Collaborative Sensing Scheme for CR in XG Networks

Olayinka Taibat Jinadu[1], Folake Akinbohun[2] and Victor Korede Owa[3]

[1]Department of Computer Science, Rufus Giwa Polytechnic, Owo, Nigeria; [2]Department of Computer Science, Rufus Giwa Polytechnic, Owo, Nigeria; [3]Department of Computer Science, Rufus Giwa Polytechnic, Owo, Nigeria.
Email: yimikajinad@gmail.com, folakeakinbohun@yahoo.com, vkorede.owa@gmail.com

ABSTRACT

Cognitive Radio (CR) technology, the building block of next generation (xG) network help mitigate spectrum scarcity in the paradigm shift to dynamic spectrum access (DSA) approach of wireless communication. Reliable communication is guaranteed when licensed (primary) and un licensed (secondary) spectrum users co-operatively utilize the s pectrum. Though, radio spectrum is statically allocated to different services, applications and users, observations showed spectrum usage is low despite increase in wireless communication needs. Required effective spectral utilization is hinged on secondary user's (SU) ability to detect primary user's (PU) signals accurately and make use of any time the frequency is unoccupied. Major task of PU detection relied on SU sensing technique. Analysis of existing schemes showed SNR computable in adv ance for av ailable channels. Improved technique of collaborative spectrum sensing (CSS) for energy detection in CR-super-layer and correct detection rate (CDR) algorithm on logical (PHY + MAC + Netw ork) structure is formulated for reliable channel sensing results. CSS algorithm is equipped to track all changing environment condition in terms of each SNR o btainable to be used for CDR p robability schemes. Remarkable improvement in sp ectrum usage efficiency is achieved with suggested sensing scheme and the inclusive algorithm because collaborative SU's SNR computation in AWGN channels enabled suggested algorithm track changing environment parameters effectively for optimized spectrum hole detection and usage.

Keywords: CRN, DSA, Energy detection, Licensed Users, SNR, Spectrum hole

1. INTRODUCTION

Wireless communication has gone a big way and Cognitive Radio Network (CRN) is one major future-based technology of wireless systems. [1] described CR technology as a wireless communication paradigm, under the Institute of Electrical Electronics Engineer (IEEE) 802.22 Wireless Regional Area Networks (WRAN) standard and interface, which enable network parameters to change during communication. CRN is thought of as an ideal goal of providing highly reliable communication whenever and wherever needed with efficient radio spectrum utilization for all users as depicted in fig. 1. CR nodes, equipped with varied technologies and standards can include UMTS, W-LAN/Wi-Fi, Wi-MAX, WSN, WRAN etc and facility for interoperability among the various interfaces.

Evolved from software-defined radio, CR technology implements intelligent sensing and l earning capabilities. F or optimized wireless service delivery as shown in f ig. 1, it features as multi-standard radio for network convergence. Its d eployment in wireless systems will enable co-existence of heter ogeneous devices operating in wireless systems [2]. Limited spectrum availability and non-efficient use of existing RF resources necessitate a new communication paradigm to exploit wireless spectrum. In view of this, spectrum hole

