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ADAPTIVE SENSING RANGE FOR CO-OPERATIVE SENSING COGNITIVE RADIO.

[1]AARTI MANDAL, [2]A. KARTHIKEYAN, [3]T.SHANKAR, [4]V.SRIVIDHYA

[1]M.TECH II YEAR Student, School of Electronics Engineering (SENSE), VIT University, Vellore.
[2,3]Asst. Prof.(Sr.), School of Electronics Engineering (SENSE),VIT University, Vellore.
[4]Assistant Professor, Kingston Engineering College Anna University Chennai,.
Email: [1]mandal_aarti@yahoo.com ,[2]akarthikeyan@vit.ac.in, [3]tshankar@vit.ac.in
[4]srividhya@kingston.ac.in,

ABSTRACT

Cognitive radio is emerging as an effective solution against the spectrum scarcity issue. The main processes which make up the cognitive radio working are the spectrum sensing, learning and adapting procedures. Co-operative sensing is a method in which the nodes share the spectrum sensed data. In ad-hoc network the decentralized nature makes it quite difficult to gather sensing data with constraints like energy consumption, shadowing, hidden terminal and fading effect. In cognitive radio ad-hoc network these effects creates issues in spectrum allocation and management. In this paper, the hidden terminal issue is considered with the solution of adaptive sensing range in a static network. The nodes in the ad-hoc network have sensing and transmitting ranges. The sensing helps to gain knowledge about the channels which are occupied by overhearing the RTS/CTS or ACK transmission or reception by the nearby nodes. The sensing range of a node is always greater than the transmitting range of a terminal. The sensing range if varied as per the transmission to the receiver then hidden node issue can be dealt to a great level. With the help Cognitive radio Network Simulator (CR-NS) adaptive sensing is simulated for an ad-hoc network and also its effect on throughput, packet loss, normalized routing load, end-to-end packet delay is also compared with respected to a fixed sensing environment.

Keywords: *Cognitive Radio, Hidden Node, Co-Operative Sensing, Cognitive Radio Network Simulator (CR-NS).*

1. INTRODUCTION

Present day telecommunication scenario is such that the spectrum resource is proving to be insufficient and thereby effective method for higher utilization of available resources needs to be developed. Cognitive radio is theoretically proving to emerge as a good solution. The idea of cognitive radio was first given by J. Mitola in 2002[1]. The fundamental task of a cognitive radio (CR) is to locate a free channel in the CR network and adapt to its characteristics for its usage. In this task a major step is spectrum sensing. A cognitive radio network is a secondary network over a primary network.

Later to sensing process comes the learning and adapting process. The learning and adapting process include genetic algorithm (GA), neural network (NN), Hidden Markov Model (HMM) method and Fuzzy logic method.

Spectrum sensing in cognitive radio network:[2]

Spectrum sensing is a method by which the radio locates the *white spaces* (free spectrum slots) by avoiding any interference to the primary user (PU) and the other secondary user (SU) in the network. An individual node can perform spectrum sensing by various sensing methods as mentioned below:

1. ***Energy detection:*** the secondary user (SU) maintains a threshold over which it decides the presence of the primary user (PU) in a channel.
2. ***Cyclostationary method:*** each of the secondary user is assigned a cycle frequency over which it transmit. A signal is said to be cyclostationary if the auto-correlation and mean of the signal is periodic in nature.
3. ***Multi-taper spectrum estimation:*** avoid the spectral leakage and issues in periodogram. In this method, the small finite signal is passed through heaps of band-pass filters or windows. Each window calculates the periodogram of the whole finite signal independent and orthogonal to each other.

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Other methods are Hough's transform, Eigen value method, time-frequency method etc. however, in a network if the nodes instead of performing individual processes co-operate to share the sensed data among themselves will reduce the burden on the nodes and help in efficient performance.

Problems faced by nodes in the practical environment:

Hidden node problem:

Consider three nodes, node A,B and C as shown in figure1.

