furthermore, the multiple distributed SUs provides the diversity gain. The diversity gain, in turn, greatly improves the global performance and efficiency [12]

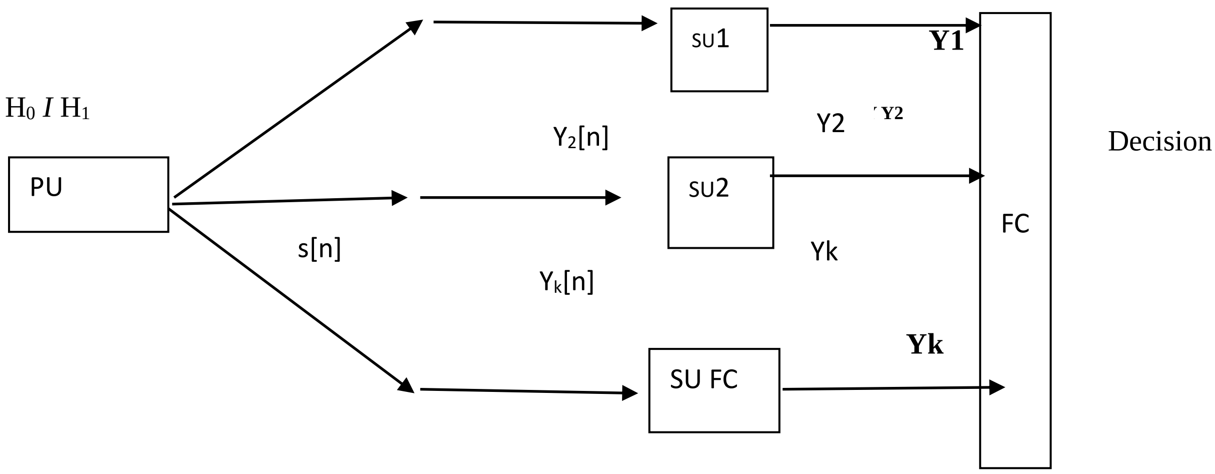

Fig.4: Depicts of Cooperative Cognitive Radio (CCR).

The model is made up of a PU, K SUs, and a Fusion Centre (FC). The impediments on the connected channels are shown by the thick black vertical lines. Each SU senses the spectrum band of interest through an individual sensing channel, employs an energy detection approach, that is, computes the amount of energy of the signal received from the PU over a set time interval, and transmits it to the FC over an error-free reporting channel.

The FC collects the information on the energy of PU's signal received by all SUs, combines them, and applies some rule to make the global decision considering the occupancy of the spectrum band. If the messages sent by the SUs are in form of local binary decision about the present or the absent of the PU, then the FC combining rule is called hard combining method [9]. If the messages sent to the FC are the local test statistics, the FC combining rule will be a soft combining method [4], [13]. If every SU forwards the signal from PU to FC and the test statistics is computed by the FC then it is still said that the FC performs soft combining method [14]-[16]. be small [17]. Complex coupling relation between the local quantization rule and the fusion combining rule is the most important task in hard combining technique and that is not present in soft combining technique. The soft combining technique (soft-fusion policy) can achieve optimal diversity, providing a higher diversity gain and better detection accuracy compared with the hard combining one (decision-fusion policy) [18]. Obstacles can considerably reduce the performance of cognitive radio in practice. Hence, the fading channel that occurs in most of the realistic wireless environments, degrade the performance of the channels. CSS is analysed superficially by [19]. In [15] the performance analysis of CSS in CR over Nakagami-m channels is studied. In [20] the performance analysis of CSS is examined for multipath fading channels based on energy detection. In [6] the analysis is based on fast-fading and block-fading channels where only the average SNR is available. In [9] block flat-fading channels are assumed in the model for analyzing the CSS and in [7] Nakagami-m fading channels are assumed with MRC reception. This paper describes the effect of the presence of obstacles on the sensing channels. The work presents a performance analysis of spectrum sensing over multipath fading for a system with obstacles between PU and SUs as depicted in [21]. Specifically, we suggest the use of available channel models as Rayleigh channels, Rician channels, and Nakagami-m channels and the use of Central Limit Theorem (CLT) to derive the closed-form expression of the performance measures

