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Joint Channel and Interference Aware Cooperative Routing for Cognitive Radio Network

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Abstract: Cognitive Radio based network technology provides a promising solution for various types of real-time wireless communication by offering better spectrum utilization and resource allocation. Generally, the dynamic network topology, interference, channel switching and under-utilization of resource can degrade the network performance. Therefore, development of promising solution to obtain the desired performance is a challenging research topic in CRNs. Several researches have been carried out which have focused on development of routing protocol for CRNs to improve the performance. These routing protocols are classified as local and global routing which are mainly focused on overhead reduction and optimal route selection respectively. However, the conventional approaches suffer from various issues such as interflow-interference, channel switching delay and node overhearing problems which can progress towards the poor network performance. In this paper, our objective is to focus on the inter-flow interference, channel switching delay, and develop a cooperative communication based approaches where inter-flow interference and overhearing issues are mitigated using cooperative communication. Furthermore, Switching Delay and Interference (SDI) routing metric is developed to reduce the switching delay and also finally, a cooperative scheme of packet transmission is developed where direct or cooperative communication is selected for successful packet transmission. The proposed approach jointly considers channel and interference issue, hence it is known as Joint Cooperative Channel and Interference Aware Routing (JCIAR). 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, packet delivery rate and throughput. The obtained result shows a significant improvement in network performance.

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

I. INTRODUCTION

TDuring last decade the demand for wireless communication has increased drastically which has proliferated due to increased use of wireless devices such as smartphones, tablets and all electronic gadgets. The use of smartphone 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. Accordingly, spectrum scarcity issues need to be addressed for better future wireless communication systems. 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 channel, then SU has to switch to another available channel without affecting the performance of PU [4].Routing is the key component of any wireless network which allows to communicate among nodes by finding the optimal routing 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. These routing techniques are widely adopted in wireless networks. Several challenging issues present in the development of routing for cognitive radio network. The dynamic channel availability causes variations in PU0s activities resulting in variation of white space, another challenge is raised due to the multiple heterogeneous channels where appropriate channel selection is a crucial task. The dynamic nature of channel availability is a challenging task because dynamic nature of channel degrades the common control information exchange which affects the routing. Similarly, heterogeneous channels and dynamic channel availability results in the frequent channel switching which affects the SU0s performance. Due to these issues development of efficient routing protocol for CRNs becomes a tedious task.

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On the other hand, several techniques have been introduced to analyze and provide the solution for the efficient resource allocation to serve the increasing demand of users through the fixed spectrum range. Due to this increased demand of wireless communication and multimedia services, the demand of quality of service (QoS) also increases.

Therefore, the resource allocation becomes a challenging task which influences the performance of cognitive radio network significantly. The irregular and sporadic utilization of resources lead towards the under-utilization of available resource. Hence developing an efficient approach for better utilization of resources becomes an important task [5]. Due to these issues, spectrum scarcity can be considered as outcome of poor spectrum management schemes. The Cognitive Radio play an important role in this type of scenario which are capable of sensing the unused spectrum/spectrum holes. The conventional approaches of spectrum allocation assign the spectrum portions to the communication technologies. This type of spectrum assignment is known as static spectrum allocation. However, this approach of spectrum allocation prevents users to utilize the available spectrum efficiently because sparse populated area no targeted device causes spectrum holes, and no transmission through channel which causes blank period.

From this, it is observed that the sporadic utilization of resources leads 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 [6], DSA using reinforcement learning [7] and DSA for improving the energy efficiency [8] etc. Generally, DSA based models are classified into three models such as interweave, underlay, and overlay [9]. The interweave DSA model is also known as opportunistic spectrum access where secondary users are allowed to access the available spectrum in an opportunistic manner and utilize the spectrum holes. The Interweave DSA can sense the neighboring spectrum and then selects the optimal spectrum band to transmit by switching to this band. According to the concept of underlay DSA model, SUs have permission to communicate on the available licensed spectrum band without taking into account whether PU is accessing that spectrum causes interference. Similarly, the overlay DSA model is also allowed to transmit over the spectrum but it does not induce interference however limits the transmit power. Recently, interweave DSA models are widely adopted for better communication and spectrum utilization to improve the QoS. The detailed study about these models can be found in [9]. During communication, when PU is utilizing the spectrum, SU has to detect accurately the existence of PU signal hence spectrum sensing is a challenging task. Furthermore, the 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. *Issues and Challenges*

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

- Dynamic network topology: There are several networks which faces several challenges due to dynamic network topology such as Mobile Ad-Hoc Networks (MANETs) and Vehicular Ad-Hoc Networks (VANETs). However, in general cognitive radio network results in a dynamic network topology because the links between nodes are assigned based on the PU activities thus the CRNs suffer from rapidly changing network topology.
- Node Deafness: According to the cognitive radio network, when a node is accessing the specific frequency band, during that time it cannot receive any transmission from other frequencies. Due to this issue, the exchange of RREQ and RREP packets becomes a tedious task which advances towards the poor routing in the network. However, common channel control scheme has been developed recently which enables to receive and transmit the control packets. This scheme results in the wastage of bandwidth due to assigning a separate channel for communication. Similarly, channel synchronization is also considered as a new solution for the deafness problem in CRN but this results in the increased delay and power consumption.
- Physical and MAC layer interaction: In CRNs, the data is routed through the path where more frequency is available and this information should be acquired by the physical and MAC layers. Hence CRNs are directed cross-layer interaction between physical and MAC layers.

B. Contribution of the Work

C. In the previous sub-section, we have identified several challenging issues present in the cognitive radio network while routing. In this paper, we mainly concentrate on the working of [11] where a model is designed that can be incorporated in the cognitive radio network to develop an efficient routing approach which improves the network performance. However, several issues remain unaddressed in CRNs such as inter-flow interference and delay caused due to channel switching is not considered in this approach which can lead to the degradation of network performance. In order to deal with the performance related issues, we present a novel approach using cooperative networking which can mitigate the delay appears during exchange of the channel and interference caused due to the neighboring cognitive users. To overcome this problem, we present a routing metric as Switching Delay and Interference (SDI).