Node a	present
Node c	present

Node b	present
Node a	*present*

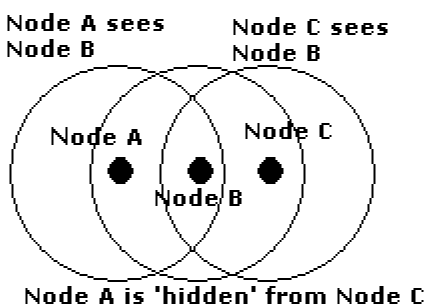

Figure 1: Hidden Node Problem

The node A can sense the presence of node B as it lies within the range of A. Similarly, node B can sense node C and vice-versa. However, node C cannot sense node A as it lies outside its range. Thereby, node A and node C are said to be hidden from each other. It can happen that node A and node C might send data simultaneously to node B leading to collision and loss of packets and also multiple re-transmissions from both ends to gain access to the channel, thus leading to inefficient network. In cognitive radio, the hidden node problem can occur when a SU is in the range of the primary receiver but absent in the range of the primary transmitter. Thus, when SU and primary transmitter transmit data to primary receiver, collision will occur.

Fading and Shadowing effect:[3]

Shadowing is caused when a node lies in the shadow of a big obstacle and becomes undetectable by the other nodes. In some situation the signal level i.e. the power level of the signal gets reduced drastically thus making it undetectable.

Shadowing effect extend for 10's to 1000's of wavelengths and increases for outdoor environment, thus it is expected to be a major factor for limiting sensing operations.

Methods to avoid shadowing effect includes technique to detect users with low SNR (i.e. -20dB 0r lower) [3], sensing of nodes even when a receiver is in shadow. However, these methods have disadvantages of long observation time for spectral occupancy. Other method which is gaining attention is the use of collaborative sensing. [4]

The method wherein nodes share the sensed data is called as co-operative sensing.

2. CO-OPERATIVE SENSING[5]

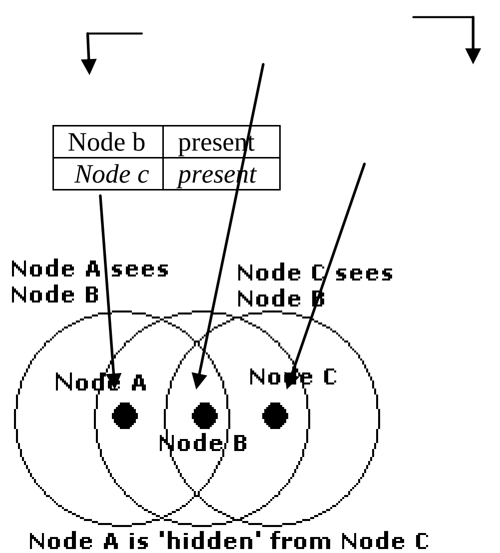

Figure 2: Co-Operative Sensing

In co-operative sensing the node A and node C came to know about each other's existence because of the sharing of information from node B. The sensing is performed first individually and then sharing takes place. However, if a node C would have adaptive sensing range then C would have detected the presence of A and also

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nodes ahead it if the physical properties like the power level permits it to do so.

The nodes taking part in co-operative sensing has different ranges namely, *transmitting/ receiving range* and *carrier sensing range*. The transmitting/ receiving range is the range upto which the nodes can transmit/receive data to other node. The carrier sensing range is the range upto which a node can detect the presence of another node. The sensing range can help in avoiding the interference from other users. It is always kept larger than transmitting range.

Advantages in co-operative sensing method is as follows:

1. *Hidden node problem is reduced as compared to individual sensing :* Individual spectrum sensing has higher chances of hidden node problem due to non-cooperative nature and range limitation. This effect is thus reduced to some extent in co-operative sensing as the nodes will have knowledge of the nodes present in their neighbor's neighbor which mainly remain hidden in other case.

2. *Increase in agility and accuracy:* the cooperation among the nodes provide more accurate picture of the network to the nodes and also improves the channel move decision thereby, increasing the agility. The improved accuracy also improves the reliability over the network.