4. RESULT AND ANALYSIS

We consider a CCR with K secondary users, $\{SUk\}$ k=1 K, which cooperatively observe the presence and the absence of the primary signal, $s[n]$, transmitted by PU, with a specified frequency, via independent sensing channels, in certain successive observation intervals. Each interval consists of N samples which is selected based on the bandwidth-observation time product. The nth received signal sample at SUk, $y_k\ [n]$, for k = 1,2, ⋯ , K and n = 1,2, ⋯ , N, can be written as

$$Y_k(n) = \begin{cases} W_x \ldots\ldots\ldots\ldots\ldots\ldots .. H_0 \\ h_k s[n] + W_k[n] \ldots\ldots H_1 \end{cases} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots .1$$

where the null hypothesis, H_0, represents the absence of PU and the alternative hypothesis, H_1 , represents the presence of PU. Noise samples are zero mean complex Gaussian random variables with variance $\sigma_k{}^2$.

$$W_k\ [n] \sim CN\left(0, \delta_k^2\right) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2$$

where hk is the flat fading channel gain between PU and $SU_{k.}$ The energy of the primary signal, $s[n]$, from PU, during observation, i

$$E_s = \sum_{n=1}^{N} \left[s[n]\right]^2 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots 3$$

The channels with obstacles have no line-of-sight (LOS) component in their propagation paths. The fading amplitude of each channel, $|hk\ |$, can be approximated by Rayleigh distribution. The SNR, γ, distribution is [22]

$$f_y(y) = \frac{1}{y} exp\left\{-\frac{y}{\bar{y}}\right\} \ ,\gamma \geq 0 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 4$$

where $\bar{\gamma} = E[\gamma]$ is the expectation value of γ. The channels with no obstacle have one strong direct LOS component in their paths. They can be considered as Rician channels approximately. The SNR distribution is [22]

$$f_y\langle Y\rangle = \frac{k+1}{\bar{y}} I_0\left\{\frac{yk\{k+1\}}{\dot{y}}\right\} exp\left\{-\frac{y\langle k+1\rangle}{\bar{y}}\right\} - 1 \;\; ,y \geq 0 \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots..5$$

where the function I_0 is the modified Bessel function of 0-th order and κ is the ratio of the power in the LOS component to the power in the non-LOS multipath components. It can be seen that for $\kappa = 0$, Ricean distribution becomes Rayleigh distribution so it can be used to approximate the channels without LOS component as well. The problem of obstacles also can be approached by Nakagami-m distribution which has SNR distribution as [22]

$$f_y\{y\} = \frac{m^m y^{m-1}}{\bar{y}^m[m]} exp\left\{-\frac{my}{\bar{y}}\right\} \;\; ,y \geq 0 \qquad \ldots\ldots\ldots\ldots\ldots\ldots6$$

where $\Gamma(\cdot)$ is the Gamma function and m is the Nakagami-m fading parameter. We can see that for m = 1 the distribution reduces to Rayleigh fading so it can be used to model the channels with obstacles. For $m = (\kappa + 1)$ 2 /(2κ + 1) the distribution is approximately Rician fading which can be used to represent the channels without obstacle. The instantaneous SNR at the k-th secondary user is

$$\bar{Y}_k = \frac{E_s[h_k]^2}{\delta_k^2} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots7$$

and its average value is

$$\bar{\bar{y}}_k = \frac{E_s|h_k|^2}{\delta_k^2} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots8$$

Each secondary user, SU_k, performs energy detection on the received signal, $y_k\,[n]$, to produce test statistics, Y_k,

$$y_k = \sum_{n-0}^{n-1} |y_k\{n\}|^2 \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots9$$

According to the central limit theorem (CLT) [23], for a large N (the number of samples), Y_k is asymptotically normally distributed

The probability distribution function (PDF) of Y_k then can be expressed as

$$y_k \sim N\{\mu_{y_k,}\; \delta_{y_k}^2\} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots10$$

$$f_{y_k}(x) = \frac{1}{\delta_{y_k}\sqrt{2\pi}} exp\left(-\frac{1}{2}\left[\frac{x-\mu_{y_k}}{\delta_{y_k}}\right]^2\right) \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots11$$

where the local test statistics mean, μY_k, and the local test statistics variance, σY_k, are [24]

$$E[Y_k] = \mu_{y_k} \begin{cases} N\delta_k^2 & H_0 \\ N(1+2y_k)\delta_k^4 & H_1 \end{cases} \qquad \ldots\ldots\ldots\ldots\ldots\ldots.\ \ldots\ldots.13$$

$$Var[y_k] = \delta_{y\,k}^2 = \begin{cases} N\delta_k^2 & H_0 \\ N(1+2y_k)\delta_k^4 & H_1 \end{cases}$$

