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JCPICS: JOINT COOPERATIVE PATH AND INTERVENTION COGNIZANT SCHEDULING IN MULTI-HOP CRN

Shyleshchandra Gudihatti K N[1], S H Manjula[1], Venugopal K R[2]
[1]University Visvesvaraya College of Engineering, Bangalore University, Bengaluru, India
[2]Bangalore University, Bengaluru, India, venugopalkr@gmail.com
[1]Contact:shyleshchandra444@gmail.com, shmanjula@gmail.com

Abstract: Cognitive Radio based network technology provides better spectrum utilization and resource allocation. Generally, the dynamic network topology, interference, path switching and under-utilization of resource can degrade the network performance. The routing protocols are classified as local and global which are mainly focused on overhead reduction and optimal route selection respectively. However, the conventional approaches suffer from various issues such as interflow-interference, path switching delay and node overhearing problems. In this paper, we present a Joint Cooperative Path and Interference Cognizant Scheduling (JCPICS), which focus on the inter-flow interference, channel switching delay, and a cooperative communication based approaches. Furthermore, Switching Delay and Interference (SDI) routing metric is developed to reduce the switching delay and cooperative scheme of packet transmission is developed where direct or cooperative communication is selected for successful packet transmission. The performance of proposed approach is compared with the existing techniques such as Primary User Aware k-hop route discovery scheme (PAK), AODV, Cognitive-AODV, and Location-Aided Routing for CRN (LAUNCH) in terms of delay and throughput.

Keywords: AODV; Cognitive Radio Network; Cooperative Communication; Interference; Primary User Aware k-hop route discovery(PAK).

I. INTRODUCTION

During last decade, the demand for wireless communication has increased drastically which has proliferated due to increased use of wireless devices such as smart phones, tablets and all electronic gadgets. The use of smart phone and other wireless applications such as social networking, online gaming, and online multimedia data accessing, etc has augmented the mobile data traffic [1]. This kind of growth in data traffic is increasing continuously which may lead to the communication spectrum related issues. Recently, Cognitive Radio Network (CRN) have been introduced which is considered as a promising technique to overcome the wireless communication by improving the spectrum efficiency and efficiently meets the increased data traffic demand [2]. Cognitive Radio comprises of Primary Users (PU) or Licensed Users (LU) and Secondary User (SU) or Unlicensed User (UU) where SU is allowed to sense and access the available spectrum opportunistically. The opportunistic detection of vacant spectrum bands and safeguarding the working of PU is the main advantage of cognitive radio network which helps to improve the spectral efficiency, and spectrum utilization [3]. In this scenario, the licensed channel is assigned to the PU for a specific time duration, during which the PU can communicate without causing any interference to other users and SU utilizes under-utilized channels of PU. However, if PU reutilizes the path, then SU has to switch to another available path without affecting the performance of PU [4].

Routing is the key component of any wireless network which allows communicating among nodes by finding the optimal route from source node to destination node. However, the overall network performance depends on the efficiency of routing mode. The routing schemes are classified as global and local routing. The global routing requires information about entire network whereas local routing requires information about next hop. Several challenging issues present in the development of routing for cognitive radio network. The dynamic channel availability causes variations in PU's activities resulting in variation of white space, another annels where appropriate path selection is a crucial task. Similarly heterogeneous channels and dynamic channel availability results in the frequent path switching which affects the SU's performance.

It is observed that the sporadic utilization of resources lead towards the low-level utilization of resources thereby Dynamic Spectrum Access (DSA) techniques are developed recently to deal with this issue. DSA is a new approach for spectrum sensing and sharing which utilizes spectrum holes to mitigate the spectrum scarcity issues and improves the spectrum utilization. In this scenario, the SUs dynamically search for available spectrum and access them temporarily. Several approaches are present in this field of DSA such as DSA for cognitive radio wireless networks [5], DSA using reinforcement learning [6] and DSA for improving the energy efficiency [7] etc. Generally, DSA based models are classified into three models such as interweave, underlay, and overlay [8].

Furthermore, shadowing, multipath fading, and radio interference are also critical issues which need to be addressed. Hence, in this work, we focus on the development of routing scheme for cognitive radio and dynamic spectrum access for better utilization of resources.

A. Motivation

The cognitive radio network suffers from various challenges which affect the communication performance. Some of the well-known challenges are listed as follows:

- Dynamic network topology
- Node Deafness
- Physical and MAC layer interaction

B. Contribution

The main contribution of the work is as follows:

- Development of efficient routing protocol for CRNs.
- Introducing a new cost metric for building the reliable routing.
- Design a model of route discovery and switching delay and interference maintenance using on-demand routing scheme for cognitive radio network.