Furthermore, a cooperative cost metric is also included during the route discovery phase which helps to reduce the node overhearing issue with the help of cooperative networking. Finally, we introduce a cooperative communication metric which helps to decide whether to transmit packets using direct transmission or cooperative transmission.

The main contribution of the work are as follows:

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

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 describe the performance and comparative analysis of proposed model with state-of-art techniques and finally, section V presents the concluding remarks of the work.

II. LITERATURE SURVEY

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., [10] studied about the routing protocol for cognitive ad-hoc radio networks where energy management is considered as a challenging task for network performance. This shows that several routing protocols are present but these approaches fail to satisfy the network throughput, energy efficiency and robustness. Hence, multipath routing is presented to overcome the performance related issue. The proposed approach is based on the multi-path routing which also considers energy efficiency, residual energy and channel 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. These routing multipath are identified based on the residual energy, channel stability and energy consumption. Multi hop routing based communication systems has a significant impact on the network performance. Based on this assumption, Banerjee et al., [11] presented a combined model for power allocation (to improve the power consumption performance) and route selection (for better routing) 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 help to cooperate among nodes to establish the energy harvested data transmission. The high mobility scenarios affect the system performance; vehicular networks are the well-known example of this type of systems. Suzuki et al., [12] 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. To address these issue, it uses several information of PU such as position information, channel availability, transmission capacity and mobility. With the help of information provided by PU, the spectrum availability in SU is obtained according to the SUs mobility.

Based on the concept of multi-hop, Cacciapuoti et al., [13] 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. Particularly each forwarding node participates in the path discovery, channel selection and multiple channels can be utilized to develop the routing protocol. In this process, route request (RREQ) packet is broadcasted to the neighboring nodes. The forwarding node replies the RREP packet as route-reply which provides the complete information about the channel and route. This 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. [14] 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., [15] 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., [16] 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., [17] 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 cognitive radio network performs cooperation to establish the coherent communication. Generally, the wireless links

may get affected due to channel impairments issues such as multipath fading which

affects the link quality. According to the fundamental assumption of cognitive radio, the secondary user cannot use the spectrum if primary user is using it. The cooperation and collaboration among users can effectively improve the performance. Based on this assumption, Jiang et al., [18] introduced a collaborative routing for cognitive wireless networks.

This approach works as clustering where clusters are formed based on the transmission distance, transmission angle control, collaborations, power control and channel allocation. This work also considers the interference issues for secondary users. However, enabling the communication for secondary users is a challenging task because PUs have acquired the spectrum, to mitigate this issue, Guirguis et al., [19] developed a cooperation based routing protocol where secondary users are grouped together and collaborate to transmit in the region of primary user. This protocol is known as undercover which uses beam forming and multi-hop routing protocol for CRNs.

In this approach, a node transmits the RREQ packet to the neighboring nodes and based on the relative distance from the destination node, the node which is near to the destination node is considered as a potential node which sends the route reply packet to the node. Further, interference aware scheme is also incorporated where a node keeps the record of interference caused due to its own transmission which affects the routing decision.

These routing schemes are mainly focused on developing an efficient approach for packet delivery, energy optimization and resource allocation. 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. [20] 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 a utility function and later this problem is modeled in the form of stochastic games. In order to solve this problem, the nodes exchange the information from previous nodes. Wang et al., [21] discussed about multi-hop and multi-channel routing in CRNs. In this approach, secondary users participate to form a stochastic game where path utility information are used as backward propagation to identify the next-hop, this utility forms series of stochastic games and the best response is considered for further process which guarantees better network coverage.

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 are 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 PUs 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 depend 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. Figure 1 shows a multi-hop routing network scenario from source node to destination in the considered cognitive radio network.

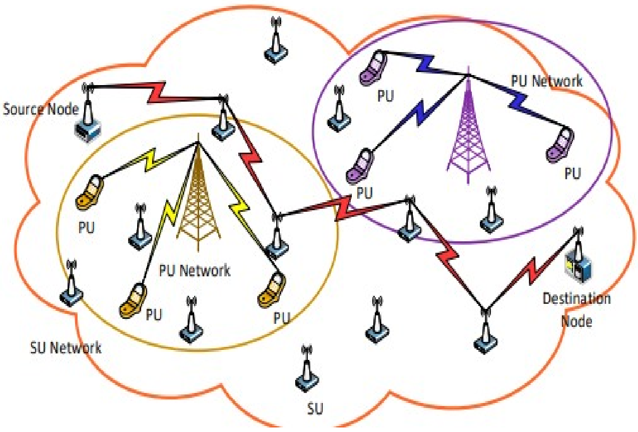


Fig. 1: Routing model for Multi-Hop Cognitive radio network

B. Problem Definition

The spectrum availability varies dynamically that becomes a crucial issue for traditional approaches. According to [16] [22] [23], 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 [24] but most of the traditional cooperative schemes do not consider the primary user activity and channel availability aspects in the cognitive radio network. Moreover, the existing approaches of CRN routing require relay node, next hop, and spectrum information. The next hop information requires global knowledge of next hop and topology control information. 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 channel and interference aware routing scheme called as JCIAR. 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 and the obtained cost is arranged in the RREQ which is evaluated after reaching to the destination node. There may exists several intermediate nodes where all RREQ are combined together until

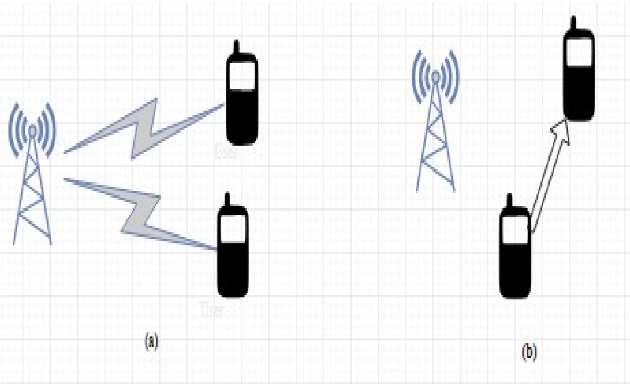


Fig. 2: Three node communication scenario (Node Overhearing)