respectively. All SUs sends their local test statistics to FC via independent and perfect reporting channels. FC applies weighted summation rule and combines linearly all Y_k to generate a single global test statistics Z,

$$Z = \sum_{k=1}^{k} \beta_k Y_k \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots14$$

where β_k is the weight applied to each channel. Since all Y_k are normal random variables, their linear combination is normal too. We can see that equal gain combining (EGC) and maximum ratio combining (MRC) are two special cases of weighted summation combining. If all weights are unity, $\beta_k = 1$ for all k, then we have EGC and if each weight is proportional to the SNR at SUk , $\beta_k \propto \gamma_k$, then we have MRC. The distribution of the global test statistics can be expressed as

$$Z \sim N\{\mu_z, \delta_z^2\} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots 15$$

where the global test statistics mean, $\mu Z = \sum \beta_k \mu Y_k\ K\ k$=1, and the global test statistics variance, $\sigma Z\ 2 = \sum \beta_k$ $2\sigma Y_k\ K\ _2\ k$=1 are expressed in detail as

$$E[Z] = \mu_z = \begin{cases} N\sum_{k=1}^{k} \beta_k \delta_k^2 & H_0 \\ N\sum_{k=1}^{k} \beta_k \ \{1+y_k\}\delta_k^2 & H_1 \end{cases} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 16$$

respectively. The FC makes a decision based on the global test statistics, Z,

$$[Z] = \delta_z^2 = \begin{cases} N\sum_{k=1}^{k} \beta_k^2 \delta_k^2 & H_0 \\ N\sum_{k=1}^{k} \beta_k^2 \ \{1+y_k\}\delta_k^2 & H_1 \end{cases} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots 17$$

$$Z \underset{H_0}{\overset{H_1}{\gtrless}} \lambda \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots 18$$

$$P_f = Pr\{Z > \lambda I H_0\} \quad \ldots\ldots\ldots\ldots\ldots 19$$

$$= \int_{\lambda}^{\infty} f_z(xIH_0)\, dx$$

$$= 1 - F(\lambda I H_0)$$

where $F(\cdot)$ is the cumulative distribution function (CDF) of the global test statistics, Z. In terms of the AWGN noise, the channel SNR, the number of samples, the weighting constant, and the decision threshold, the probabilities of false alarm and detection can be expressed as

$$P_d = Pr(Z > \lambda I H_1) \ldots\ldots\ldots \ldots\ldots\ldots\ldots\ldots\ldots 20$$

$$= \int_{\lambda}^{\infty} f_z(xIH_1)\text{dx}$$

$$= 1 - F(\lambda I H_1)$$

$$P_f = Q\left(\frac{\lambda - E[ZIH_0]}{\sqrt{Var[ZIH_0]}}\right) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots 21$$

$$= Q\left(\frac{\lambda \sum_{k-1}^{k} \beta_k \delta_k^2}{\sqrt{N\sum_{k-1}^{k} \beta_k^2 \delta_k^2}}\right)$$

respectively. where $Q(\cdot)$ is the Q-function defined as the tail distribution function of the standard normal distribution

$$P_d = Q\left(\frac{\lambda - E[ZIH_1]}{\sqrt{Var[ZIH_1]}}\right)$$

$$= Q\left(\frac{\lambda - N\sum_{k-1}^{k} \beta_k (1+Y_k)\delta_k^2}{\sqrt{N\sum_{k-1}^{k} \beta_k^2 (1+2y_k)\delta_k^4}}\right) \quad \ldots\ldots\ldots\ldots\ldots\ldots 22$$

$$Q(x) = \frac{1}{\sqrt{2\pi}} \int_{x}^{\infty} exp\left(-\frac{1}{2}x\right) dx$$

The Q-function can be expressed in term of the error function or the complementary error function.

In this paper a hybrid method for sharing spectrum was proposed that allows for sensors that perform sub-optimally. The proposed method only requires that the PU share the equation for the SU operating boundary with potential SUs. The SU operating boundary provides a limit