3. *Reduced false alarms:* False alarms are caused in cognitive network when a SU makes a wrong decision about channel occupancy by the PU or other SU. Since this case is less likely in co-operatively sensed network, false alarms are reduced.

However, in some situation when a receiving node is close to the transmitting node, to avoid interference from other nodes the sensing range need not be of larger radius. This can also help the energy conserved to be utilized to increase the carrier sensing range when a receiving node is at far distance. This paper works towards studying the throughput, packet loss between nodes performing adaptive sensing range to combat hidden node problem using IEEE 802.11 MAC in a cognitive radio ad-hoc network. The simulation is performed in NS-2.31 (CR-NS) environment.

3. ADAPTIVE SENSING RANGE METHOD

Consider a large scale path loss model with the assumption that all the nodes have the same transmission power and other radio parameters. The assumption is made to simplify the calculation. The received power at distance d is given by:

$$Pr = Gt\ Gr\ Pt\ \frac{ht^2\ hr^2}{d^{\propto}}$$

where Pt is the transmitted power, ht and hr are the heights of the transmitter and receiver antennas respectively, Gt and Gr are the antenna gains, d is the distance between the transmitter and the receiver. α is the path loss exponent which reflects how fast the signal attenuates. (e.g., 4 in the two-ray ground reflection model and 2 in a free space model).

If Pr and Pi denotes the power received at the receiver and power received at the interfering node which are at a distance d and r respectively from the transmitter, then the signal to the interference ratio, neglecting the thermal noise, is given by[6],

$$SIR = \frac{Pr}{Pt} = \frac{Gt\ Gr\ Pt\ \frac{ht^2\ hr^2}{d^{\propto}}}{Gt\ Gr\ Pt\ \frac{ht^2\ hr^2}{r^{\propto}}} = \left(\frac{r}{d}\right)^{\propto}$$

For the correct reception, SIR > = S_0
which means for the interfering node must be at least
$\sqrt[\propto]{S_0} \times d$ meters from the receiver. Interference range Ri is given by[4],

$$Ri = \sqrt[\propto]{So} \times d$$

The transmitting range(Rt) and sensing range (Rs) is given by,

$$Rt = \bar{d}\left(\frac{P_{rx}}{Pr}\right)^{\frac{1}{\propto}}$$

where Prx is the reference signal strength as measured at the distance d
Pr is the reception power threshold.

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$$Rs = \bar{d}\left(\frac{P_{rx}}{Pc}\right)^{\frac{1}{\propto}}$$

where Pc denotes the carrier sensing threshold.

The sensing range of the SU transmitter must be upto the transmitter for a hidden receiver node which can be a PU or other SU. Thus, the minimum sensing range is[6],

$$Rs = \bar{d}\left(\frac{P_{rx}}{Pc}\right)^{\frac{1}{\propto}} = Ri + Rt = (1 + \sqrt[\propto]{So}) \times Rt$$

The neighboring nodes can correlated their location r_i from the hidden node based on the received power of the request packet send,

$$r_i = \sqrt[\propto]{Gt\ Gr\ ht^2 hr^2 \frac{Pt}{Pr}} = k \times \sqrt[\propto]{\frac{1}{Pr}}$$

Where, k= $\sqrt[\propto]{Gt\ Grht^2hr^2\ Pt}$ is constant.

Thus the cooperative sensing range (CPSR) is given by[7],

$$CPSR = Rs - r_i = \left[(1 + \sqrt[\propto]{So}) \times Rt\right] - \left[k \times \sqrt[\propto]{\frac{1}{Pr}}\right]$$

4. SIMULATION ENVIRONMENT AND CALCULATION

For the verification of the theory NS-2.31[8,9] is used as the simulation tool. NS-2.31 has features available for implementing cognitive radio scenario with the Cognitive Radio Network Simulator (CRNS) freely available as an open source. [10]

The CRNS performs energy detection method and shares the data with the neighboring nodes.