TABLE 1: Notations used for simulation parameters

Sl No	Name	Notation
1.	Network Graph	G
2.	Vertices	V
3.	Edges	E
4.	Primary User	PU
5.	Secondary User	SU
6.	Transmission Range	T_r
7.	Density of SU	γ
8.	Frame	f
9.	Cooperative Communcation	CC
10.	Capacity	Cap
11.	Source Node	**s**
12.	Delay	**r**
13.	Destination	**d**
14.	Loss Factor	L_f
15.	Interference	I
16.	Transmission power of node *j*	P_j
17.	Distance between nodes	d
18.	Transmit Antenna Height	h_i
19.	Receiver Antenna Height	h_r
20.	Transmitter Antenna Gain	G_i
21.	Receiver Antenna Gain	G_j
22.	Attenuation Factor	k
23.	Available Number of Routes	r
24.	Channel Utilization	U

it reaches to the destination. After reaching at the destination 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_{PU} 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 The n_{PU} = V_{SU} 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 the density of SUs can be given as $\gamma = \frac{n_{SU}}{l^2}$. In the proposed scenario, the proposed Joint Cooperative Channel and Interference Aware Routing (JCIAR) is partitioned into total *f* time frames which consists of two operating phases known as data control and transmission phase. As discussed before that the spectrum management i.e. sensing and allocation is an important mechanism in CRN. The data controlling phase performs spectrum sensing to obtain the spectrum information and the available spectrum's can be used by secondary users when PU is not accessing that spectrum. During RREQ, the information is exchanged between the neighboring node and source node at this stage. The secondary users can transmit their updated information during the exchange of information between communicating nodes.

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 g 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 → γ) known as link 1 expressed L1, (s → d) known as link 2 expressed L2, and (γ→ d) known as link 3 expressed L3. The cooperation rate can be expressed as:

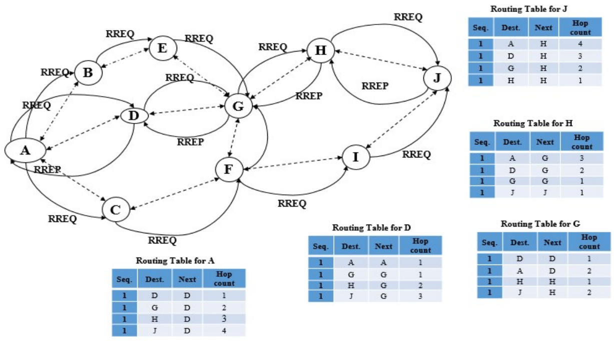
$$CC_{rate}(s,\gamma,d) = BW/2\min\left\{\log_2\left(1+SNR_{L1}\right), \log_2\left(1+SNR_{L2}+SNR_{L3}\right)\right\} \quad (1)$$

where SNR_{L1} denotes the the signal to noise ratio for the considered communication link 1, SNR_{L2} represents the signal to noise ratio for link2 and SNR_{L3} presents the signal to noise ratio for link 3, BW represents the channel 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:

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

A. *Proposed Routing Protocol*

The proposed routing protocol is divided into five stages in which we perform route discovery later, we 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 (IDRREQ), 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. Additionally, selected channel for communication, probability of channel availability and cooperative cost. 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:

$$Cost_{i,j} = 1/max\left(CC_{rate}\right) \tag{3}$$

The destination node may receive several RREQs, here we assign a timeout period for RREQ. Once the timeout period is finished the RREP message is transmitted to the source node with the current information and the destination node can select a path which has the least cost and better ratio of channel availability. The exchange of RREP and RREQ is depicted in the given Figure 3 along with their corresponding routing table. According to Figure 3 the source node is A and the destination node is J, the obtained final path is A → D → G → H → 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 exists multiple path 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 do 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 channel c can be denoted as:

$$I_{i,c} = \sum_{j \square S_i} P_{j,c} \tag{4}$$

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 channel can be computed as:

$$P_{j,c} = \sum_{j \square S_i} P_j \left(h_i^2 h_j^2\right) G_i \cdot G_j / d_{i,j}^k L_f \tag{5}$$

Where h_i denotes 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:

$$I(t) = \sum_{i,c} I_{i,c}(t), i = 1,2,3,\ldots N \quad \text{and } c = 1,2\ldots M \tag{6}$$

Where *N* denotes the total CR users, *M* denotes the total number of channel 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:

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

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.

3) *Cooperative communication metric:* Generally, ad-hoc routing networks aims on achieving the higher capacity link by considering several metrics to identify the quality of selected path such as number of hop count and expected transmission time etc. However, these metrics are not suitable due to heterogeneous nature of CR devices. The channel availability and utilization are subjected to the secondary user location and activities of primary users. Hence, some percentage of channel may be utilized by the primary user for a specific time duration. Here, we define a channel utilization process for node over the channel, channel utilization information can be achieved from the information exchange which provides the information that how frequently a channel is occupied by the primary user. During communication phase in CRN, the cognitive users request the bandwidth from primary users to establish the communication. This bandwidth is known as the operating amount of bandwidth for channel c in a given time duration of t, this amount of bandwidth can be expressed as:

$$BW_i^c = b_w^c\left(1 - U_i^c\right) \tag{8}$$

Where b^c_w represents the channel bandwidth and U denotes the channel utilization. At this stage, we have available bandwidth information of the CR user at channel *c* but the available bandwidth between links of two nodes at a channel *c* can be computed as:

$$BW^c_{i,j} = b^c_w\left(1-U^c_i\right)\left(1-U^c_j\right) \quad (9)$$

Eq. (9) concludes that channel which is available for both transmitter and receiver simultaneously selected for effective communication. With the help of this usable bandwidth, we can measure the capacity between two nodes. According to (1) and (2), direct data transmission capacity can be denoted as given in Eq.(9) which is used to identify whether to transmit the directly or using a cooperative relay:

$$Cap_{direct}(i,j) = BW^c_{i,j}\left(1+SNR\right) \quad (10)$$

Sim $CC^c_{coop}(i,r,j) = \frac{1}{2}\min\left\{BW^c_{L1}, BW^c_{L2}\right\} \times \min\left\{\log_2\left(1+SNR_{L1}\right), \log_2\left(1+SNR_{L2}+SNR_{L3}\right)\right\}$ with the help

$$CC^c_{coop}(i,r,j) = \frac{1}{2}\min\left\{BW^c_{L1}, BW^c_{L2}\right\} \times \min\left\{\log_2\left(1+SNR_{L1}\right), \log_2\left(1+SNR_{L2}+SNR_{L3}\right)\right\} \quad (11)$$