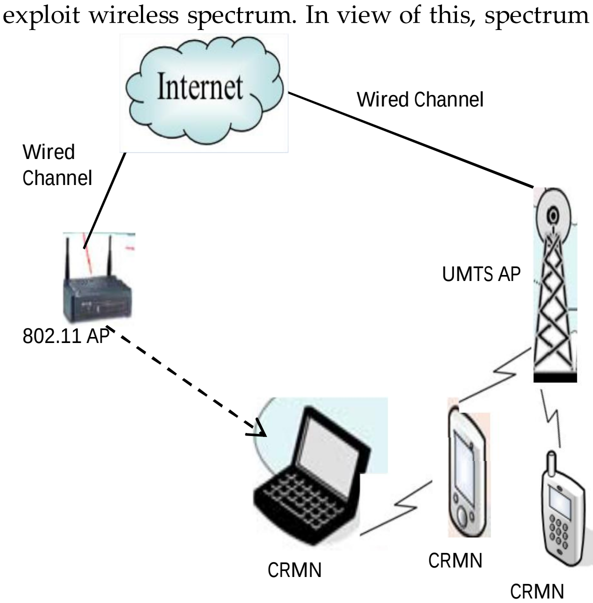

Fig.1 Cognitive Radio technology users

hole or white s pace detected by SUs within licensed spectrum band is used for CRN communications. Spectrum holes as temporarily unused sections of licensed spectrum are free of primary user activity and CR devices, which use unlicensed bands, need to have higher performance capability to manage required quality of service. Therefore, spectrum hole is a drive for the need to *collaborate sensing* required for efficient detection of PU signals on allocated bands.

[3] also asserts that CR techn ology supports dynamic spectrum access (DSA), offered as solution to address spectrum scarcity illusion created by increasing demand of new wireless applications and increasing users while [4] further explained how CRs boosts up spectrum availability and utilization significantly while bringing no harm to licensed users. They modifies wireless system operations to facilitate interoperability and mitigate interference while providing maximum throughput via efficient spectrum sharing schemes.

Technically, CRs as multi-radio user elements (MUEs) and characteristic mobile node shown in fig. 1, featuring various technologies and standards. CR technology modifies transmission parameters of mobile nodes, classifying users as licensed and unlicensed [5]. Licensed users are primary (PU) with allocated band of spectrum for exclusive use while unlicensed users are secondary (SU) with no allocated band of spectrum [1]. Major task of CR is detection of licensed PU tasks. When there are no assigned PU on licensed spectrum, holes are detected by SU and CR technology implements various strategies to utilize detected spectrum holes more efficiently than the other wireless systems.

Cognitive Radio (CR) senses operational electromagnetic environment autonomously and dynamically adjust operating parameters to mo dify system operation. This technique facilitates interoperability with lower standards, allowing access by secondary users. [6] in agreement with [4] described CR as transceiver that intel ligently detect co mmunication channels used while moving into unused channels avoiding occupied ones. With no license holder in a CRN as shown in fig. 2, all network entities have same right of spectrum access and multiple CRs are allowed to coexist communicating on same portion of spectrum while engaged in co-operative sensing.

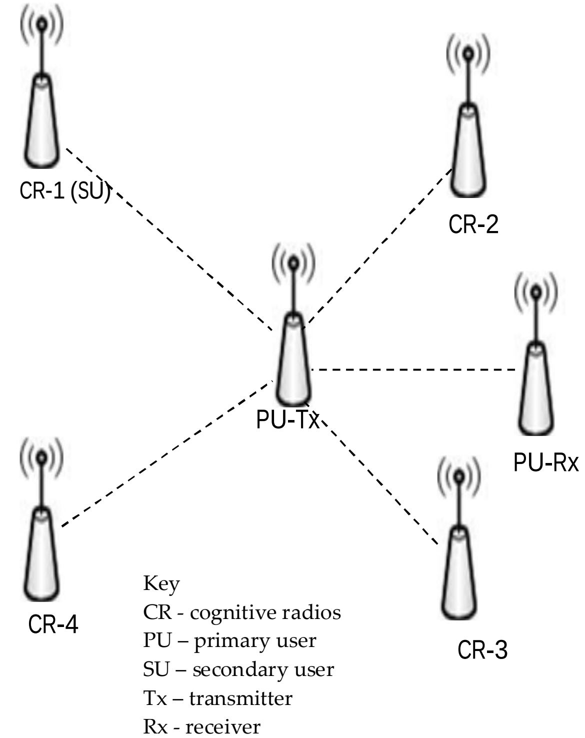

Fig. 2 Cognitive Radio Network with Multiple Radios

Opportunistic access into spectrum without interfering with PU's activity is a strategy used to increase spectrum availability. With collaborative sensing, subsequent use of detected 'holes' as 'idle band' is geared towards a major goal of resources optimization. Therefore, CRN is reconfigurable wireless systems that automatically vary its co mmunication variables with network and user demands.

