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CURRENT STATE OF BENCHMARKING SPECTRUM SENSING AND ROUTING STRATEGIES IN COGNITIVE RADIO AD HOC NETWORKS

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ABSTRACT

Cognitive radio technology is one of the prominent solutions developed to address under-utilization of spectrums. The CR technology provides different solutions by exploring different segments in the spectrum based on the opportunities created due to the temporary vacation of licensed users. Ease of networking the devices equipped with cognitive abilities for creating CRAHNs networks poses several challenges at different layers of the network. These challenges arise primarily due to the inherent flexibility in accessing spectrum by multiple devices.

This paper offers a survey of the contemporary spectrum sensing and routing solutions in *CRAHNs* . The report commences through listing the spectrum sensing and routing challenges which are linked to the *CRAHNs* . In the next sections, the research work discusses multiple routing protocols and sensing protocols mostly designed for the cognitive radio network. These protocols can be broadly classified into six groups on the basis of routing metrics. The routing metrics considered for this analysis include-hop/delay, throughput performance, reasonable stability, energy consumption awareness along with multi-metric protocols. These multi-metric protocols either unite multiple metrics or engage different metrics as per specific rules. The paper also offers a discussion of the directions which ought to be taken by the future research.

Keywords: *Cognitive Radio Ad Hoc Networks, Spectrum Sensing, Routing, Channel Scheduling, Quality Of Service*

1 INTRODUCTION

According to McHenry [1], current spectrum measurements (indicate that fixed spectrum assignment policy has generally not been suitable for wireless communication in the current world. Federal Communications Commission (*FCC*) [2] report indicates that numerous spectrum bands allocated via static assignment policies are only adopted in restricted geographical regions or over limited time durations. The report also indicates that the average use of bands like that are varying between 15 percent and 85 percent. So as to make good use of the brands that are not utilized bands, devices having cognitive abilities may be networked for the creation of a Cognitive Radio Network. It is worth pointing out that the cognitive radio ad hoc networks (*CRAHNs*) have become an emerging ad hoc or multi-hop wireless networking solution in which nodes are capable of changing their reception parameters or transmission based on their interactions with their environments. In *CRAHNs* networks, two types of users exist with the different set of rules but access same spectrum. Of this two types, Primary Users are given top priority for spectrum usage in the licensed band. Secondary users, on the other hand, have to opportunistically have right to use to the spectrum devoid of interfering with the primary users.

1.1 The need and Objective of the Study

The study of CR networks is primarily focused on techniques for optimum sharing of spectrum and schemes for sensing spectrum.

The spectrum sensing schemes work on identifying the available portions in the spectrum and checks the readiness of secondary users for accessing the temporarily available spectrum space [3]. It checks if the Secondary Users (SU) is operating within a licensed band so as to escape any kind of damaging and destructive interference to the *PUs* . Spectrum sharing schemes typically aim to offer fair and acceptable scheduling techniques for users by providing access to a suitable channel.

In contrast, varying behaviors of primary users often pose failure in routing in CR networks. The varying behaviors of these users dynamically affect the opportunities available to secondary users. To address routing failure problems in CRAHNs, researchers proposed several new algorithms.
On the basis of the metric which is employed in constructing the route, they may be grouped as: link stability based, delay based, location-aware, throughput based, combined metrics, energy based, as well as multi-metric protocols. This report is mainly aimed at surveying diverse *CRAHNs* routing protocols with the main emphasis on describing the different metrics employed in the routing discovery, as well as maintenance procedures of every protocol.
The research is organized into various kinds of sections. Section two generally offers a summary of the major challenges that are experienced in routing information via multi-hop *CRAHNs* while Section three offers the discussion of the taxonomy of routing protocols in the *CRAHNs* . Section four concludes the paper by pointing out some of the open research issues which can be used in conducting future research.

2 REVIEW OF CONTEMPORARY LITERATURE

The contribution of this section is a systematic literature survey of benchmarking models available for secure QoS aware spectrum sensing and routing in cognitive radio ad hoc networks. Section 2.1 explores the contemporary spectrum sensing models depicted in recent literature. The later section (2.2) depicts an explorative view on preponderant routing strategies related to CRAHN.

2.1 Prevailing Spectrum Sensing Strategies

Of the existing strategies for spectrum sensing, utilization of Beta reputation concept is one of the most discussed assessment system [5]. The system identifies a node's ability to sense reputation and is used as a primary factor for deciding spectrum scheduling.
The principal concept presumes that the user transmission range is adequate enough to be obtained by all nodes in CRN and SUB stations. It also assumes that an interaction is possible between PU and SU base station. The interaction is subject to successful reporting of errors on CRN procedure to the base station. However, as the concept assumes that a primary user is unable to sell unutilized bands, no compensation is provided for its interaction with CRN. Accordingly, primary use faces additional overhead in the form of hardware addition and increased system complexity.

