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NECESSITY OF COOPERATIVE COGNITIVE RADIO NETWORKS IN WSN – A STUDY

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Abstract

Cognitive Radio Networks is an emerging technology for improving the utilisation of frequency spectrum. The goal of this work includes gathering recent research contributions and the advances of cooperative cognitive radio networks.

Future wireless network performance can be improved by using the combination of cognitive radio with cooperative communication with multiple relays.

The cooperative communication system, with the same total power and bandwidth of legacy wireless communication systems, can increase the data rate of the future wireless communication system. Efficient resource allocation in Cooperative Cognitive Radio Network (CCRN) is essential in order to meet the challenges of future wireless networks.

Cognitive Radio (CR) devices are equipped to detect the unused spectrum and providing it for the unlicensed user. A survey of resource allocation in CCRN is presented and the taxonomy of objectives and protocols used in the literature are discussed for resource allocation in cooperative CRN.

Keywords:

Cognitive radio networks, Co-operative communication, Spectrum Sensing, WSN.

Introduction: Cognitive radio networks are used for several applications such as traffic, industrial, scientific, military for successful wireless communication. The general architecture of CRN is shown in the figure 1. The CRN consists of Base Station (BS), Primary User (PU) and Secondary User (SU). Cognitive techniques can be used for opportunistic spectrum access in cognitive radio wireless sensor network.

To utilise the unused licensed spectrum (called as white spaces) cognitive radio is placed in the module. In cognitive technique, there is the possibility of channel aggregation and use of multiple concurrent channels.

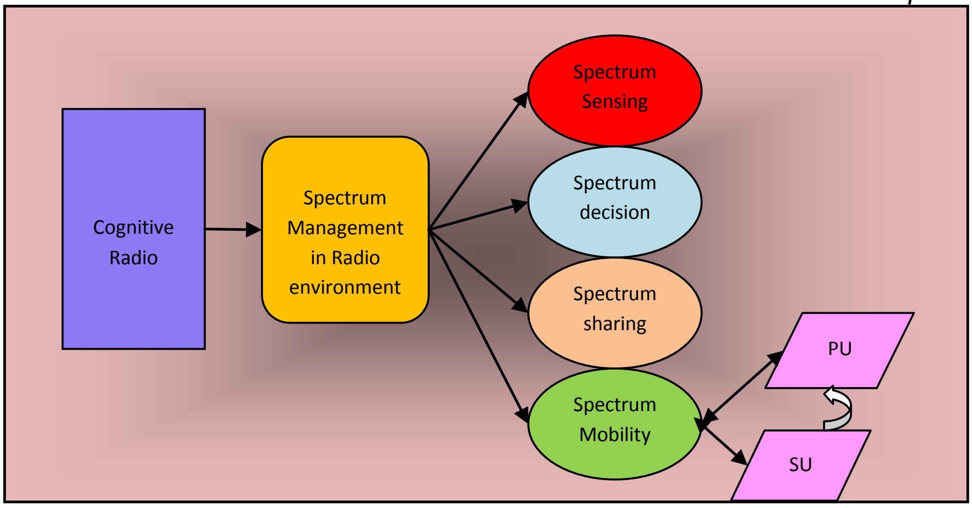

Figure 1. Basic Architecture for Cognitive Radio Networks.

The spectrum becomes more congested and the need for data rate increased because of rapid development in communication applications. Generally Radio spectrum is restricted to limited resource and the service is allocated in the fixed spectrum assignment manner. In the dynamic environment some frequencies are heavily used and other frequency bands are weakly used according to the user availability. Nowadays more number of devices utilizing the unlicensed spectrum is growing, which indicates the increase in spectrum demand.

Spectrum scarcity is a major issue faced by wireless networks. CR is continuously used to sense the available unused frequency band which already been allotted to the primary or licensed users. Radio resource allocation schemes in CRSNs are classified into three major categories, i.e., centralized, distributed and cluster-based. The schemes are further divided into several classes on the basis of performance optimization criteria that include energy efficiency, throughput maximization, QoS assurance, interference avoidance, fairness and priority consideration, and hand-off reduction. Research in utilization and management of the radio frequency (RF) spectrum in both licensed and unlicensed bands is still in its infancy, but it is progressing rapidly by using the recently emerged spectrum access techniques.