Since main goal of spectrum sensing is to determine spectrum usage status of li censed user's activities. Collaborative sensing, achievable via co-operative sensing, is a form of distributed sensing by participating CRs. In view of CR features, this paper is geared towards specific objectives of:

(i) modeling of logical framework for sensing;
(ii) formulation of slotted rendezvous for SUs and
(iii) verification of fitness function of operating parameters.

2. REVIEW OF SPECTRUM SENSING TECHNIQUES

Spectrum management functionalities, which are in distributed co-ordination of CRN includes spectrum sensing, spectrum sharing, spectrum decision and spectrum mobility [7]. Three basic types of spectrum sensing techniques for detecting PU licensed spectrum band outlined in [1] include *co-operative, transmitter and interference-based spectrum sensing* techniques. Cooperative detection allows multiple CR work together to supply required information in detecting PU activities [8]. Spatial diversity intrinsic to multiuser network is exploited in distributed or centralized structure. Distributed approach enables CRs exchange spectrum observations among themselves while each develops a spectrum occupancy map based on signal information detected. This approach mitigates multipath fading and shadowing RF problems, which increase probability of PU detection. The scheme also help combat common hidden node problem peculiar to ad-hoc wireless networks [9].

Cognitive radio architecture shown in fig. 3 pre-supposes cross-layer optimization of resources and prevention of performance degradation to licensed users [9] and [10]. Associated with ordinary wireless MAC protocols, sensing error/delay make system suffer degradation because maximum cognitive capability and reconfigurability is prevented [11]. Controlled PHY layer channel sensing expedient for efficient decision and optimized joint MAC and NET function beneficial to multi-hops and other adaptation profitable for application layer objectives is provisioned in cognitive MAC shown in fig. 3 [9].

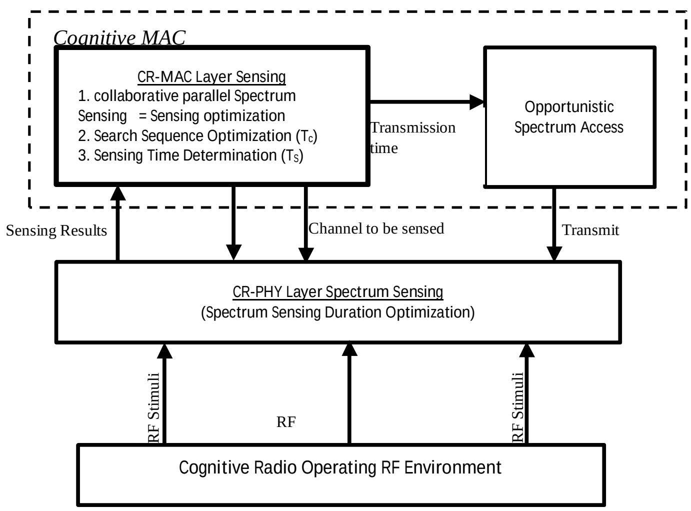

Fig. 3 CRN cross-layer optimized structure

Since signal-specific co-operative sensing approach requires prior knowledge of PU signal, matched filter detection technique is optimum for coherent detection using prior information of PUs to increase SNR. As PU signal information (modulation type, pulse shape, packet format and size etc.) is known at CR-PHY, optimal detector in stationary Gaussian noise is a matched filter that maximizes received SNR of transmitted signals. This approach minimize false detection even as radio frequency (RF) samples of participating SU is exploited in the collaboration.