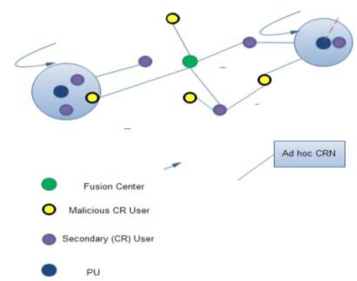

Figure 1: Ad Hoc CRN With Malicious Nodes.

Sensing reports from primary user's coverage bans only must be considered for spectrum scheduling. Further, only related secondary user's prominence weights are updated.
Further, the CRN can utilize freely available spectrum bands without interfering with other requirements of Licensed User.
The study also negates the mobility of both primary and secondary users by suggesting a strategy of collaboration based spectrum sensing [6]. It works by designing two reliability criteria- reliability of location along with malicious intent.
The Dempster-Shafer Theory of substantiation is used for evaluating the reliability of exposing SU's nodes. The proposed collaboration strategy allocates reliability values to different cells in each of the networks which can gain access to exceptional stages of PU's signal. This is due to weakening signals, multi-path consequences and other considerations in the network. The secondary users' spectrum sensing recorders using trust values and Equal-Gain Combining (EGC) assigned to the respective cells gives equal weights for data consolidation.
The underlying assumption for this strategy is that interaction range of a licensed user is highly sufficient to be accessed by entire CRN network. Further, it arrives at ultimate spectrum allocation decision by assessing each CRN node related reports on spectrum sensing.
In [7] and [8], researchers designed strategies with considerations that the range of transmission of Licensed User is highly adequate to be accessed by entire CRN network. The study in [7] conducted pre-filtering of each sensing report so as to arrive at simple design strategy and

eliminate the presence of any drastic sensing reports.

Researchers in [8] hypothesized the spectrum sensing task as the M-ary hypotheses testing problem and suggested a cluster approach. In the cluster based network, cluster heads obtain and process raw sensing data and transmit it to the fusion center.

Analyzing both the studies presented above, one can conclude that their underlying assumption is that a primary user's range of transmission is adequate enough to all the nodes in CRN to access. However, in practice, both approaches fail to address the case scenarios where primary users' transmission range is less than CRN size.

The set of spectrum sensing models [9], [10], [11], [12] observed in recent literature are based on game theory strategy. The QoS factors optimized in orthogonal modulation based cooperative cognitive radio networking [9] are throughput and transmitter power output [13], The carrier shifting optimality (also referred as joint rate) and transmitter power output are two metrics considered as prime objectives of the approach called "joint rate and power control in cognitive radio networks" [10]. The common objective of the models [11], [12] is the cost of the spectrum sharing. Spectrum sharing model [11] along the price, the scope of performance degradation due to the increase in a number of secondary users with divergent channel preferences. The approach of price analysis towards optimal spectrum sharing [12] is achieving the spectrum sharing under competitive price, which is done by the cooperative pricing model proposed. The QOS objectives of the downlink joint power control and resource allocation scheme [14] are transmitter power output control and achieving optimality in resource allocation. This scheme is devised in the context of co-channel deployed femtocells in macrocell networks. The experiments evincing the optimal allocation of power and frequency to femtocells. The adaptive channel allocation scheme [15] that aimed at QoS objectives transmission power output control, inference in spectrum sensing and optimal bit rate in Orthogonal Frequency Division Multiplexing (OFDM) systems.

The novel price based spectrum sharing scheme [11] that scheduling the resources in descending order of users with maximal weighting time. Alongside, the throughput and fairness are other two QoS factors considered in this scheme. Interference-aware channel allocation for Device-to-Device communication scheme [16] aimed to maximize the D2D communications with minimal inference. Another cooperative spectrum sharing scheme [17] aimed to achieve fair throughput under multi-channel sensing in divergent traffic conditions. In order to this, the Hungarian and greedy assignment and transmission algorithms [18] are customized. The experimental study evincing the usage of Hungarian algorithm is optimal than the greedy approach.

The Hungarian algorithm based channel allocation and transmission scheme is also adapted by two-way relay cognitive radio networks [19]. This scheme uses the selective secondary users as relays to the primary users that minimizes the signal to inference plus noise ratio for primary user transmissions and accordingly maximizes at secondary user transmissions. The performance of this scheme is outstanding that compared to traditional power allocation and relay selection algorithms. The other novel cooperative spectrum sensing model [20] that uses iterative Hungarian channel allocation and transmission approach was evinced the success to achieve optimal spectrum sensing.