At this stage, we measure the direct communication capacity and the cooperative communication rate, if $CC_{coop} > Cap_{direct}$ then the relay node based scheme is selected for improving the throughput.

4) Route establishment: Once all RREQ packets are received, the 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 using the following process. First of all, we compute the delivery rate based on the channel availability. Let us consider that a routing path from source to destination node is expressed as p(s,d) = {s,r1.r2,..r$_i$,d}, the delivery rate for the link can be given as:

$$P_{s,d} = P\left(P_{s,r1} = 1, P_{r1,r2} = 1, P_{r_i,r_i+1} = 1\right) \quad (12)$$

Here, $P_{s,r1}$ = 1 denotes that the available current channel is accessible by cognitive users. Later, we compute DRREQ based on the time stamp and assign the path for communication which satisfies the link delivery rate from the sequence of D_{RREQ}.

5) *Route maintenance:* 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 channel is available, if the channel is not available then the complete path is rebuilt. Let us consider that we have total C number of channels are available but the link between current node and next node fails where communication channel is c1 then this channel is also discarded and another neighboring next hop channel is selected. If no suitable channel is available, then the complete process is repeated to establish the communication route.

Algorithm 1 Algorithm

Input: Network configurations, Primary Users, secondary users

1: Network deploy as =G (V_{SU} ; V_{PU} ; E)

2: Find the neighboring node and node cooperation rate for the communication links using Eq. and Eq. (2). The cooperation rate is CC_{rate} || This process is for node overhearing

Route discovery Mechanism

3: Broadcast RREQ message with the information such as destination node ID & its location, Time stamp, relay node information from source to destination nodes, selected channel for communication and ratio of channel availability, and cooperative cost.

4: Compute the cooperative cost as:

$$Cost_{i,j} = 1/max\left(CC_{rate}\right)$$

5: Assign a timeout period for current RREQ to avoid the collision of other upcoming RREQs.

6: Identify whether the next hop node is suitable for transmission and send RREP message to the source node. This process is repeated until the destination node is

7: Switching delay and interference

8: Compute the path loss as :

$$P_{j,c} = \sum_{j \in S_i} P_j\left(h_i^2 h_j^2\right) G_i.G_j / d^k_{i,j} L_f$$

for the considered channel and measure the interference

9: Construct the routing matrix based on the interference and delay caused during channel switching.

10: Compute the direct communication capacity as Cap^c_{direct} cooperative communication capacity as CC^c_{coop}

11: if $CC^c_{coop} > Cap^c_{direct}$ then transmit the data using cooperative relay nodes.

12: Route Establishment

13: Establish the communication route based on the links between cognitive users.

14: Route Maintenance

15: Identify another suitable channel from the available channels

16: else

17: Repeat the complete process to reconstruct the route.

18: End

TABLE 2: Notations used for simulation parameters

Sl No	Considered Parameter	Considered Value
1.	Number of PU	2
2.	Number of SU	100
3.	SU Transmission Range	125 meter
4.	PU Transmission Range	140 meter

5.	Packet Size	512 Bytes
6.	Data Rate	16Kbps
7.	Network Deployment	$1000 \times 1000m^2$
8.	Network Capacity	1.5Mbps

IV. RESULTS AND DISCUSSION

This section presents the experimental analysis using proposed approach and the performance of proposed JCIAR approach is compared with the state of art techniques such as Primary User Aware k-hop (PAK) [16], AODV [13], CAODV [13], and LAUNCH [25]. According to the proposed model we have introduced an interference parameter which has significant impact on the switching delay performance. The Simulation parameters are presented in the given table 2 and 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 $1000 \times 1000m^2$ 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 a CBR data traffic with the 16Kbps data rate.

1) Performance measurement metrices : In order to evaluate and compare the performance of proposed model, we consider four different types of performance metrics which are network throughput, packet delivery ratio, average end-to-end delay, and routing overhead ratio. A brief discussion about these metrics is presented below:

• Network throughput: This is the measurement of total number of bits transmitted successfully and correctly to the destination node in each second of the simulation. For entire network, the throughput of all sources is considered for the given simulation time. If more number of bits are transmitted successfully, then the network throughput increases.

• Average End-to-End Delay: This is the measurement of average time taken by all packets to reach to the desired destination node. It is also measured by computing the delay of all packets from all source nodes. To achieve the better performance, the delay should be minimized.

• Packet delivery ratio: Ratio of total number of packets successfully received out of the total sent packets at the destination. The better packet delivery rate lead towards the better communication.

• Routing overhead ratio: This is measured by taking the ratio of transmitted control packets and total number of transmitted data packets. Routing overhead must be less for any network to achieve the reliable communication.

2) 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.

TABLE 3: Network Throughput

Number of SUs	AODV	CODV	PAK α=0.5	PAK α=0.9	JCIAR
50	30	35	55	65	80
100	65	80	110	125	135
150	90	105	115	136	160
200	105	122	125	140	172
250	115	130	130	145	175

The above given Table 3 shows the comparative performance in terms of network throughput for varied numbers of SUs. As the number of SUs are 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 shown in Fig.4..

The given Figure 5 below 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 number 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.