Importance of CR in WSN

- CR has the ability to determine the unused or unutilised spectrum by the licensed user.
- By integrating cognitive radio with wireless sensors, many challenges and issues are faced in current WSNs.
- CR allows unlicensed users to access manifold licensed channel bands opportunistically.
- The operating parameters on CR can be able to change in order to adapt the channel conditions.
- Continuously monitors its own performance to determine the RF environment, channel condition, link performance to deliver the quality of service subject to appropriate user requirements.

This characteristic of CR gives potential advantages to WSNs by increasing the communication reliability.

Cognitive Radio: The main intention of the cognitive radio is to sense the available or vacant spectrum and to choose the best one. The cognitive radio alters its transmission parameters according to the environmental change in which it operates. The vacant spectrum is called as the spectrum holes or white space. The white space spectrum can be used by the secondary user or unlicensed user when it is sensed as free by the cognitive. The spectrum can be shared among the SU only if the spectrum is not used by the licensed user. The secondary users need to detect the presence of vacate spectrum in the neighbouring network.

I. Spectrum Sensing

Spectrum sensing techniques can be categorized into different types. There are several classical methods for this purpose such as Non cooperative sensing, Cooperative sensing and Interference based sensing example Energy Detector (ED), Matched Filter (MF) and Cyclostationary Feature Detection (CFD),

1. Non co-operative Sensing techniques

Sensing techniques includes co-operative sensing (primary receiver detection) and non cooperative sensing (primary transmitter detection). The primary transmitter detection is a spectrum sensing technique used to identify the weaker signal and the different non-cooperative sensing techniques are ED, MF and CFD.

a. Energy detection

By analysing the energy of the received signal, the presence of the primary user in the environment can be detected. The threshold value is determined by the channel condition and if the energy of the signal is greater than the threshold then PU is present else PU is absent.

b. Matched filter detection

The received signals are compared with the primarily used signals. Prior knowledge of the signal such as modulation type, packet format, pulse shape are compared with the current received signal parameters, if the matched filter detection seems incorrect then it performance poorly. Acquires very less time to achieve high processing gain is the main advantage of Matched filter detection.

c. Cyclostationary feature detection

The signal types can be easily differentiated here by using the cyclostationary features such as, mean, autocorrelation and periodicity in signal. This cyclostationary feature has the ability to differentiate noise from the PU. If the autocorrelation of the received signal is “0” then it indicates the absence of PU i.e. there is only noise.

2. Co-operative Based Sensing

The co-operative spectrum sensing technique can be used to face some issues like noise uncertainty, fading and shadowing. Several SU were combined and working together to find an optimal unused spectrum. The hidden primary user is detected using this technique

3. Interference Based Sensing

Interference based detection technique to sense unoccupied spectrum in CR. Proper allocation of power avoids the interference between the PU and the SU. Based on the amount of interference at the PU the CR node power can be calculated.

Interference Temperature Model (ITM): The interference temperature model is the measure of the power and bandwidth occupied by interference. The idea is that by taking a single measurement, a cognitive radio can completely characterize both interference and noise with a single number. However, interference is typically more deterministic and independent of bandwidth over noise. For a given geographic area, an interference temperature limit, TL would be established. This value would be a maximum amount of tolerable interference for a given frequency band in a particular location. Any unlicensed transmitter utilizing this band must guarantee that their transmissions added to the existing interference must not exceed the interference temperature limit at a licensed receiver.