The network setup considered for verification is as follows.

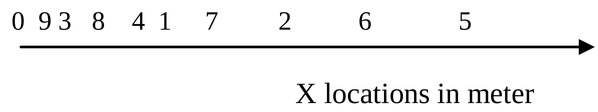

Figure 3: Node Arrangement

The parameter setup for the network are:

Parameter	Value
Channel	Wireless
Propagation model	Shadowing
Physical layer	Wireless
Antenna type	Omni-directional
Routing protocol	AODV
Queue type	Priority queue
Maximum number of packet in queue	50
MAC layer type	802.11
Number of nodes	10
Simulation time	50

Table 1: Parameter set in NS-2.31 with CR-NS

Two situations are considered for comparison: first with fixed sensing range of 550m i.e. threshold of 9.21756e-11 and the other with adaptive sensing range. Also a small amount of mobility was set for the nodes.
The nodes were setup with:

Table 2: Parameter Set For Each Node

Parameter	Value
Receiver threshold power	1.7845e-10
Bandwidth	512Kb
Transmitted signal power	0.2818 W
Frequency	2.4e9
Loss exponent	1
Capture threshold	10

.

TCP traffic pattern was: node 5 to node 6, node 2, node 7, node 1, and node 4.Later, node 6 to node 7.

Calculation of sensing range for node 5 for transfer of TCP packet to node 6:

Pt = 0.2818 W default for NS-2.31
Gt = Gr = 1 default for NS-2.31
ht = hr = 1.5m default for NS-2.31
d = 300 m calculated

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Thus, $Pr = \frac{(0.2818 \times 1 \times 1 \times 1.5^2 \times 1.5^2)}{(8.1 \times 10^9)} = 176.125 \times 10^{-12}$

$$k = \sqrt[4]{(1 \times 1 \times 1.5^2 \times 1.5^2 \times 0.2818} = 1.093$$

$$CPSR = \left(\left(1 + \sqrt[4]{10}\right) \times\ 250\right) - \left(1.093 \times \sqrt[4]{\frac{1}{176.125 \times 10^{-12}}}\right) = 394.57 \text{ m}$$

Parameters considered for verification within the network are:

Throughput: is average rate of successful message delivery over the communication channel.

$$throughput = \left(\frac{no.of\ packets\ send\ from\ a\ node\ to\ other\ node\ with\ same\ sequence\ number}{total\ simulation\ time}\right)$$

Packet loss: number of packets which remain undelivered to the destination node.

$$Packet\ loss = (no.of\ packets\ send\ from\ a\ sender\ ) - (no.of\ packets\ received\ by\ the\ receiver\ )$$

Normalized routing load (NRL)[11]: is number of routing packet per data packet delivered at destination.

$$NRL = \left(\frac{routing\ packet}{no.of\ TCP\ packets\ received}\right)$$

Packet delivery fraction (PDF)[11]: is the total number of packets send and received over the whole network.

$$PDF = \left(\frac{no.of\ packets\ send\ over\ the\ network}{no.of\ packets\ received}\right) \times 100$$

Average end-to-end delay[11]: is delay taken by a packet to be send and received in the network.

$$delay = \left(\frac{end\ time\ of\ received\ packet - start\ time}{number\ of\ packets}\right)$$

Number of packets dropped[12]: the packet send by a node but not received by the receiver.