Due to these significant contributions of proposed approach focuses on both path and interference to improve the network performance. Therefore, this approach is known as Joint Cooperative Path and Intervention Cognizant Scheduling (JCPICS).

C. Organization:

The rest of the manuscript is organized as follows: section II presents a brief review about recent techniques of routing, spectrum access and spectrum allocation in Cognitive Radio Network. Section III presents the proposed solution for joint routing and spectrum access, section IV describes the performance and comparative analysis of proposed model with state-of-art techniques and finally, section V presents the conclusions.

II. RELATED WORKS

This section presents a brief discussion about routing protocols in CRNs. As discussed in previous section, the global and local routing are the two main routing approaches. Several schemes are developed to introduce novel routing technique to mitigate the various routing challenges in the CRNs.

Singh et al., [9] studied about the routing protocol for cognitive ad-hoc radio networks where energy management is considered as a challenging task for network performance. The proposed approach is based on the multi-path routing which also considers energy efficiency, residual energy and path stability to achieve the desired performance of the network. However, due to some network issues, if any path fails, then the alternative routing path can be selected and performs communication without any packet drop. Multi-hop routing based communication systems has a significant impact on the network performance. Based on this assumption, Banerjee et al., [10] presented a combined model for power allocation and route selection in the cognitive radio network. This CRN architecture consists of secondary transmitter and receiver which are connected through the decode-and-forward relays. These relay nodes helps to cooperate among nodes to establish the energy harvested data transmission. Suzuki et al., [11] proposed cognitive radio based study for multi-hop inter-vehicular network where link connectivity is highly affected due to the dynamic nature of vehicles which can degrade the performance of network. In order to overcome this issue, proposed a novel combined approach which addresses routing and resource allocation issues jointly.

Based on the concept of multi-hop, Cacciapuoti et al., [12] developed a routing protocol for mobile ad-hoc cognitive radio network. According to this study, the primary user activity regions are avoided during the route formation and packet discovery phase. The RREQ and RREP broadcast messages do not affect the PU activity. Several routing approaches are developed based on this concept of routing. Rahman et al. [13] also introduced a combined approach which focuses on the path construction and spectrum diversity in CRNs. This approach facilitates the dynamic switching of the cognitive users (CUs) to different path and available spectrum bands for communication.

Ping et al., [14] introduced a spectrum aggregation based cooperative routing approach for Cognitive radio Ad-Hoc Networks. This technique is mainly focuses on maximizing the throughput by selecting the suitable relay nodes and reducing the delay by minimizing the number of re-transmissions. As discussed in previous section, the routing is classified as local and global routing which require neighbor hop information and entire network information respectively. However, there exists a tradeoff between routing overhead and route selection. In order to overcome this issue, guirguis et al., [15] presented a primary user-aware k hop routing scheme which represents the routing discovery radius and this model can be incorporated into any CRN protocol. In this case, multiple hops are identified and adapted in the network topology based on the user-defined utility function. shylesh et al.,[16] studied the review on spectrum management techniques which supports sensing, deciding and allocation. This analyzes the energy efficient routing protocols with several metrics to route the available information from source to destination by optimally reducing the energy consumption.

The development of joint approach of routing and resource allocation is a challenging task due to tradeoff between resource allocation and routing. Recently, Du et al. [17] presented a joint approach for multi-hop Cognitive Radio Network to deal with the issue of transmission delay and energy efficient communication. To mitigate these issues, a cross-layer routing protocol is developed where all delay and power efficiency issues are addressed using an utility function and later this problem is modeled in the form of stochastic games.

III. PROPOSED MODEL

In the previous sections, we have studied about several aspects of cognitive radio network. Its communication concepts where routing and accessing the available spectrum dynamically are considered as the most challenging issues. Hence, in this paper, we focus on the development of a joint scheme for multi-hop routing and dynamic spectrum access scheme.

A. Assumptions

In this paper, an Ad-Hoc Cognitive Radio Network is considered for designing the routing protocol in CRN. This network contains two main components as PU and SU where PUs is allowed to access the available spectrum whereas the SUs can only access the unoccupied spectrum. The SU has to vacant the spectrum if any PU arrives to access that spectrum. The assumptions are adopted from [11] where PU's are deployed uniformly in the deployment area. The PU activities are represented in the form of ON-OFF birth death process which are denoted by α and β. These parameters depends on the PUs traffic assumed that PUs are stationary. Similarly, the SUs are also deployed uniformly in the given region. In the considered network, each SU maintains the location information and location of direct neighboring node for a multi-hop routing network scenario from source node to destination in the considered cognitive radio network.

