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Energy Efficient Protocol for Multi Hop Routing In Cognitive Radio Networks

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***Abstract:** In recent decades, with the increase in usage of wireless devices for a wide and varying range of applications, we experience a situations where the radio spectrum to be utilized in a better way. But in several cases parts of the spectrum remains unused by the licensed users there by resulting in the wastage of the radio spectrum. The unused parts of the radio spectrum bands result in spectral holes which if used effectively can be utilized among the unlicensed users whenever there is no intervention from the licensed users. The spectrum holes can be identified and can be made useful for the unlicensed secondary users. In this aspect we need to identify the available spectrum hole which is best suitable for the proper utilization of the secondary user. This task has to be done without any interference of the primary users and it also should consider the occupied spectrum holes. The main challenges faced in the routing protocol were as follows firstly, the routing module should be aware about the physical environment and such that an accurate decision can be made in path selection. Secondly the path needs to be maintained in case of any interference from the primary user. Thirdly in case of sudden appearance of the primary user may leads to the identification of an alternative path if necessary and it may cause a delay in the routing procedure and in some cases it may also leads to a link failure and requires rerouting. Considering these challenges we have proposed a system where it undertakes the routing process considering the overall delay and also the load maintenance at each node as the metrics. An Energy efficient routing protocol for a multi hop cognitive radio network is proposed in the research article based on the energy detective sensing and also the routing decision is being based on the Channel Quality Indicator. And the obtained results were presented in an analytical framework and a better and its approach is followed and discussed.*

***Keywords:** Cognitive radio network, Routing metrics, Delay based protocol, Load based protocol.*

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I. INTRODUCTION

The development in the field of mobile device usage has in turn resulted in the increase of wireless networking communication in today's life. A wireless network can be categorized into an ad-hoc network and infrastructure based network [1]. An infrastructure based network has a wired network as the main backbone network to which the switching devices called base stations are connected. These base stations are supported with the required adapter cards which enable the access coordination between the mobile devices and the transmission channel [2]. Accessing of the transmission channels is carried out either by Frequency Division Multiple Access (FDMA), Time Division Multiple Access (TDMA) or Code Division Multiple Access (CDMA). An ad hoc network is where the backbone network is absent or even if present, it is designed in a virtual manner and all the communicating mobile devices remain connected to one another by the timely transmission of the topology information between them in the network. An ad – hoc network is useful in case of a dynamic, unstable and an unsystematic multi hop network. The effective utilization of the wireless network must be done, as the Federal Communications Commission (FCC) [3] of United Sates is accountable and deals with the allocation of the spectrum band between the users. The users who are allocated with the spectrum bands are called as the licensed users or the Primary users (PUs). The unlicensed or the Secondary Users (SU) also called as the cognitive radios are not provided with the licensed spectrum bands. The term cognitive radio has been used as these are provided with the ability to adapt to the networking environment and to make use of the spectrum bands so that there is no interference to the licensed users. FCC has also introduced a few unlicensed bands called as the Industrial Scientific and Medical (ISM) bands which are mainly used by the Wi-Fi devices, but even these unlicensed bands are being utilized in a wider range often leading to the shortage of the available spectrum band. Studies in the recent years have highlighted that large portions of the licensed spectrum bands remain unused for around 90% of the time resulting in wastage of the licensed spectrum band.

II. RELATED WORK

In case of shortage of the unlicensed spectrum band, the SUs have to search for the free licensed spectrum and then utilize it without causing any interference to the licensed users.

So the SUs are supported with a CR which is a Software Defined Radio (SDR) and it is also capable of reacting to new situations and learning from its actions [4]. This type of spectrum sharing between the primary and secondary users results in improving the spectrum efficiency [5].