5. SIMULATION RESULTS

The results obtained can be tabulated as:

Table 3: Result Obtained In NS-2.31with (CR-NS)

Parameter	Adaptive sensing	Fixed sensing
Packets send	161	73
Packets received	119	41
No. of routing packets	372	155
PDF	73.91	56.16
NRL	3.13	3.78
Avg. end-to-end delay	174.56 ms	285.49 ms
Dropped data	121 packets	55 packets

The numbers of packets send is more in case of adaptive sensing because due of adaptive sensing capability helping in knowing the hidden nodes. The received packets are also increased as compared to the fixed type. The NRL is also reduced as routing need not be performed very often for the data packets to be transmitted. This happen because the nodes which want to send the data is aware of the ongoing transmission over its receiver and thereby waits for the ongoing transmission to be completed. The average end-to-end delay is also reduced due to routing being performed effectively and also because of the better knowledge of the topology of the network making it easier to transmit and receives by avoiding collisions. The number of dropped packet is more in case of adaptive sensing because at the time of transmission at the end nodes the hidden node could not be found out because of the physical limitation of the sensing range. However, in case of fixed nodes environment the nodes didn't have the knowledge of the existence of the receiver nodes

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thus packets were not send at all to the destination node.

The throughput over the network is as shown in figure below. The green line is for the fixed case *and red for the adaptive case. It can be observed that the throughput in adaptive case is quite high as compared to the fixed case.*

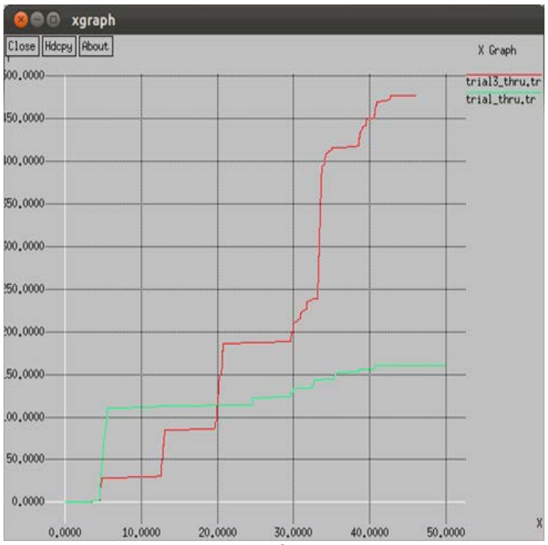

Figure 4: Throughput Of The Two Environment.

In figure 5, the packet loss for transmission between node 5 and node 2 is shown. The red indicates the adaptive and the green indicates the fixed environment. The location of node 5 is 900m and that of node 2 is 400m. When node 2 moved away from node 5 to a distance greater than 550m, node 5 decided that node 2 is absent and did not transfer the packets. However, in case of adaptive sensing, the node 2 was sensed and thus packets were transmitted. When node 2 went beyond the maximum limit if sensing range then the transmission were stopped finally.

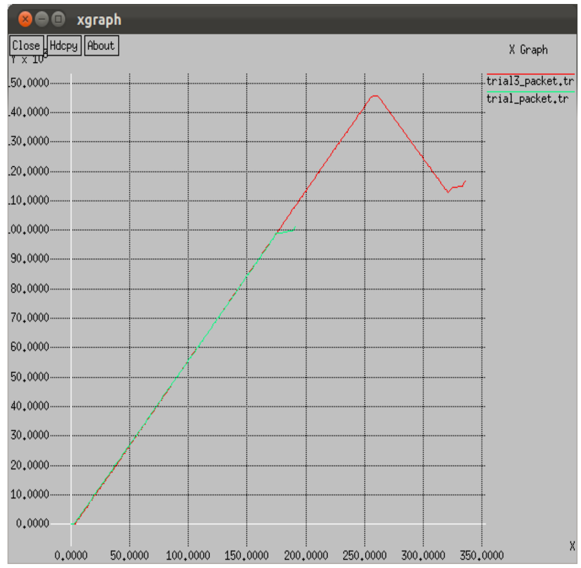

Figure 5: Packet Loss Between Node 5 And Node 2.

6. CONCLUSION AND FUTURE WORK

Adaptive sensing method for co-operative sensing has been discussed and its effect on the network characteristics has been observed. The work can be extended by incorporating a learning process like the genetic algorithm, neural network, fuzzy logic so that the cognitive nodes can adapt to the required channel characteristics. Also this adaptive sensing method can be included to develop a MAC layer for the cognitive radio ad-hoc networks.

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