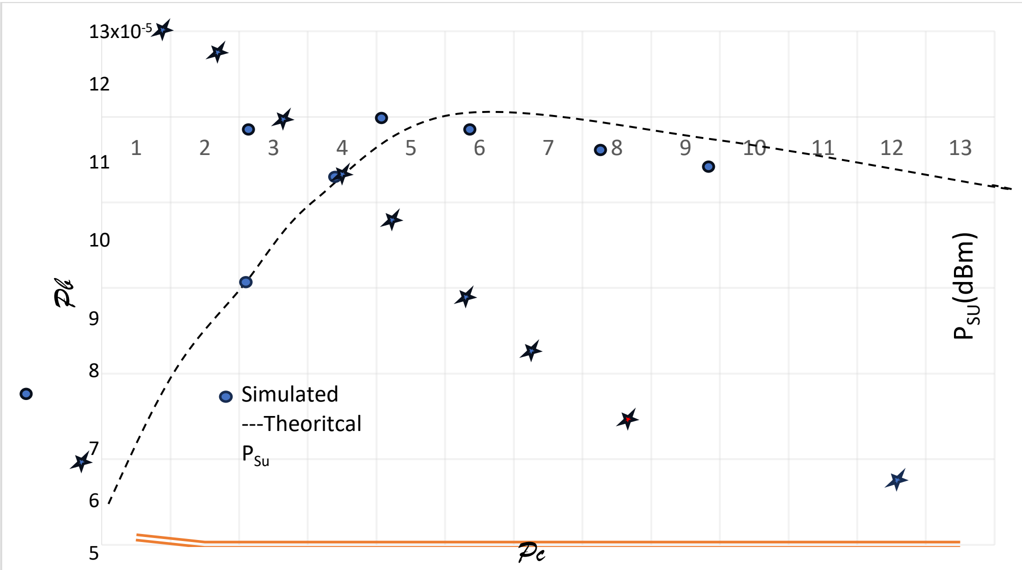

Figure 05. PU performance with a fixed SU value PY = .9 and a range of SU (Pc, PSU) operating pairs on the linear boundary

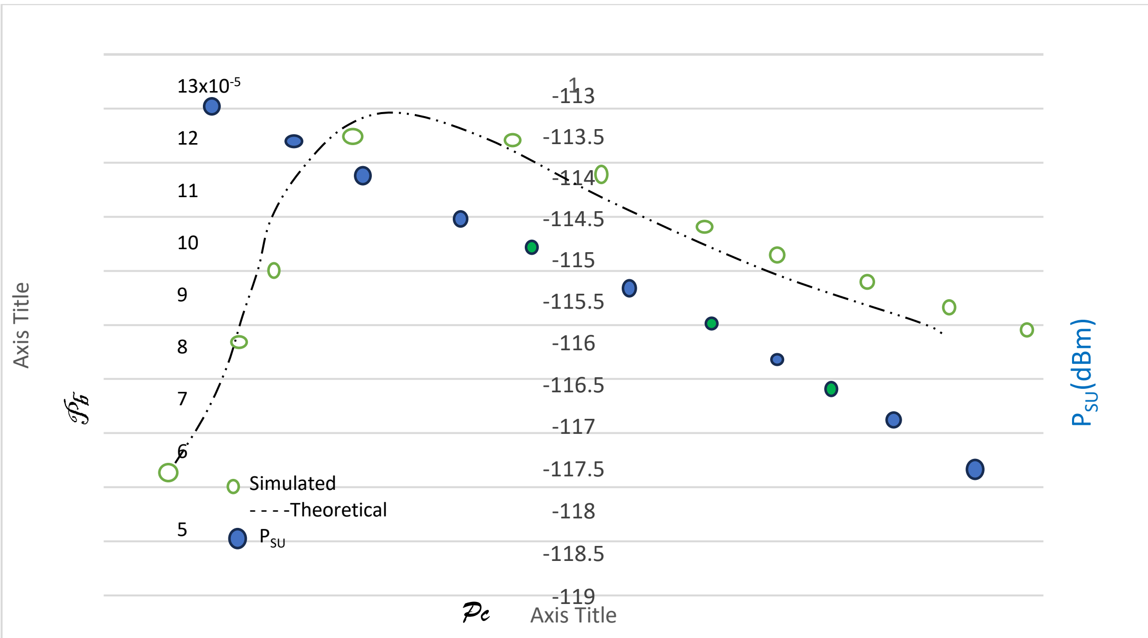

Figure 06. PU performance with a fixed SU value PY = .9 and a range of SU (Pc, PSU) operating pairs on the 2nd-order polynomial boundary.