B. Problem Definition

The spectrum availability varies dynamically that becomes a crucial issue for traditional approaches. According to [15] [18] [19], the on demand AODV routing approaches are introduced but these routing approaches do not consider network communication delay and also inter-flow interference caused due to neighboring nodes. These issues can be addressed using cooperative schemes [20]. Hence, this type of routing schemes can cause higher latency and congestion. Accordingly, there is a need to develop a light weight routing approach for low-latency and reduced congestion in the network.

C. Proposed Solution

In this paper, we present a routing protocol which is based on the on-demand routing proposal. The proposed approach is based on the Joint Cooperative Path and Intervention Cognizant Scheduling (JCPICS). In general, the source node or cognitive user broadcasts the RREQ message to establish the communication with neighboring node before transmitting any data to the destination node. After transmission of RREQ, the intermediate node receives the RREQ packet and computes the total cost from source node to the current intermediate node. The final destination node selects the minimum cost path and reply with a route reply packet (RREP) on common control channel (CCC) to initiate the transmission over selected path also cost is computed based on the metrics.

Let us consider a Cognitive Radio Network which is represented in the graph form as G = (V_{SU}; V_{PU} ; E) where V_{SU} denotes the set of secondary users, V P U denotes the set of primary users which are connected by an edge e ∈ E. These nodes are connected successfully, if the PU and SU are in the specified transmission range. The $n_{SU} = V_{SU}$ represents the total number of secondary users and $n_{PU} = V_{PU}$ denotes the total number of PUs in the network. This network is considered to be deployed in a square region with the side length, thus n_{SU} the density of SUs can be given as: $\Upsilon = \frac{n_{SU}}{l^2}$

In the proposed scenario, the proposed Joint Cooperative Path and Intervention Cognizant Scheduling (JCPICS) is partitioned into total f time frames which consists of two operating phases known as data control and transmission phase. The secondary users can transmit their updated information during the exchange of information between communicating nodes.

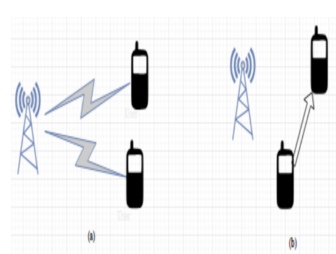

Figure 1: Three node communication scenario (Node Overhearing).

In the next phase, data transmission takes place where secondary user can transmit the packets to the next hop. This data transmission can be performed using direct communication or with the help of cooperative communication. Let us consider a scenario as given in figure 2 where one source, one destination and one relay nodes are present.

Figure 2(a) shows the packet transmission at time t where the data is transmitted from the current source node s to the destination node d where the relay node γ also overhears this packet. Similarly at time (t+1) the relay node transmits the packet to the destination node according to the figure 2(b). At this stage, diversity combining schemes can be incorporated on the received data from two different path. Thus the maximum gains can be obtained at this stage. Here, rate of cooperation between these nodes can be measured based on the signal to noise ratios. By considering communication links between $(s \rightarrow \gamma)$ known as link 1 expressed L_1 , $(s \rightarrow d)$ known as link 2 expressed L_2 , and $(\gamma \rightarrow d)$ known as link 3 expressed L_3 . The cooperation rate can be expressed as:

$$Cc_{rate}=(s,\ \gamma,d)=\frac{BW}{2}\min\{\log_2(1+SNR_{L1}),\ \log2(1+SNR_{L2}+SNR_{L3})\} \quad (1)$$

where SNR $_{L1}$ denotes the signal to noise ratio for the considered communication link 1, SNR $_{L2}$ represents the signal to noise ratio for link 2 and SNR $_{L3}$ presents the signal to noise ratio for link 3, BW represents the path bandwidth. The Eq. (1) provides the capacity of communication for Fig 2(b) scenario whereas the direct next hop communication capacity can be given as:

$$CC_{L2}(s,d) = BW\{\log_2(1+SNR_{L2})\} \quad (2)$$

D. Proposed Routing Protocol

The proposed routing protocol is divided into five stages in which we perform route discovery, evaluate the interference and switching delay of channels, cooperative metrics, route establishment and route maintenance phase.