Figure 6 depicts a performance analysis in terms of packet delivery rate. The proposed scheme achieves better performanceasitachievestheaverageperformanceis80.6,the other techniques achieves 44.4, 57.2, 40, and 45 using AODV, CODV, PAK α=0.5 and PAK α=0.9. The performance of proposed approach is improved by 81.53%, 40.90%, 24.76a% and 13.52% when compared with the AODV, CAODV, PAK α=0.5 and PAK α=0.9. The figure 7 illustrates the performance comparison in terms of routing overhead for varied number of SUs.

The routing overhead increases due to the increased number of paths. The average overhead is obtained as 0.12, 0.11, 0.054, 0.076 and 0.043 with the help of AODV,

CAODV, PAK α=0.5, PAK α=0.9 and JCIAR.

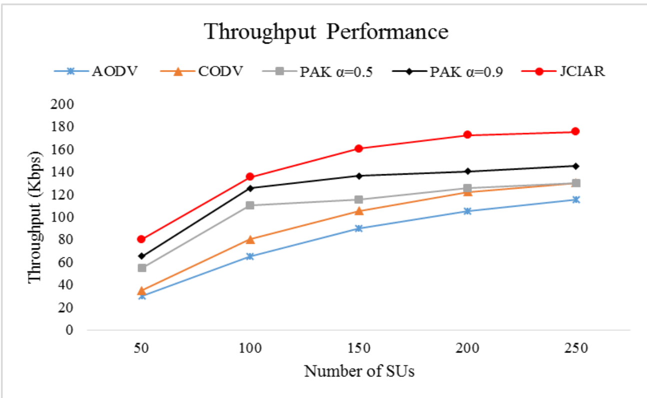


Fig. 4: Throughput Performance for varied SUs

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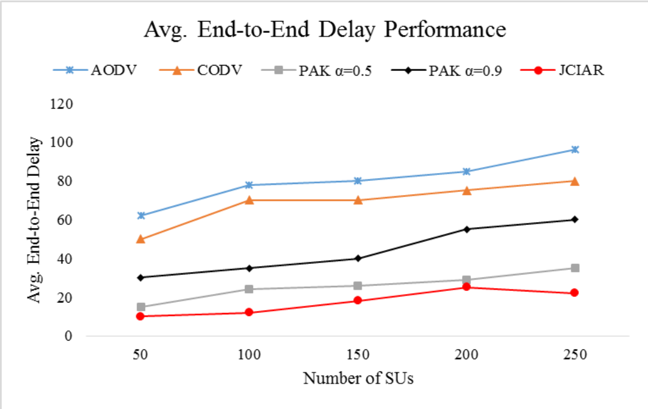

Fig. 5: Avg. End-to-End Delay performance

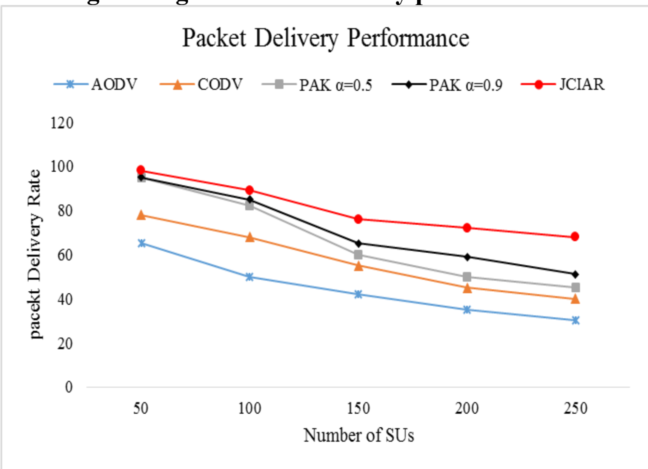

Fig. 6: Packet Delivery Performance

3) Performance measurement for varied rate of packet generation: In this sub-section, we present the comparative performance analysis with different rate of packet generation during simulation. In order to show the comparative performance, we consider AODV, CAODV, PAK and LAUNCH [25] protocols.