Each cognitive radio is designed in such a way that it is configured to sense the spectral environment and adapt dynamically to the environment and effectively utilize the spectrum bands by taking care of the performance quality with respect to the PUs. Each cognitive radio performs the functionality of spectrum sensing, spectrum sharing, spectrum decision and spectrum mobility by which a coordinated spectrum access can be done between the different users enabling effective spectrum sharing. Cognitive ability dealing with transmission frequency, power and modulation and re-configurability which enables rapid adaptation to the network parameters are the principle features which enhance the working of Cognitive Radio Network [6]. The peer-to-peer communication between the secondary users is brought about by performing routing between the SUs by taking into account the network topology changes, interference from the primary users and related issues. There are several protocols for routing in CRNs which have considered delay, link stability, throughput and location [7-14] for making the routing decisions but often the selection of a right routing metric becomes necessary for the selection of the optimized path. in this paper, we in Receiver based routing protocol which is an On – Demand routing protocol considering the combination of delay and load based on which routing decision is made. The rest of the paper is organized as follows. In section III, the framework of the proposed protocol is described. Section IV describes Receiver based Routing Protocol in detail. The simulation results are illustrated in Section V followed by conclusion in Section VI.

III. PROTOCOL OVERVIEW

A. Framework of the proposed Routing Protocol

In a CRN each node which is interested in data transmission i.e. source node initially forwards a request asking for a suitable route. The Route Request (RREQ) is forwarded to the intermediary node; this is followed by sensing of suitable channel and updating the routing tables of the nodes through which RREQ is forwarded. On receiving the RREQ at the destination node, channel decision along with the delay occurred in channel selection and load on each channel is taken into account before moving into CR Medium Access Control (MAC) layer and CR Physical layer. The selected channel details that is eligible for data transmission is sent back to the source node in the form of Route Reply (RREP) along with the information of the generated traffic. Once the source node receives the RREP it starts forwarding the data packets. The routing protocol is supported with the traffic generation based on which the packet size is decided.

B. Modular Approach

The functionality of the routing system is better understood at the modular level involving several phases namely Route Negotiation and Sensing phase, Route Establishment phase, Data/Acknowledgement Transfer phase and finally Route Maintenance phase. In the Route Negotiation phase the channel is sensed based on the simple energy detection method [15, 16]. This energy detection scheme is primarily based on the based on the Additive white Gaussian noise [15] and the channel gain from the primary users. Two possible cases are considered during the sensing phase i.e. one with the presence of the PU in the spectrum band and the other case with the absence of PU in spectrum band. The Hypothesis model of the received signal is calculated as in [15].

$$\mathcal{H}_0: y(t) = n(t), \quad (1)$$

$\mathcal{H}_0$ is a null hypothesis, meaning that there is no primary user present in the band,

$$\mathcal{H}_1: y(t) = h\,x(t) + n(t) \quad (2)$$

$\mathcal{H}_1$ indicates the presence of primary user

From the above mentioned equations 1 and 2 we understand that x (t) is the PU's signal to be detected at the local receiver of a secondary user, n (t) is the additive white Gaussian noise, and h is the channel gain from the primary user's transmitter to the secondary user's receiver.

$$T = \frac{1}{N}\sum_{t=1}^{N} |y(t)|^2 \quad (3)$$

Form the equation 3 we can understand that T is a Threshold value predetermined and the decision on whether the spectrum is being occupied by the primary user is made by comparing the detection statistics T with a predetermined threshold. The detection statistics is the average energy of N observed samples. Route negotiation is followed by route establishment where an optimal routing path is to be selected taking into consideration the delay and the load metric. After the route establishment, data transfer at the rate of 64 packets per second takes place and subsequently followed by acknowledgement transfer after the completion of data transfer. The route selected must be stable and must not be interfered by the PU activity. In case of interference, a backup channel i.e. the next intermediate neighbor node of the node where interference has occurred must perform the further routing is to be performed. Before transmission of data the source node must be aware of all the possible paths to the destination node such that in case of interference it can immediately select the next possible neighbor node and continue with routing. This time duration taken to switch between the spectrum bands is calculated as the switching delay.

C. State Transition Diagram

Each node of the routing system is present in any of the four states: Idle state, Active state, Waiting state, Transmission / Reception state. On the sender side the system exists in idle state when it is waiting for an event to be triggered for the generation of data to be transmitted.