1) *Route discovery phase*: This subsection presents the route request with the help of RREQ and route reply process with the help of RREP to discover the suitable route from source node to destination node. In order to discover the route, the source node broadcasts the route request packet RREQ to the neighboring nodes. The RREQ packet maintains a communication table where route request ID (ID $_{RREQ}$), Source node information such as node ID and its location, destination node information such as destination node ID & its location, time stamp, relay node information from source to destination nodes. The cooperative cost between two nodes can be achieved with the help of cooperation rate between any two nodes represented as *i* and *j*. Thus the cost can be computed as:

$$Cost_{i,j} = \frac{1}{max(CC_{rate})} \quad (3)$$

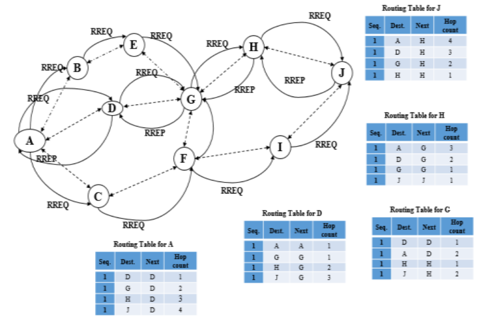

Figure 2: RREP and RREQ message exchange

According to Figure 3 the source node is *A* and the destination node is *J*, the obtained final path is $A \rightarrow D \rightarrow G \rightarrow H \rightarrow J$ where node *J* sends a *RREP* message with their corresponding routing tables are also presented. The routing table shows the hop count, next hop and destination nodes. In this case, initially the node transmits the *RREQ* packet to the neighboring node and waits for the reply packet *RREP*. If the sufficient channel and resources are available with the neighboring node, then it replies with a *RREP* packet and communication can be established.

2) Switching delay and interference: Here, we introduce the delay and interference metrics to obtain the most suitable path from source node to destination node. In the cognitive radio scenarios, the switching delay between channels and interflow interference may lead towards the degraded throughput and communication quality. There may exist multiple paths where CR users are present. These users can cause interference which is known as interflow interference whereas interference caused due to the CR users from the same path is known as intra-flow interference. The existing on demand protocols does not consider these interferences in a single protocol. Hence, in this work we propose a novel solution to mitigate the different types of interferences such as inter and intra flow interference which are caused due to several issues. However, these issues can be mitigated with the help of appropriate routing protocol.

The intra-flow interference is considered in the routing metric and the inter-flow interference can be mitigated with the help of appropriate transmission power in the physical layer. The overall interference in the network can be computed by summing up the interference of all users. The interference for user *i* at the current path *c* can be denoted as:

$$I_{i,c} = \sum_{j \in S_i} P_{j,c} \quad (4)$$

Where S denote the count of switching channels, based on the path loss model the overall interference from node *j* to *i* on the same path can be computed as:

$$P_{j,c} = \sum_{j \in S_i} P_j \frac{\left(h_i^2 h_j^2\right) G_i G_j}{d_{i,j}^k L_f} \quad (5)$$

Where h_i denote the height of transmitter antenna, h_j denotes the receiver antenna height, G_i denotes the gain of transmitter antenna, G_j denotes the gain of receiver antenna gain, L_f is the loss factor, P_j represents the transmission power and *k* denotes the attenuation index.

With the help of these assumptions, the overall interference from source to destination node at time t can be obtained as:

$$I(t) = \sum_{i,c} I_{i,c}(t),\ i = 1, 2 \ldots N \text{ and } c = 1, 2 \ldots M \quad (6)$$

Where *N* denotes the total CR users, *M* denotes the total number of path switching in this path. Based on the joint consideration of interference and switching delay, we present a routing metric as switching delay and interference *SDI* given as:

$$SDI = \frac{\sum_{i,c} I_{i,c}}{\sum_r \sum_{i,c} I_{i,c}} (1 - Y) + \frac{\sum_{i,c} S_{i,c}}{\sum_r \sum_{i,c} S_{i,c}} * Y \quad (7)$$

Where α is a constant factor which varies from 0 to 1 and it is decided based on the performance requirement i.e., if the value of Y>0.5 then the routing metric focuses on improving the delay. Due to this constant factor, we can make the adaptive transmission which can focus on the delay and throughput jointly.

In Cooperative communication metric, we measure the direct communication capacity and the cooperative *c* communication rate, if $CC^c_{coop} > Cap^c_{direct}$ then the relay node based scheme is selected for improving the throughput.