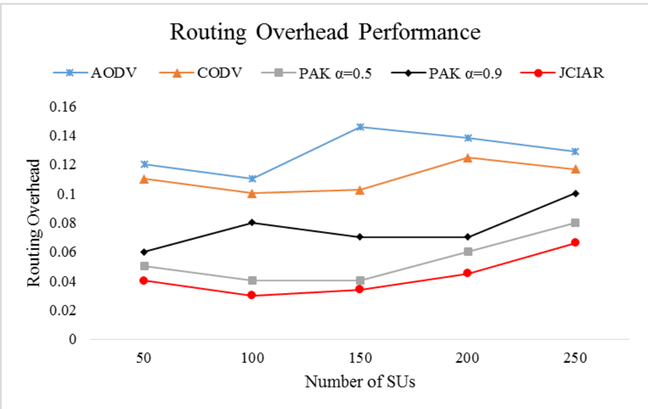

Fig. 7: Routing Overhead performance

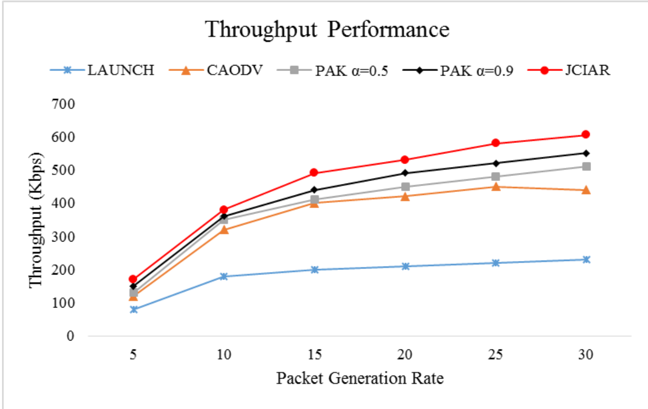

Fig. 8: Throughput performance for different rate of packet generation

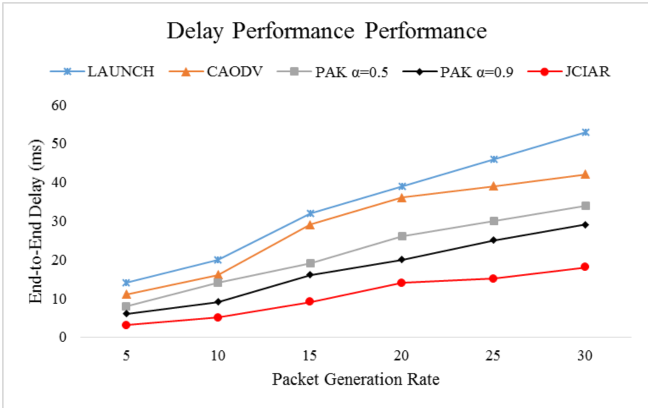

Fig. 9: Delay performance for varied packet generation rate

4) Performance measurement for varied rate of packet generation: In this sub-section, we present the comparative performance analysis with different rate of packet generation during simulation. In order to show the comparative performance, we consider AODV, CAODV, PAK and LAUNCH [25] protocols. The obtained

5) performances are carried out in terms of network throughput, packet delivery, end-to-end delay, and routing overhead. Figure 8 shows a comparative performance in terms of throughput where proposed JCIAR approach achieves better performance. The average throughput is obtained as 186.6%, 358.3%, 388.3%, 418.3%, and 459.1% using LAUNCH, CAODV, PAK α=0.5, PAK α=0.9 and JCIAR respectively.

Similarly, we compute the performance with respect to end-to-end delay. The obtained performance is depicted in figure 9. This study shows that the packet generation rate affects the delay performance because more number of packets causes congestion in the network hence the total time required to deliver a packet is also increased. In this simulation, the average delay performance is obtained as 34, 28.83, 21.83, 17.5, and 10.6 using LAUNCH, CAODV, PAK α=0.5, PAK α=0.9 and JCIAR respectively.

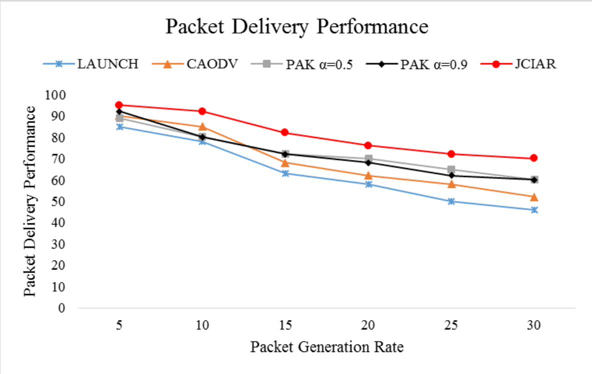

Fig. 10: Packet delivery performance

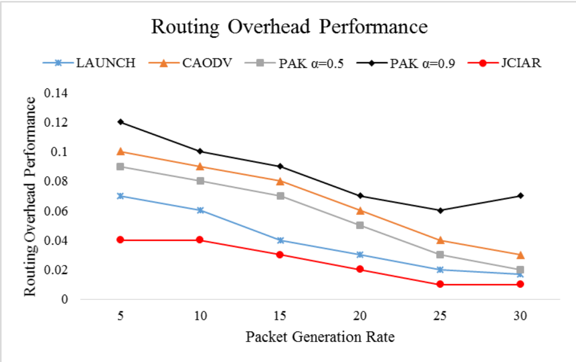

Fig. 11: Routing overhead performance

The delay performance comparison is depicted in Figure 10. It increases as the number of packet generation rate increases. This affects the packet delivery performance and the rate of packet delivery also decreases. The simulation analysis shows that the average packet delivery performance values are obtained as 63.3, 69.1, 72.6, 72.3 and 81.16 using LAUNCH, CAODV, PAK α=0.5, PAK α=0.9 and JCIAR routing protocols for cognitive radio network.

In Figure 11 illustrates the routing overhead performance for different rates of packet generation. This study shows that when number of packets are generated more the control packets are transmitted less comparatively also routing overhead decreases. The average overhead is obtained as 0.039, 0.066, 0.056, 0.085 and 0.025 using LAUNCH, CAODV, PAK α=0.5, PAK α=0.9 and JCIAR respectively.