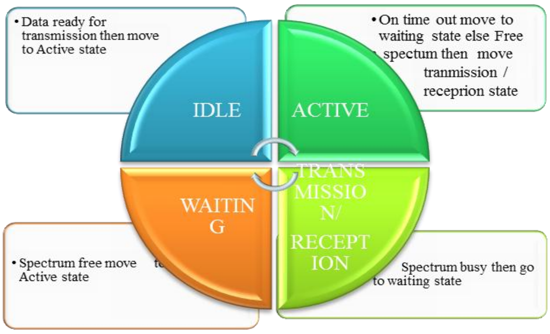

Figure 1: State transition diagram of routing

Similarly a receiver would be in the idle state until it receives a routing request from the sender. Transition to the waiting state takes place based on the availability or unavailability of the spectrum band. The transition from the active state to the waiting state occurs when the secondary user is unable to sense a free primary band on reaching the waiting state each node waits for a certain period of time and then transits back to active state. The state transition diagram is illustrated in Figure 1.

D. Computation of Delay and Load

Delay is one of the important metric in the design of our routing protocol; there exist mainly three types of delay which are the switching delay, queuing delay and back-off delay. A switching delay is caused when a node changes or switches from one frequency band to another in a given path since not all the nodes along the path can find free spaces in the same spectrum range. The back-off delay or the medium access delay is caused in identical frequency bands in order to bring about network congestion avoidance. It is dependent on three factors namely the bandwidth on the frequency band i.e. presently used, number of nodes which are sharing this frequency and the packet size during transmission. Queuing delay is caused based on the capacity of transmission of a node in a particular frequency band. . The delay caused both at the node and the path is taken into consideration while calculating the delay along the path. Delay at each node is calculated using the relation as in [18, 19].

$$D_{node} = D_{switching} + D_{queuing} + D_{backoff} \quad (4)$$

The traversal path which contains H hops, and then the switching delay along the path at a given node i^{th} and j^{th} frequency band is represented as

$$D_{Switching,i} = \sum_{j=i}^{H} k\,|Band_j - Band_{j+i}| \quad (5)$$

Where H is the number of intermediate hops covered along the path between the source node and the destination node, k is the constant value. Path delay is calculated as the sum of switching delay and back-off delay. The back-off delay is calculated as the time duration from which the packet is ready to be transmitted to its successful transmission. Another routing metric used is load which is calculated based on the number of entries in the routing table maintained at each node. Each routing table of a node i extensively contain a field which maintains the number of source – destination entries which are currently travelling through the node i. So, a node with more number of source – destination entries is considered to be highly loaded and a search for a node which containing less number of source – destination entries i.e. in case of more than one neighbor node, the node with minimum load is selected as the eligible node. A combination of delay and load forms the main core of deciding the stable path.

E. Route Selection

The source node forwards the route request (RREQ) to all its neighbor nodes. Each node maintains a routing table with the entries containing the Node ID (NID), Source ID (SID), Destination ID (DID) and the Source – Destination pair entry. When the neighbor node receives the RREQ makes a consequent entry in its routing table and then forwards the RREQ to its next neighbor node until it reaches the destination node. Each RREQ is forwarded by sensing the spectrum opportunity (SOP) which is coupled with the delay, load and the node ID's through which it has travelled along the path. Final decision of selecting the best path is done by the destination node or the receiver node from the received SOPs. The path covering the nodes with minimum delay and minimum load is taken as the best path and this is sent back to the source node as the route reply (RREP). The source node on receiving the RREP starts with data transmission.

IV. MULTI HOP ROUTING PROTOCOL

A. Route Negotiation

The proposed Receiver based Routing Protocol is designed in a manner such that it is proactive on – demand routing protocol. The RREQ sent is in the form of SOP (nodei… noden+1) to the destination node by performing sensing based on energy detection method. The detector performance can be characterized into two probabilities: PF be the probability of false alarm and PD be the probability of detection. PF denote the probability that the hypothesis test decides ΄H1 while it is actually ΄H0. T is calculated by the detection statistics.

$$PF = Pr\,(T > \lambda |\, ΄H0) \quad (6)$$

As shown in equation 7 the propability of detection (PD) denotes the probability that the test correctly decides ΄H1.

$$P_D = P_r\,(T > \lambda |\, ΄H_1) \quad (7)$$

The frame format for the RREQ packet is follwed by source ID(SID), Destination ID(DID), network ID(NID), Trafficrate and buffer and is been shown clearly in figure 2 as follows

The frame format of RREQ is represneted as shown in Fig 2. It consists of the IDs of the source, destination and the current node, along with the traffic rate and the buffer size available at the node. The size of each RREQ frame is 24 bits.The frame formatof RREP is represneted as shown in Fig 3.