Similarly route establishment is done, where all *RREQ* packets are received and route reply packet is transmitted from the destination node where entire information about the path is aggregated in the *RREP* packet. If multiple *RREQ* are received then the final optimal path can be filtered.

In order to maintain a reliable and better communication, we present route maintenance model where the forwarding node from the failed link identifies if any other common path is available, if the path is not available then the complete path is rebuilt.

IV. RESULTS AND DISCUSSION

This section presents the experimental analysis using proposed approach and the performance of proposed Joint Cooperative Path and Intervention Cognizant Scheduling (JCPICS) approach is compared with the state of art techniques such as Primary User Aware k-hop (PAK) [15], AODV [12], CAODV [12], and LAUNCH [21]. According to the proposed model we have introduced an interference parameter which has significant impact on the switching delay performance. The Simulation setup is conducted using Matlab software with windows operating system platform.

According to the given network configuration, total 100 SUs are present in the network area of 1000 × 1000 m^2 where total 2 PUs are present. The transmission range of PU is assigned as 140 m and transmission range of SU is 125 meter. In this work, we have considered CBR data traffic with the 16Kbps data rate.

1) Performance measurement for varied SUs: Here, we measure the performance of proposed approach by varying the number of SUs. This performance measurement is carried out in terms of performance measurement metrics as described in the previous sub-section.

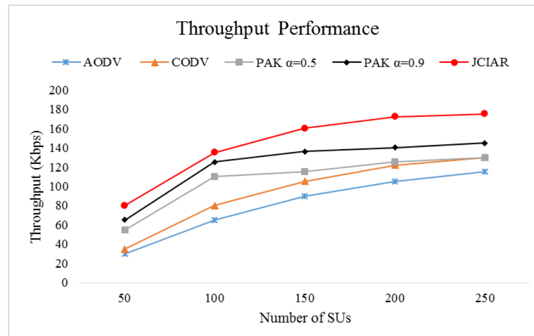

Figure 3: Throughput Performance for varied SUs

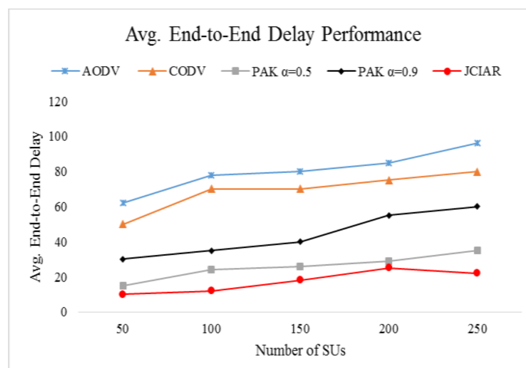

Figure 4: Avg. End-to-End Delay performance

The above given Figure 3 shows the comparative performance in terms of network throughput for varied numbers of SUs. As the number of SUs is increasing, the throughput performance increases because of successful packet transmission using multi-hop and multipath communication. For this simulation, the average throughput for varied SUs is obtained as 81 Kbps, 94.4 Kbps, 107 Kbps, 122.2 Kbps and 144.4 Kbps using AODV [8] , CODV [8], PAK α=0.5 [11], PAK α=0.9 [11] and JCIAR. This simulation result shows that the performance of proposed JCIAR approach is improved by 78.27%, 52.96%, 34.95% and 18.16% when compared with AODV , CAODV, PAK α=0.5 and PAK α=0.9.

The above given Figure 4 illustrates a comparative analysis in terms of average end-to-end delay for varied number of SUs. The average end-to-end delay performance is obtained as 80.2ms, 69ms, 40ms, 75ms and 17.4 using AODV, CAODV, PAK α=0.5, PAK α=0.9 and JCIAR approaches. As the numbers of SUs are increasing, the end-to-end delay also increases due to network congestion and overhead. However, proposed model reduces delay when compared with the existing techniques.

V. CONCLUSION

In this paper, we have presented a novel routing approach for cognitive radio network. The proposed approach considers interflow interference and path switching delays are the key challenging issues which degrade the network performance. Hence, we present a Joint Cooperative Path and Intervention Cognizant Scheduling (JCPICS) approach where cooperative communication scheme is incorporated to enhance the network performance. The cooperative scheme is used for route discovery and mitigates the node overhearing issue. The performance of proposed JCPICS is compared with the existing techniques. The simulation study shows that the proposed approach achieves better performance in terms of network throughput, and delay.

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