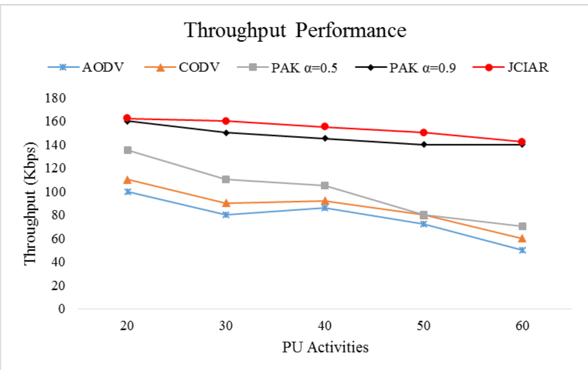

Fig. 12: Throughput performance for varied PU activities

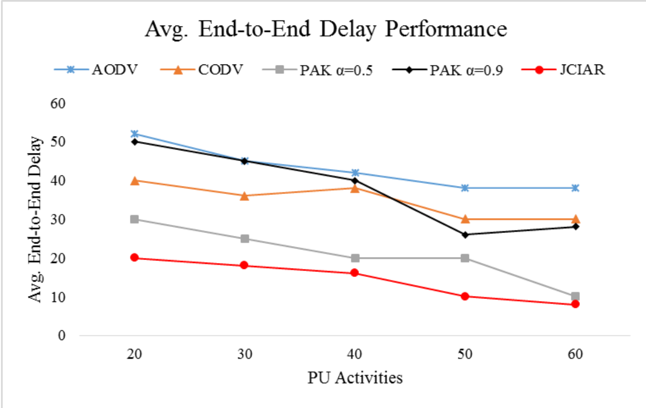

Fig. 13: End-to-End Delay Performance

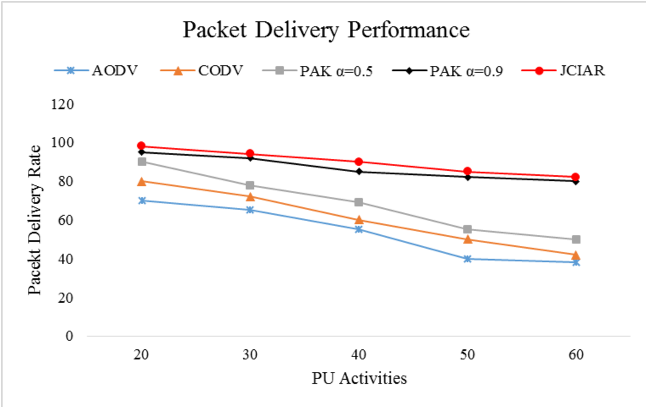

Fig. 14: Packet Delivery Performance

6) Performance measurement for PUs activities: In Cognitive Radio Network, PU activities have significant impact on the network performance because the more PU activity results in the higher interference. Hence increased activities of PU degrades the network performance. The performance is measured and compared with the existing techniques.

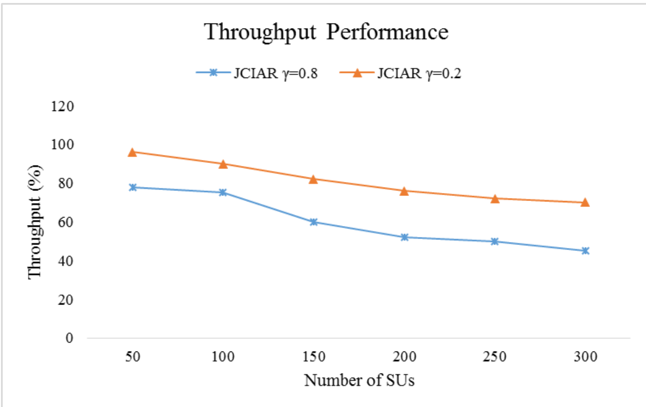

Fig. 15: Throughput performance

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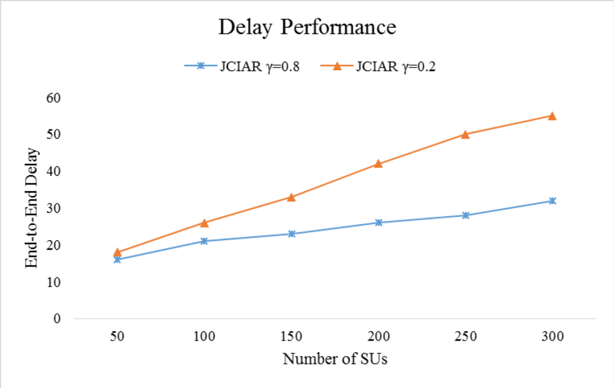

Fig. 16: Delay performance

Figure 12 represents a comparative performance in terms of network throughput for varied number of PU activities. Due to more activities high interference is generated in the network with that the average throughput performance is obtained as 77.6, 86.4, 100,147, and 153.8 Kbps using AODV, CODV, PAK α=0.5, PAK α=0.9 and JCIAR respectively. The performance of proposed JCIAR approach is improved by 98.19%, 78%, 53.8% and 4.62% when compared with AODV, CODV, PAK α=0.5, and PAK α=0.9 respectively.

Similarly Figure 13 depicts a comparative performance with respect to average end-to-end delay. The average delay for varied PU activities are obtained as 43, 34.8, 40, 75, and 14.4 using AODV, CODV, PAK α=0.5, PAK α=0.9 and JCIAR respectively.

By considering the same packet generation rate, Figure 14 shows a comparative performance in terms of packet delivery. The proposed approach achieves the average packet delivery rate as 89.8% whereas existing techniques achieves 53.6, 60.8, 68.4, and 86.8 using AODV, CODV, PAK α=0.5, and PAK α=0.9 successively.

7) Performance measurement for varied values of gamma: In this sub-section, we present a comparative study by considering the interference control parameters as γ=0.8 and γ=0.2. As we have mentioned before, it mainly focuses on reducing the delay otherwise focuses on throughput. A comparative performance for these two scenarios is presented in Figure 12, 13.

Likewise Figure 15 illustrates that when control parameter is considered as γ=0.8 the average throughput is obtained as 60% whereas the average throughput is obtained as 81% for γ=0.2. In this scenario, the performance gradually decreases where number of SU users count increased.Finally, we evaluate the delay performance for varied number of SUs depicted in Figure 16. In this simulation, we have considered similar configuration as considered to obtain the throughput performance using control parameter. In this case, the performance linearly increases where number of SU user's increases. According to the simulation, we conclude that the average delay performance is reduced.

V.CONCLUSIONS

In this paper, we have presented a novel routing approach for cognitive radio network. The proposed approach considers interflow interference and channel switching delays are the key challenging issues which degrade the network performance. Hence, we present a joint approach for interference and channel aware routing 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 Joint channel and Interference Aware Routing (JCIAR) is compared with the existing techniques. The simulation study shows that the proposed approach achieves better performance in terms of network throughput, delay, routing overhead and packet delivery rate.

In future work, we focus on developing a security aware resource allocation mechanism for cognitive radio networks.