ID	ID	ID	affic rate	er

ID_to be BROADCASTED
SOURCE _ADDRESS
SOURCE _SEQ

DESTINATION _ADDRESS					
DESTINATION_SEQ					
DST_POS	SRC_POS	SRC_ SPEED	SRC_ Direction	CQI	SOP

igure 2: Frame format of RREQ.

.The Channel Quality Indicator (CQI) field present in the RREP frame is represented as ($\acute{H}_0$ / $\acute{H}1$, delay, load). The buffer in each neighbor node is assumed to be a double ended queue.

SID	DID	NID	CQI

Figure 3: Frame format of RREP.

B. Route Establishment

In order to bring about data transfer, a path has to be selected prior to the transmission of data as represented in Fig 4. The selected link along the path must be kept active until the data has been sent from the sender and an acknowledgement has been received back. Consider 5 nodes with node ID as 1, 2, 3, 4 and 5. Assume that node 1 is the source node and node 4 is the destination node. Node 1 forwards the RREQ in the form of SOP (node ID). As the SOP travels from one node to the next, the node ID is incremented with SOP, concurrently updated in each of the node's routing table and then finally reaches the destination node. The destination node 4 receives two SOPs represented as SOP (1, 2, 3) and SOP (1, 5, 3). On receiving the SOP, the destination node sends back the RREP to the source node in the form of CHOICE (node ID). The source node in the current scenario receives two CHOICE's namely CHOICE (4, 3, 2) and CHOICE (4, 3, 5) from node 4. Based on the value of the CQI a suitable and effective path is selected.

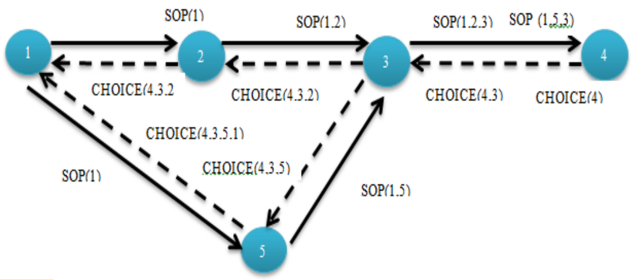

Figure 4: Route Establishment

This selection of the path is followed by the initiation of data transmission from the source node to the destination node assuming that the selected path is the most stable path on which data transmission is readily triggered.

C. Data Acknowledgement and Transmission

The arrival of the data packets at each of the nodes is based on the Poisson process and follows the M/G/1 queuing model similar to a drop tail queuing model. The size of each data packet is 64 bytes. The data before transmission has to be modulated following any has to be modulated following any of the modulation scheme, but in the proposed system amplitude modulation is considered. Multimedia data is considered for transmission here.

In case of interference from the primary users during a data transmission between the secondary users, then immediately the frequency band is allocated back to the usage for the primary user. The left over data to be transmitted in made to store at the buffers of the intermediate nodes unless the seconadry user is alloted the alternate routing path with minimal consumption of time. Consider a scenario where there are four possible paths between the source and destination i.e. A, B, C and D. The best possible path A is selected for data transmission, but due to interference from the primary user the path A has to be vacated. In this case, the secondary user goes for the next available path and selects one path among B, C or D. In case if all the four paths are busy, then a default message stating that all links are busy is sent to both source and destination.

D. Route Maintenance

If a node is transmitting data, then the node broadcasts the channel reservations periodically and announces the usage of the channel by doing this the channel used is scheduled with a specific with a specific timeout period, this ensures that the management and maintenance is simplified further it provides the robustness against the node failures and node mobility. To minimize broadcast overhead and contention, each reservation message has a time-to-live (TTL) field that limits its reach to neighbors within the sender's interference range. Once the data transmission is completed, and acknowledgement has been received, and if there are no more transmissions to be done along the same path, then a teardown message is broadcasted to all the nodes along the path. By this route maintenance and link failure is taken care.