Availability of PU:

Sensor node consists of RF amplifier, a bank of local oscillator. The local oscillator is tuned such that the desired incoming LO leakage signal will fall in to the fixed IF band. Once the Intermediate Frequency (IF) filtering was done the signal is sent to the detector circuit. The detector is implemented in each node for channel supervising purpose. The desired down-converted LO leakage signal in addition to additive Gaussian noise is given as the input to the detector. The PU availability can be determined by using the formula,

$$P(A_{k,i}) = (1 - \frac{1}{m})^{k} \qquad (1)$$

II. Spectrum Decision

The CR network should select the best spectrum out of the sensed spectrum in order to meet the QoS. Spectrum decision includes spectrum characterization, spectrum selection and reconfiguration. The spectrums are characterised based on the sensed information then the spectrum which meets the required QoS is selected among the spectrum.

- Characterisation of spectrum

Interference

Path loss

Link delay

The spectrum characteristics changes over the time so it should be reconfigured with time. According to the applications reconfiguration and spectrum decisions are considered.

III. Spectrum Sharing

Based on the usage the spectrum is shared or distributed among the cognitive radio users without causing any interference to the PU. In Licensed spectrum sharing the PU has higher priority to access the channel. SU can access the channel only in the absence of PU. In unlicensed spectrum sharing, all users in the network have same priority. SU can access only the unlicensed spectrum. If the spectrum is free then the user can access the spectrum. If the interference measurements of each node are shared among other nodes then it is said to be cooperative spectrum sharing. In non cooperative spectrum sharing, the nodes never exchange their interference measurements to other nodes.

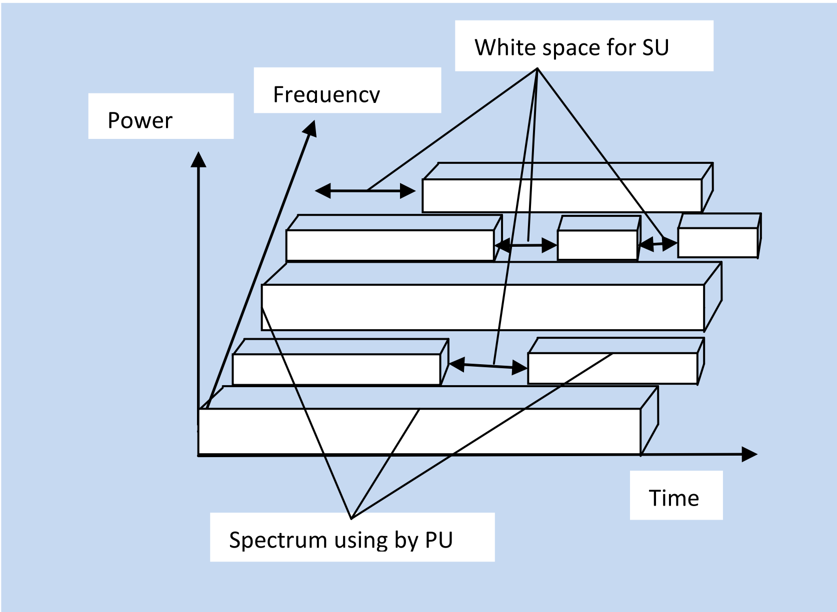

Figure 2. Spectrum Usage by PU and SU.

IV. Spectrum Mobility

Whenever the PU or licensed user arrives at a specific spectrum which is currently use by the SU, then the SU should vacate the spectrum. Spectrum handoff is the main function of spectrum mobility. In order to provide seamless communication the CR user moves to vacant spectrum which can maintain the QoS requirements. Spectrum mobility occurs due to link failure, PU reappearance, and CR user mobility.

- Adaptive spectrum handoff strategy

SU should apply the most suitable handoff strategy based on the PU traffic pattern. SU must adapt the handoff strategy accordingly whenever the traffic pattern for PU changes.

- Switching delay

While moving from one spectrum to another, the switching time should be minimized. Otherwise the data transmission discontinued.