REFERENCES

1. A. Cammarano, F. L. Presti, G. Maselli, L. Pescosolido, and C. Petrioli, "Throughput-Optimal Cross-Layer Design for Cognitive Radio Ad Hoc Networks," IEEE Transactions on Parallel and Distributed Systems, vol. 26, no. 9, pp. 2599–2609, 2015.
2. X. Tang, J. Zhou, S. Xiong, J. Wang, and K. Zhou, "Geographic Segmented Opportunistic Routing in Cognitive Radio Ad Hoc Networks using Network Coding," IEEE Access, vol. 6, pp. 62766–62783, 2018.
3. J. S. P. Singh and M. K. Rai, "CROP: Cognitive Radio Routing Protocol for Link Quality Channel Diverse Cognitive Networks," Journal of Network and Computer Applications, vol. 104, pp. 48–60, 2018.
4. Y. Saleem, K.-L. A. Yau, H. Mohamad, N. Ramli, and M. H. Rehmani, "SMART: A SpectruM-Aware ClusteR-based Routing Scheme for Distributed Cognitive Radio Networks," Computer Networks, vol. 91, pp. 196–224, 2015.
5. A. Ahmad, S. Ahmad, M. H. Rehmani, and N. U. Hassan, "A Survey on Radio Resource Allocation in Cognitive Radio Sensor Networks," IEEE Communications Surveys & Tutorials, vol. 17, no. 2, pp. 888–917, 2015.
6. Y. Zhang, "Dynamic Spectrum Access In Cognitive Radio Wireless Networks," in 2008 IEEE International Conference on Communications. IEEE, 2008, pp. 4927–4932.
7. Y. Lin, C. Wang, J. Wang, and Z. Dou, "A Novel Dynamic Spectrum Access Framework based On Reinforcement Learning for Cognitive Radio Sensor Networks," Sensors, vol. 16, no. 10, p. 1675, 2016.
8. J. Ren, Y. Zhang, N. Zhang, D. Zhang, and X. Shen, "Dynamic Channel Access to ImproveEnergy Efficiency in Cognitive RadioSensor Networks," IEEE Transactions on Wireless Communications, vol. 15, no. 5, pp. 3143–3156, 2016.
9. A. J. Goldsmith, S. A. Jafar, I. Maric, and S. Srinivasa, "Breaking Spectrum Gridlock with Cognitive Radios: An Information Theoretic Perspective." Proceedings of the IEEE, vol. 97, no. 5, pp. 894–914, 2009.
10. K. Singh and S. Moh, "An Energy-Efficient and Robust Multipath Routing Protocol for Cognitive Radio Ad Hoc Networks," Sensors, vol. 17, no. 9, p. 2027, 2017.
11. A. Banerjee, A. Paul, and S. P. Maity, "Joint Power Allocation and Route Selection for Outage Minimization in Multihop Cognitive Radio Networks with Energy Harvesting," IEEE Transactions on Cognitive Communications and Networking, vol. 4, no. 1, pp. 82–92, 2018.
12. T. Suzuki and T. Fujii, "Joint Routing and Spectrum Allocation for Multi-Hop Inter-Vehicle Communication in Cognitive Radio Networks," International Journal of Intelligent Transportation Systems Research, vol. 15, no. 1, pp. 39–49, 2017.
13. A. S. Cacciapuoti, C. Calcagno, M. Caleffi, and L. Paura, "CAODV: Routing in Mobile Ad-Hoc Cognitive Radio Networks," in 2010 IFIP Wireless Days. IEEE, 2010, pp. 1–5.
14. M. A. Rahman, M. Caleffi, and L. Paura, "Joint Path and Spectrum Diversity in Cognitive Radio Ad-Hoc Networks," EURASIP Journal on Wireless Communications and Networking, vol. 2012, no. 1, p. 235, 2012.
15. S. Ping, A. Aijaz, O. Holland, and A.-H. Aghvami, "SACRP: A Spectrum Aggregation-based Cooperative Routing Protocol for Cognitive Radio Ad-Hoc Networks," IEEE transactions on communications, vol. 63, no. 6, 2015.

16. A. Guirguis, F. Digham, K. G. Seddik, M. Ibrahim, K. A. Harras, and M. Youssef, “Primary User-Aware Optimal Discovery Routing for Cognitive Radio Networks,” IEEE Transactions on Mobile Computing, vol. 18, no. 1, pp. 193–206, 2019.
17. S. G. K. N., S. H. Manjula, and V. K. R., “A Comprehensive Review on Spectrum Management, Security and Energy-Efficient Cognitive Radio Networks,” International Journal of Computer Applications, vol. 182, no. 37, pp. 25–44, 2019.
18. D. Jiang, X. Ying, Y. Han, and Z. Lv, “Collaborative Multi-Hop Routing in Cognitive Wireless Networks,” Wireless personal communications, vol. 86, no. 2, pp. 901–923, 2016.
19. A. Guirguis, M. Karmoose, K. Habak, M. El-Nainay, and M. Youssef, “Cooperation-based Multi-Hop Routing Protocol for Cognitive Radio Networks,” Journal of Network and Computer Applications, vol. 110, pp. 27–42, 2018.
20. Y. Du, C. Chen, P. Ma, and L. Xue, “A Cross-Layer Routing Protocol Based on Quasi-Cooperative Multi-Agent Learning for Multi-Hop Cognitive Radio Networks,” Sensors, vol. 19, no. 1, p. 151, 2019.
21. W. Wang, A. Kwasinski, D. Niyato, and Z. Han, “Learning for Robust Routing based on Stochastic Game in Cognitive Radio Networks,” IEEE Transactions on Communications, vol. 66, no. 6, pp. 2588–2602, 2018.
22. G. Cheng, W. Liu, Y. Li, and W. Cheng, “Spectrum Aware On-Demand Routing In Cognitive Radio Networks,” in 2007 2nd IEEE International Symposium on New Frontiers in Dynamic Spectrum Access Networks. IEEE, 2007, pp. 571–574.
23. Z. Yang, G. Cheng, W. Liu, W. Yuan, and W. Cheng, “Local Coordination based Routing and Spectrum Assignment in Multi-Hop Cognitive Radio Networks,” Mobile Networks and Applications, vol. 13, no. 1-2, pp. 67–81, 2008.
24. J.-P. Sheu and I.-L. Lao, “Cooperative Routing Protocol in Cognitive Radio Ad-Hoc Networks,” in 2012 IEEE Wireless Communications and Networking Conference (WCNC). IEEE, 2012, pp. 2916–2921.
25. K. Habak, M. Abdelatif, H. Hagrass, K. Rizc, and M. Youssef, “A Location-Aided Routing Protocol for Cognitive Radio Networks,” in 2013 International Conference on Computing, Networking and Communications (ICNC). IEEE, 2013, pp. 729–733.

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