V. SIMULATION AND RESULTS

The simulation model of the proposed system is developed in MALAB to understand the behavior of the system in the environment with the supporting parameters provided in Table 1. For the initial case, the number of PUs considered is 5 with 20 SUs which are in need of the free spectrum band. The number of PUs is gradually increased based on the requirement. Each node is enabled with a drop – tail queue structure with the queue length varying from 25 to 50. The data type of the generated traffic is in the UDP – CBR form. The proposed system on using these simulation parameters initially performs channel sensing based on the energy detection method and this is represented as in the Figure 5.

Table 1: Simulation parameters

Parameters	**Range**
No of SUs	20
Transmission range of SU	120m
Transmission range of PU	300m
Traffic data type	UDP – CBR
Channel Switching time	5ms
Timeout for route expiration	3000ms
Transmission interval for each node	100ms
Queuing model	M/G/1
Queue type	Drop Tail
Simulation timeout	300s
Network Interface Type	Phy/ wireless Phy

ROC curves for random signal in AWGN channel is calculated using MATLAB. The results obtained are shown in following figures.

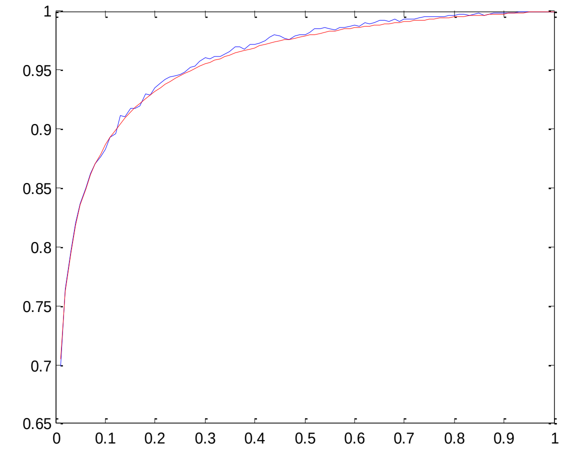

Figure 5: Channel Sensing before RREQ transmission

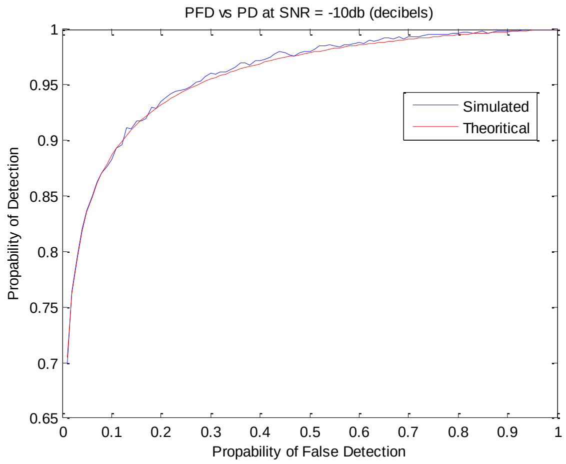

Figure 6: Channel Sensing before RREQ transmission at SNR as -10 db

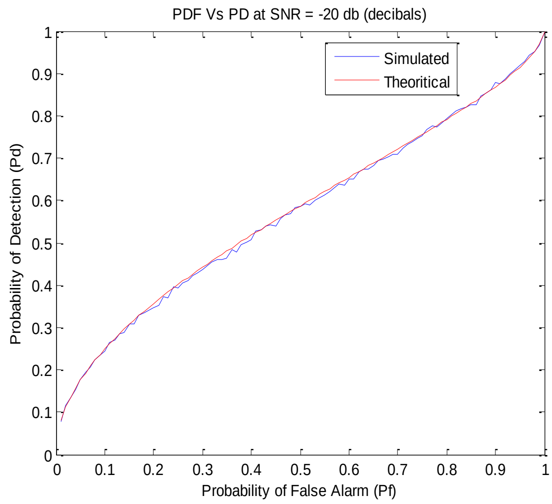

Figure 7: Channel Sensing before RREQ transmission at SNR as -20 db

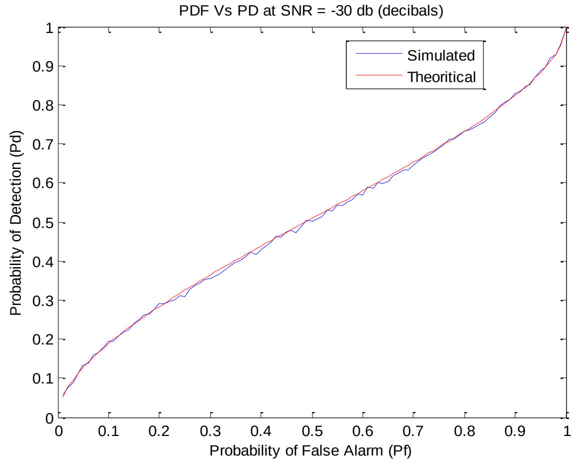

Figure 8: Channel Sensing before RREQ transmission at SNR as -30 db

The ROC curves shown is for different SNR values say at no Specific SNR ,When SNR is -10 db, -20 db, -30 db respectively as shown in the figures5,6,7,8. It is seen that probability of detection is different and detection quality is good at higher SNR values.