Cooperative Cognitive Radio Networks (CCRN):

To utilize the available spectrum in an efficient manner the cognitive radio system is proposed. Cooperative cognitive radio networks (CCRN) [2] are accounted to serve various purposes such as reliable spectrum sensing, interference reduction during PU transmission and outage minimization problem, improving spectrum efficiency. However due to the involvement of several SU nodes, the up gradation in spectrum efficiency is achieved at the greater expense of energy consumption, which in turn leads to reduction in energy efficiency. Hence, improvement in spectrum efficiency and energy efficiency simultaneously becomes a paramount design issue in CCRN. The spectrum efficiency and energy efficiency trade-off issue is addressed as energy efficiency maximization for a minimum spectrum efficiency requirement, analyzing the amount of energy consumption to maximize spectrum efficiency or as joint maximization of spectrum efficiency and energy efficiency.

To improve spectrum efficiency (SE) cooperative spectrum sharing in CCRN is explored in the different forms which includes a successive interference cancellation to assist in the transmission of both PU and SU, cooperative relaying in a multiple-antenna-based cognitive radio system, a novel framework in to decide whether SU nodes participate in cooperation or not, etc.

Spectrum Sharing On Interference Channels with a Cognitive Relay:

Li et al, 2015 had proposed a scheme Spectrum called Sharing System on Interference Channel with a cognitive relay (IFC-CR). Here both the licensed and unlicensed users are forwarding their messages to the respective destination nodes. After first transmission phase the cognitive radio uses successive interference cancellation scheme to decode the primary and secondary messages. Power allocation is performed by cognitive radio and in the second transmission phase, the decoded primary and secondary messages are forwarded through linear weighted combination.

Secondary spectrum sharing is achieved by proper power allocation and at the same time better performance is achieved for the primary user than the case without spectrum sharing. In the second phase, CR broadcasts the decode message called a composite message. CR is employed with DF relay protocol to decode the messages. Also at the primary receiver Maximal-Ratio Combining (MRC) is employed to decode the desired message over two transmissions while considering the secondary input as noise.

Outage probability of primary and secondary user with the proper power allocation are calculated and shown below,

$$O(\mathrm{p}) = 1 - \frac{\delta e^{-\delta}}{\delta + \alpha 1}, \alpha \lhd \frac{R'_{pt}}{R'_{pt} + 1}$$

The outage probability of secondary user is shown,

$$\mathrm{O(s)} = \mathrm{P_{sd}}^{1}\,\mathrm{P_{sd}}^{2} + (1 - \mathrm{P_{sd}}^{1})\mathrm{P_{sd}}^{3}$$

However, the spectrum sharing on interference channels is done only based on power allocation, the delay and computational overheads are high due to the analysis of spectrum usage i primary and secondary users.

Multiple-Antenna CR System with Cooperative Decode-and-Forward Relaying:

A two-phase hierarchical spectrum sharing protocol based on cooperative decode and forward relay transmission was proposed. Here outage probability is estimated for both the licensed and the unlicensed user, so that the performance is analysed. The closed form expressions are derived for outage probability in order to quantify the performance of primary and secondary users. The critical region for secondary transmitter has been calculated to determine the maximum distance within which the secondary transmitter can access the spectrum. The outage probability for primary system and secondary system is analysed by using transmission phase. In transmission phase1 the primary transmitter broadcasts the signal S_p and the signal is received by the primary receiver and it is denoted as R_{pr}. The secondary transmitter consists of several antennas and the channel between all the links are modelled using Rayleigh flat fading with corresponding channel coefficients. In transmission phase 2, if S_p is decoded successfully, secondary transmitter will transmit S_p along with its own data. The outage probability expressions for the selected secondary transmitter antenna can be derived by the expression used for calculating the spectrum access region of secondary transmitter.

On optimal sensing time and power allocation for energy efficient cooperative cognitive radio networks:

Generally secondary users have limited power resources; hence, they have to take intelligent decisions on whether to cooperate with the PU's or not and at which power level, in order to maximize their throughput [5]. Cooperation policies are required as the solution of a multiple secondary transmitter (ST) and receiver (SR) pairs sharing transmission over a spectrum of primary network. The primary network consists of single PU transmitter and receiver pair and secondary network consists of ‘n’ number of secondary transmitter and receiver pairs. All the secondary transmitter nodes act as cooperative relay to assist primary transmission. The links between primary and secondary transmitters and the link between secondary transmitters and primary receiver are designed using Rayleigh flat fading channels. Cooperative spectrum sharing is performed to detect the empty spectrum in the primary transmission. The presence and absence of the primary user is indicated using the noise in the receiver signal. The secondary user detects the idleness of primary user using Time Division Multiple Access (TDMA). The secondary users transmission divided into k equal parts with the time duration is $\frac{T-T_K}{K}$.