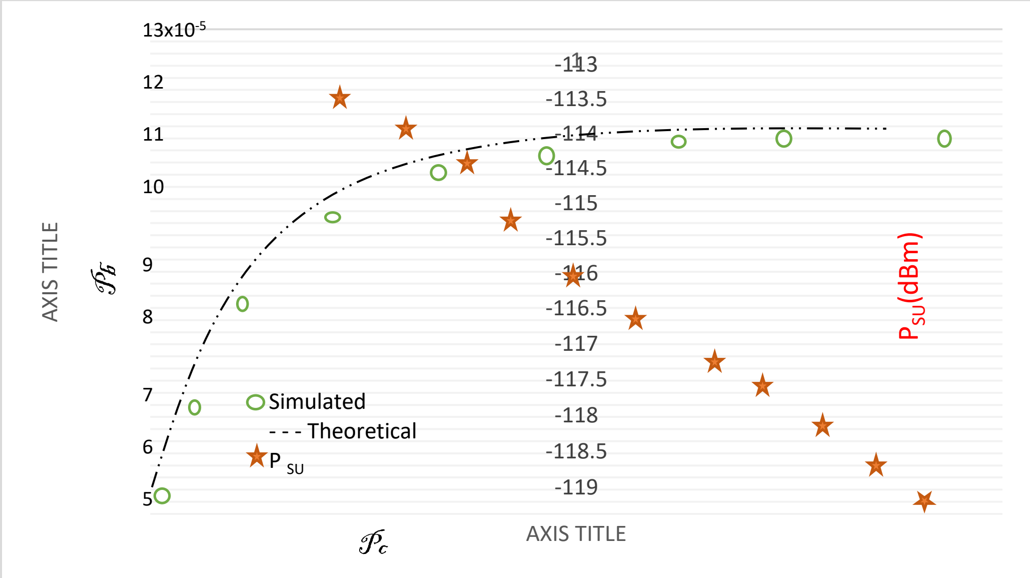

Figure 07. PU performance with a fixed SU value PY = .9 and a range of SU (Pc, PSU) operating pairs on the 4th-order polynomial boundary.

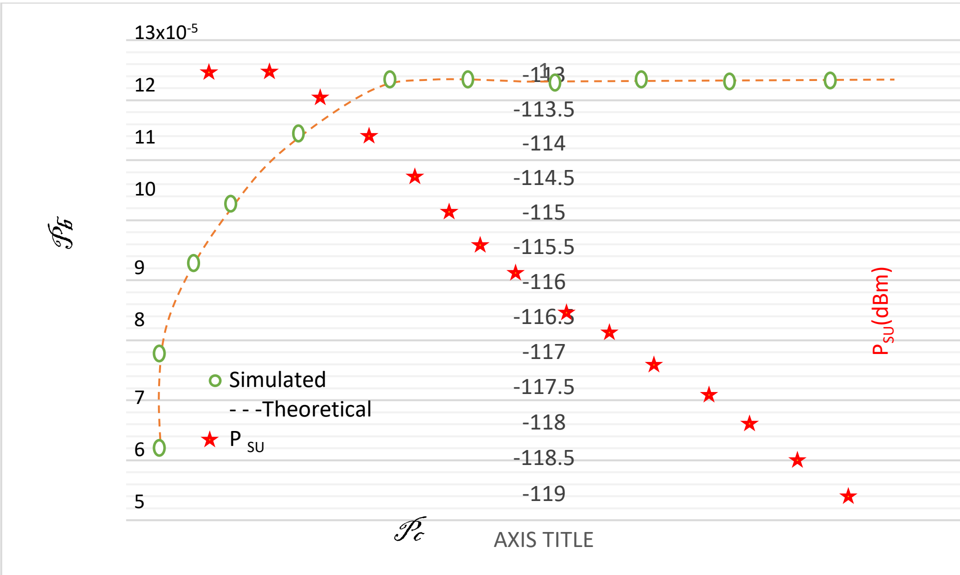

Figure 08. PU performance with a fixed SU value Pd = 0.25 and a range of SU (Pc, PSU) operating pairs on the linear boundary.