3. FRAMEWORK FOR COLLABORATIVE SENSING

CR mobile node (CRMN) features enable SUs co-exist with each other while being able to select a good channel. Though, characterized with intra-SU co-operation with minimal competition collision challenge, super-layer of logical sub-channels of participating SUs is guided for accurate sensing and interference constraints. In CRNs, CR-PHY sensing duration is controlled as each SU detects available spectrum holes as opportunity locally. Therefore, CR-MAC sensing depends on sensing period and search order of CR-PHY and network layer sensing supports SU co-operation.

For simplicity, the channels are sensed using an estimation of channel occupancy probabilities ordered by *Latin square* shown in fig. 4 (appendix). To enable each CR maintain collision-free sensing, minimal false alarm is enabled by the modeled ordered sensing scheme provisioned on participating channels.

Signal-to-Noise Ratio threshold detection ensures channel/PHY-layer sensing, whereby adaptation of operating parameters (including modulation scheme) is used to detect PU signal on available channels. Two major threshold schemes - probability of detection (P_d) and probability of false alarm (P_f) were employed. These parameters were controlled to ensure minimized P_f and maximized P_d.

3.1 DSA sharing function

Collaborating spectrum sensing resulted to highly efficient cognition as CR-MAC addresses layer sensing issues. Also, protocol performance in CR layers does not inhibit scheduled sensing period utilized. This as an enhancement of optimized CR-MAC scheme is a basis for channels forming clusters of sub-channels. This clustered approach enable SUs cluster into groups and each SU contends with elements within same cluster. This arrangement of forming set of sub-logical channels enable CR technology minimizes detection errors.

To maximize P_d , con stant false alarm rate (CFAR) scheme is ensured while minimizing P_f guarantees a no n-interference probability whenever miss detection probability (P_m) is set to a minimum. With P_d maximized, the approach establishes an optimized scenario for constant detection rate (CDR) effectiveness.

3.2 Energy Detection Model

Generally, received signal y over CRN PHY layer is expressed as (1) where x is transmitted symbol and z additive noise sample at the recei ver with h being the channel loss between source and destination.

$$y = hx + z \text{ y} \qquad \ldots(1)$$

Using PU detection model, hypothesis test H_0 indicate only noise while H_1 indicate PU presence. With noise signal s(n) assumed stationary, an independent, identical distributed random process of zero mean additive white Gaussian Noise (AWGN) with power spectral density N_0 and v ariance $\sigma_n{}^2$ is measured by P_d and P_f to determine performance.

With P_d indicating PU existence and P_f no PU in reality, [3] and [9], PHY layer energy detection model for each SU's received signal is expressed as (2) for transmission between N CRMNs where $n = 1,\ldots, N$ is the observation interval for $x(n)$ signal received by each CR.

$$x(n) = \begin{cases} w(n) & H_0 \\ s(n) + w(n) & H_1 \end{cases} \qquad \ldots.(2)$$

With $s(n)$ PU transmitted signal and $w(n)$ AWGN anticipated over the link, spectrum hole detection within PHY layer sensing statistically define CR-MAC sensing parameters as (3)

$$P_d = \Pr(signal - \det ected \mid H_1)$$

$$P_f = \Pr(signal - \det ected \mid H_0) \qquad \ldots. (3)$$

Ideally, P_d is maximized to protect PU from interference while P_f is minimized to increase spectrum usage efficiency. [12] th eoretically obtained an optimal hypothesis testing as solution for detection performance measuring a pair of (P_d , P_f) because P_f also denote false algorithm of deciding PU presence in scanned band when actually it is absent.

Collaborative detection performance criteria measured by Neyman-Pearson likelihood ratio therefore uses the res ultant pair of P_d and P_f and each pair is associated with particular threshold γ tests of decision statistics given as

$$T > \gamma \text{ decide signal present};$$
$$T < \gamma \text{ decide signal absent}$$

P_d and P_f is therefore simultaneously evaluated as (4a) and (4b) respectively.

$$P_f = Q\left(\frac{\gamma}{\sqrt{\varepsilon\sigma_n{}^2}}\right) \qquad \ldots.(4a)$$

$$P_d = Q\left(\frac{\gamma - \varepsilon}{\sqrt{\varepsilon\sigma_n{}^2}}\right) \qquad \ldots.(4b)$$

With an unlimited number of samples in the collaboration by many SUs, scalability is offered in the CRN and energy detection techniques optimizes P_d and P_f simultaneously.