The average power consumption of the primary and the secondary transmitter can be calculated as,

$$Pi_{av} = \tau s(PS/T) + (P(H0)(1-Pf) + P(H1)(1-Pd))\ \frac{T-T_K}{K} P_T i + PC\ \frac{T-T_K}{K}.$$

Significant research remains to be done to realize commercially practical cognitive radio for energy consumption based on power factor.

Energy efficient relay selection and power allocation for CCRN:

Opportunistic data transmission had been enhanced through efficient power utilization through the energy efficiency in CCRN. In this method the spectrum sharing cognitive radio network had proposed by Chatterjee et al, 2016. The radio spectrum owned by the primary system leases its unused spectrum to the secondary system for a fraction of time i.e. Secondary users served as relays to aid the transmission of the primary traffic. Joint optimisation of relay selection and power allocation are formulated based on cooperative spectrum leasing protocol under QoS requirements. The optimal relay selection, power and sharing time allocation are readily obtained by employing a greedy spectrum sharing (GSS) algorithm. The interference can be avoided between the primary and secondary systems. Mutual collisions can be eliminated by exchanging the information transmitted, when the primary network collaborates with the secondary network thus avoiding interference. The energy efficiency can be improved by applying GSS algorithm. The cooperative and optimal relay sets are selected using GSS the weighted sum energy efficiency of all secondary system is maximised.

Spectrum Leasing and Cooperative Resource Allocation in Cognitive OFDMA Networks:

Cooperative orthogonal frequency division multiple access (OFDMA)-based CRN was proposed by Tao et al, 2013. This scheme is used to determine the cooperation strategies among the primary and secondary system. By determining the cooperation strategies the sum-rate of SUs gets maximised without affecting the QoS parameters of primary system. The primary system leases some of its sub-channels to the secondary system for a tiny proportion of time in exchange for the SUs assisting the transmission of primary users (PUs) as relays. A joint optimization problem of PU transmission mode selection, SU (or relay) selection, subcarrier assignment, time allocation and power control are formulated for cooperative communication of CR user and PU. OFDMA-based systems can flexibly integrate dynamic resource allocations in CRNs. The determination of cooperation strategy between one PU and one SU was done by the application parallel per-subcarrier sub-problem which is composed from mixed integer programming problem. On each leased subcarrier, the SU exclusively act as a relay or transmit for itself.

The complexity of determining primary and secondary user on each sub-carrier

$$\text{Direct transmission} = O\,(2K_P + K_S)$$

$$\text{One way relaying} = O\,(2K_P.K_S)$$

$$\text{Two way relaying} = O\,(K_P.K_S)$$

Therefore, the total complexity of solving all N per-subcarrier problems is calculated using the following equation,

$$\text{Total complexity} = O\,(N\,(2KP + KS + 3KP\;KS))$$

The time slot allocation between a PU and a SU on a cooperated subcarrier is binary and this framework greatly improves the total throughput performance of the secondary system by about 60%, comparing to the non cooperative scheme.

Optimal primary-secondary user cooperation policies in cognitive radio networks:

Optimal primary-secondary user cooperation policies are proposed by N. Chatzidiamantis et al, 2015. Secondary users cooperate with the primary user so that the success probability of PU transmissions are improved also SUs obtain more transmission opportunities. However secondary user has limited power resource so that they have to take intelligent decisions whether to cooperate or not based on power level. Markov decision problem with infinite state space algorithm is produced. SU activation in every time slot is done in randomised decision based only on spectrum sensing. Each SU keeps track of a local metric and determines local convergence with respect to it, within a pre-specified accuracy. The number of iterations required for convergence is given with accuracy and there is a remarkable reduction in the total number of iterations required for convergence compared with the arbitrary initialization. The proposition policies in this process are required to determine the PU channels state whether it is busy or empty. The primary user channel is idle but it is sensed as busy to SU which tries to accommodate the primary user's spectrum, then this SU will be losing the opportunity to transmit its own data. However the successful transmission of SU packet is affected due to this false information and the probability is determined as,

$$P_{ST}(SU) = q_e\ (1 - \rho F)$$

However, uncoordinated interaction of numerous PUs and SUs causes interference and the computational complexity of the centralised solution gets increased.

Cooperative Spectrum Sensing in Heterogeneous CRN:

Cooperative Spectrum Sensing in Heterogeneous Cognitive Radio Network has been discussed by Yang et al, 2016. In Heterogeneous Cognitive Radio Network each SU is equipped with different numbers of receiving antennas and dissimilar signal processing capabilities. Therefore, sensing reliability of different SU is taken into account and the optimal Normalized Energy Detection Based Cooperative Sensing (NED-CS) scheme was proposed. This approach is based on the principle of log-likelihood ratio test (LRT). The LRT takes into account the reporting errors at fusion centre (FC) which can receive erroneous result from SU due to channel fading and quantization error. LRT based NED-CS scheme is the linear combination of the modified local test detection statistics of secondary user. The performance of LRT based NED-CS is analysed using Equal Gain Combination (EGC) and maximum normalised energy detector method. For each receive SNR of SU, the probability density function $P_{\Upsilon k}$ is derived and obtained closed form approximate expressions as shown below,

$$P_{\gamma k}(\gamma \mathrm{k}) = \frac{(\gamma \mathrm{k}/M_k)^{-M_K}}{(M_k - 1)!} \gamma \mathrm{k}^{Mk-1} e^{\frac{-\gamma k}{\gamma k} Mk}$$

This scheme possesses 42% increase in optimal energy efficiency for 10dbW increase in SU power budget compared to the NED-CS scheme. Limitations: Security, regulatory concerns and fear of undesirable adaptations are the major drawbacks in the cooperative spectrum in heterogeneous cognitive radio network.

Resource Exchange in Smart Grid Connected CCRN:

A New radio resource exchange scheme for a smart grid connected cognitive radio system had proposed by Huang et al, 2016. A time slotted cognitive radio network with primary base station and the secondary base station is considered. Both base stations are equipped with independent energy harvester. Here the independently harvested energy can be stored in the smart grid in the form of on-grid credit. The SU will gain spectrum utilisation by either forwarding primary data or transferring energy credit directly to the primary system. The corresponding energy forwarding process from SBS to PBS is given as follows,

$$\delta = \begin{cases} \delta', \delta' \prec P_2^{on} \\ \{P_2^{on} + (\delta' - P_2^{on})^{\phi} \end{cases}$$

In particular, to maximize the energy saving while meeting the throughput requirement, the utilities of both users are optimized by jointly designing the sub-channel assignment scheme with power control. A derived optimal power is allocated for both primary and secondary users of each sub-channel. For a downlink OFDM system, the smart grid connected primary base station (BS) and secondary system are independently equipped with green energy harvesters. The secondary BS will gain spectrum usage by forwarding primary data or transfer its saved on-grid energy credit to the primary BS.

Conclusion:

The fundamental concepts of cognitive radio with cooperative communication, its functions and issues are presented. Spectrum is a primary resource for wireless networks through which communication takes place. CR is the best mechanism to sense the spectrum in efficient manner. Based on the environment CR adapts their transmission parameters. So, it solves the spectrum scarcity problem in wireless communication and also it increases the spectrum utilization.

The main part of using cognitive radio is to detect the available spectrum and to choose the best one among them for communication. The performance of the network can be enhanced by selecting the spectrum with more precision. To provide additional bandwidth, sufficient spectrum allocation to PU and SU with less channel interference, reliable broadband communications and flexibility for rapid growing data applications cognitive radio technology can be further developed in future.

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