Once the channel has been sensed successfully then the main focus is been kept on estimating the probability of detection of the channel and in comparison with the probability of false detection of the channel. And further it is been observed that the simulation results that are obtained are in line with the theoretical analysis that were been presented in figure 9.

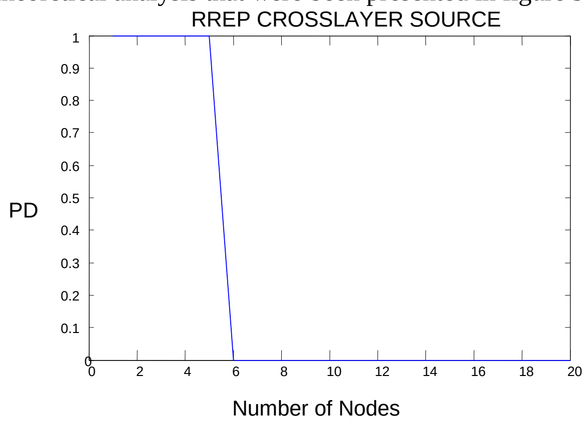

Figure 9: PDF of transmitted packet.

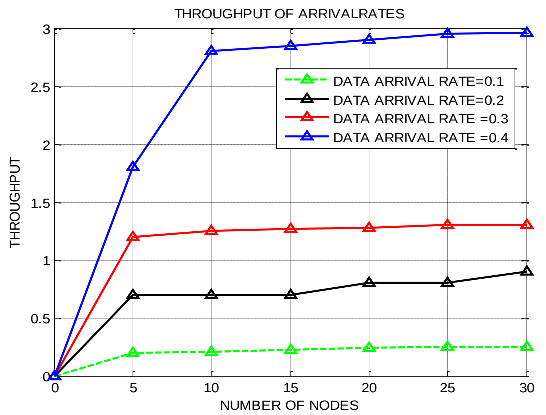

Figure 10: Throughput v/s number of nodes.

Figure 9 represents the Probability Density Function (PDF) initially and then gradually gaining a constant value. The Figure 10 projects various arrival of the protocol for throughput and the variable Data Arrival rate (R) is been plotted and the corresponding throughput is been observed to be increasing along with the data arrival rate with respect to number of nodes is concerned.

VI. CONCLUSION

The research work carried out in the article concludes that new routing protocol has been proposed which is a multi-hop receiver based system where the routing decisions are made at the receiver end. This protocol combines the metrics of delay and load in order to select a stable link along the source and the destination node. The use of Channel Quality Indicator (CQI) and the Spectrum opportunity (SOP) metrics has made the routing protocol more flexible in selection of a stable path even in case of interference from the primary users and provides the channel for the secondary users. Further the route establishment, Route Maintenance, Route Negotiation has been taken care along with the channel switching aspects has been discussed with the supporting results in case of various SNRs. The Comparative analysis for the various data arrival rates and it is been observed that the throughput has been increased along with the data arrival rates.

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