4. IMPLEMENTING SLOTTED RENDEZVOUS ALGORITHM FOR CRN

Major aim of intelligent and fair sharing of spectrum resource between PU and SUs is achievable using CR technology. As specific objective of this research, performance of the wireless system is enhanced by an implementation of controlled sensing for radio rendezvous processes. Channels sensed with highest probability as being idle (that is sensed first) is detected. With CR-1 and CR-2 sensing in same order in scenario (a) and (c), collaboration is achieved. As CR-1 senses channel 1,2,3,4,5 in s cenario (a), CR-2 in s tep 1 senses channel 3 first as channe l with highest probability of being idle. Therefore, CR-1 having detected PU presence in step 3 while CR-1 and CR-2 senses in same order in both scenario (a) and (c), a rendezvous of radio resources is established with detection probability accuracy. This is a proactive plan for fair sharing while combating changing environmental conditions.

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4.1 Analysis of slotted rendezvous scheme

In scenario (a) and (c), CR-1 and CR-2 chose the same sensing order but collision was avoided by CR-1 in (a) by finding channel 1 free in step 1 while CR-2 generate a false alarm in that step. CR-1 and CR-3 find channels 3 and 1 free in steps 4 and 5. In scenario (b), only CR-1 find channel 1 free in step 1 because the same sensing order was not used by CR-1 and CR-2. CR-2 find channel 2 free in step 4 while finding channels 1 and 4 CR-3 find channel 2 free in step 3.

Alternately, scenario (c) has both CR-1 and CR-2 find channel 4 busy in step 4 because of using same sensing order although this is resolved by CR-3 detecting non-existence of PU signal (H_0) in channel 4 (step 2) while CR-1 and CR-2 still find channel 5 busy. The same sensing order for two or more CRs is prevented to arrive at collision-free detection of spectrum holes. From the framework, entire frequency band (licensed) have its allocated channels occupied (busy) mostly at every step servicing either PU or SU.

This ability of two or more radios meeting to establish good link on same channel provide for required bootstrapped communication of the multi-channel systems. With this arrangement, SU sensing accuracy is not seriously affected as link maintains channel availability. Need of increased co-ordination between SU nodes desired for optimization of detected bands (as spectrum holes) are joined together logically as sub-channel for spectrum mobility by SUs.

While targeting to maximize P_d (that is, minimize P_f), controlled CFAR and CDR schemes dynamically provide slotted rendezvous, whereby all channels {1,2,…,N} are visited randomly (scenario (b) and then in prescribed order. Technically, slotted rendezvous is equally likely to happen on any of N channels as real-time sensing maximizes TTR as function of SNR of signal samples. This CR technology thereby, multiplicatively decreases probability of false detections.

From equation (4a), low SNR desirable for reduced P_f as normalized power detected as weak signal reveal PU busy while SU senses channel for spectrum holes. Also, static threshold schemes based on fixed noise variance defines CFAR and CDR as determinants for particular SNR values. Channel sensing algorithm (CSA) described in steps i-vii enables SU nodes obtain desired P_f and P_d even as process is iterated until entire channels are searched by all participating nodes.

i. for node n, obtain channel SNR estimate
ii. compute number of signal sample required for P_d and P_f
iii. set threshold based on 1 and 2 above
iv. compute test statistics and compare with set threshold (decide on PU presence or absence)
v. increment n
vi. find average SNR for all SU nodes within cluster on a channel
vii. make decision (allocate channel with highest probability of being idle to SU)