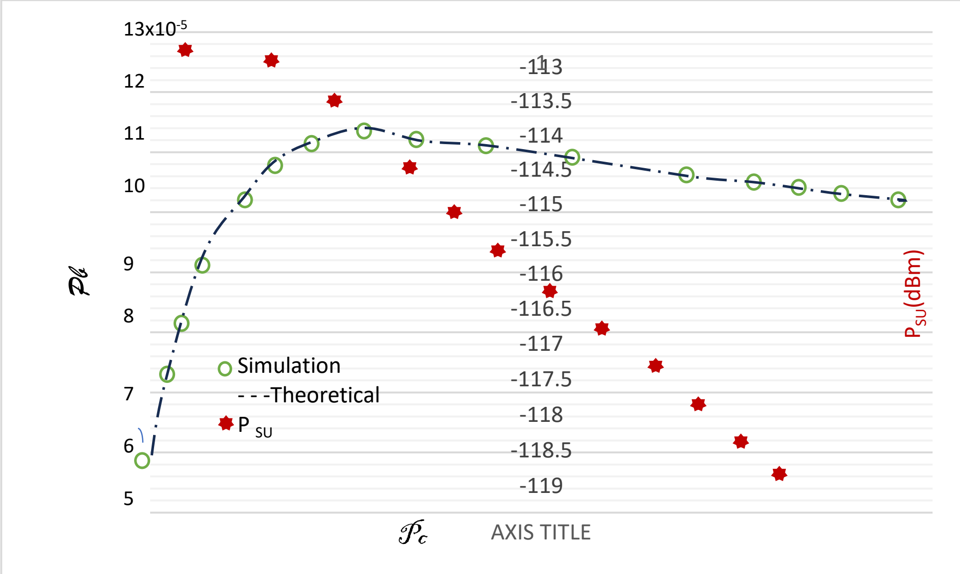

Figure 09. PU performance with a fixed SU value Pd = 0.25 and a range of SU (Pc, PSU) operating pairs on the 2nd-order polynomial boundary

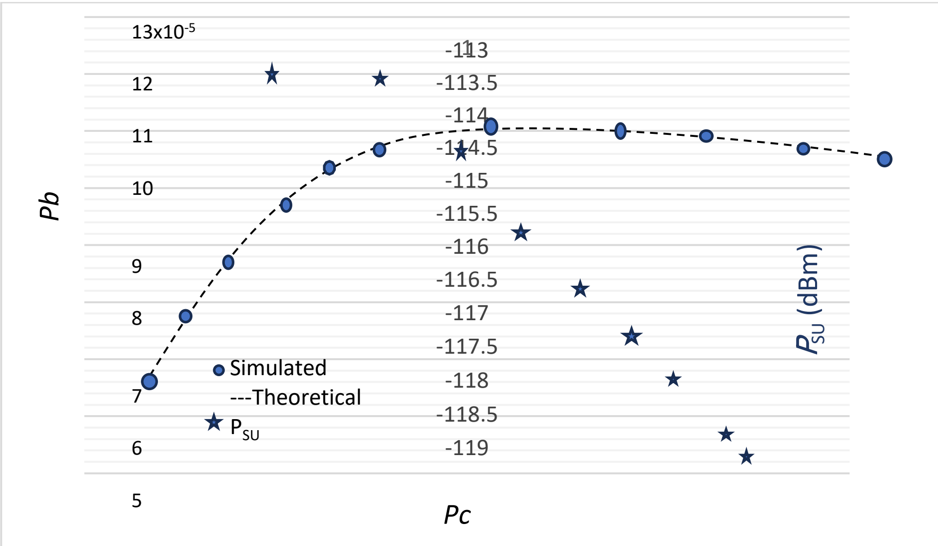

Figure 10. PU performance with a fixed SU value Pd = 0.25 and a range of SU (Pc, PSU) operating pairs on the 4th-order polynomial boundary.

for PSU given Pc or vice versa. Depending on the level at which the PU would like to obfuscate its waveform, the boundary equation can range from a simple linear equation defined by two points or may be a higher fidelity polynomial. This chapter also provided an alternate formula for the probability of collision Pc which considers both the SU duty cycle PY and the probability of missed detection Pd. In the case that the SU sensor is not able to achieve the desired Pd, the SU has the option of backing off on it's duty cycle to achieve the desired Pc. This chapter did not address how an SU can calculate or estimate its sensor performance.

5. CONCLUSION

We investigated and implemented a unique cooperative spectrum sharing technique for a wireless network with numerous primary and secondary users in this research. In CCRN, we saw a spectrum sharing method based on two-phase collaboration, which included an IU selection system. By solving the maximum weighted bipartite matching problem, cooperation pairings between PUs and IUs were found. As a result, we have the greatest overall utility. Furthermore, energy efficiency has been taken into account in the IU selection problem, and the chosen IU collaborates with the PU as well as its neighbouring SUs. The system utility and spectrum access potential have been enhanced with the assistance of the IUs. We discovered, using simulated results, that the utility acquired The Iby performing the suggested partner IU selection technique is always greater than the IUs performing the random selection scheme in our CCRN. In future studies, we will thoroughly examine the collaboration between the IU and the neighbouring SUs.

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