4.2 Evaluation of operating parameter

The constantly desired P_d offered by dynamic sensing order with number of samples varied for lower noise levels is a theoretical proof of coherent processing of turning low SNR into high SNR. Given enough samples, arbitrary weak signals are detected. Scenarios (a) and (c) demonstrate effective performance of collaborative sensing scheme equipped with slotted rendezvous algorithm. Sequential order subsequently followed by random enables environment parameters as SNR changes to reduce P_f, and in effect increases P_d.
Denoting SU event of "idle channel" as D_0 and other event of "busy channel" as D_1, probability of successful detection of available channel results to hypothesis H_0 for P_d and corresponding false alarm probability resulting to hypothesis H_1 for P_f. Mathematically, this is respectively expressed as (5a) and (5b).

$$\Pr(D_0 \mid H_0) = P_d, \quad \Pr(D_1 \mid H_0) = 1 - P_d \qquad \text{....(5a)}$$

$$\Pr(D_0 \mid H_1) = P_f, \quad \Pr(D_1 \mid H_1) = 1 - P_f \qquad \text{....(5b)}$$

Dynamic feature of slotted rendezvous in CRN reduce P_f. Increased P_d optimizes channel resources. Performance measurement metric for different values of P_d could also be evaluated for different SNRs and channel selection accuracy will be based on incumbent appearance of PUs during sensing. This has been provisioned by the controlled sensing scheme.

5. CONCLUSION

Collaborative sensing increases system throughput as time to rendezvous (TTR) increases with N. Transmission throughput, error rate and interference as performance objective has greater dependence on normalized power, which is signal strength. The improved CSS algorithm devised to track all changing environment condition is implemented in the computation of SNR (expression 4b) and hence CDR probability obtainable via the algorithm. This connote that minimum detectable signal level and sensing time is required to achieve desired P_d and P_f. Higher P_d implied reduced P_f. This scheme increased SU exploitation of unused spectrum adaptively in radio environment. Because PU activity is tracked efficiently by sequential sensing order of channels, the determinants varies with slotted change in sensing strategy from random to sequential demonstrated in the scenarios (fig. 4 - appendix).

Also, improvement offered by collaborating radios in sensing gives remarkable improvement in spectrum usage efficiency. This further guarantees *M* SUs co-operating to maximize sensing frame duration than individual nodes. Suggested algorithm also tracks all changing environment conditions and other inclusive parameters for constant and correct probability detection. Detection rates is not adversely affected in real-time sensing but the scheme benefits tremendously from the proactive plan of sensing even with changing noise variance conditions.

Reliability of cognition and reconfiguration processes of CR produces effective sensing and correction detection. Need for new DSA model where licensed users would enable SUs co-operate to provide for much more flexible spectrum sharing is evident by devised scheme and inclusive algorithm implemented. Therefore, spectrum scarcity problem is alleviated since the controlled energy detection scheme provisions for fair sharing and optimized resource usage.

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APPENDIX

CR-1 sensing order	1	…2…	3	…5…	…4…
CR-2 sensing order	1	…2…	3	5	…4…
CR-3 sensing order	…2…	….4…	…5…	3	1

(a) CR-2 generate false alarm to avoid collision with CR-1

CR-1 sensing order	1	2	…3…	4	…5…
CR-2 sensing order	…3…	4	2	5	1
CR-3 sensing order	5	1	4	2	…3…

(b) CR-1 find channel 1 free in step 1, CR-2 find 4 free in step 2

CR-1 sensing order	…2…	1	…3…	4	5
CR-2 sensing order	…2…	1	…3…	4	5
CR-3 sensing order	…3…	4	5	1	…2…

(c) CR-1 and 2 collide in step 2 (using same sensing order)

Key:

Occupied by PU	Two or more CRs find channel free	Only one CR find channel free	False alarm	Busy status
……..				

Fig.4 Three CRs sensing five channels within same sensing duration