All the above mentioned schemes, the Quality of Service (QoS) requirements such as avoidance of following are not scaled in the spectrum sensing process and channel allocation process.

(i) faded channel allocation,
(ii) compromised node cooperation,
(iii) Inference due to interference of other secondary or primary users and
(iv) Channel with improper band allocation

The overall objective of the existing benchmarking models is to prioritize the interests of a primary user under the cost of optimal spectrum allocation and transmission interests' of the secondary user. This manuscript focuses on the scope of quality of service at secondary users' spectrum sensing transmission interests in cooperative cognitive radio networks with the multi user and multichannel sensing property. The spectrum sensing decisions by a secondary user is done by the spectrum state information shared by neighbor cognitive radio enabled nodes.

Medium-Access-Control (MAC) protocols are adapted in using the DSA scheme for CRNs. In the case of MAC protocol, there are usually two phases predominantly, as contention phase and data transmission phase. In the contention phase, SUs rather than focusing on the common control channel shall focus on the idle licensed channels, through which successful SUs which shall take over the idle channels in the transmission phase.

There is numerous protocol solutions defined in for MAC protocols [21], [22], [23], [24].

In [21], distributed MAC protocol was proposed which comprise the SUs having common channels for forming groups and for multiple groups some SUs performing as gateways. The data is transmitted by SUs using the data based on their success in the contention phase.

In the distributed MAC protocol proposed by Chen et al [22], SUs shall form clusters that are controlled by a group leader for each cluster, which conducts the contention and data transmission process. Also in another model proposed in [23], the distributed multi-channel MAC protocol was proposed in which SU pair gets the opportunity to sense and access during the contention phase and use the available channels for the hardware constraint. In the case of distributed multi-channel MAC discussed in [24], all the available access channels that are sensed using the sensing policies are accessed by the SU paid during the contention phase.

In all the aforesaid conditions, there is a high quantum of control overheads as the SUs usually contend in a random manner for channels, certainly the outcome shall be much lower with the MAC protocols. [25], [26], [27], [28], [29], [30] whereas in the case of DSA that is implemented using scheduling algorithms that can achieve higher throughput. DAS system has the process in which at the beginning of every slot, information regarding bandwidth requirement is collected from the SUs by the scheduler and it is broadcasted on common control channels. From the received schedule, the SUs access the corresponding channels for the slot time that is remaining, and the model is defined as slot-based scheduling schemes.

[25] Proposes the scheduling algorithm which is based on integer linear programming (ILP), which is a unique channel user pair that is activated for varied time instants within the slot. Models in [26], [27], [28], [29], [30] presents numerous scheduling algorithms which can support in maximizing the transmission capacity for the SUs which are presented. In the scheduling algorithm discussed in [26], certain factors like the fairness, traffic demand to the SUs, link capacity, and the Signal-to-interference-and-noise ratio (SINR) are considered. Whereas, in [27], the factors like fading, interference, and packet waiting times are considered, unlike [28] in which the focus is upon throughput, maximum frequency and the packet waiting time. In [29], that achieves proportional fairness for SUs, focus on packet waiting time and the interference caused due to SU to the PUs receiver, but in [31], the model focus on assigning the idle channels to SUs depending on if the signal-to-noise ratio (SNR_ shall be used at the receiving SU which could be highest for any given channel.

The information exchange taking place by the scheduler in the slot based scheduling schemes are even comprised in the scheduling overhead for the SUs in the beginning. Considerable quantum of slot time is lost in the communication to the scheduling overhead due to low bandwidth in the common control channel and because of such model, the effective transmission of the data channels are getting reduced and are constraining the throughput achievable. Also, the scheduling overhead works on increasing the number of channels that can work on SUs, and not any of the aforesaid [25], [26], [27], [28], [29], [30] shall focus on issuing of scheduling overhead.

Review of the earlier models and the literature reflect that the scheduling overhead could majorly impact the system performance, and hence such issues have to be addressed in the scheduling scheme design.

One-Way Delay is a typical measuring parameter in routing algorithms as it faces multiple scenarios of multi-hop CRN network. In [31], [32], [33] and [34], routing metrics aware of such delays are proposed, which take into account different features of these delay components.

Whenever nodes switch between different frequency bands to decrease Back-Off delays, switching delays appear.

Medium Access Control (MAC) protocol is the primary reason for the occurrence of these delays. This leads to addressing hidden node problem and exposed node problems when operating in the same frequency band.

On the other hand, Queuing delays [32] are predominantly dependent on node transmission capacity in a specific frequency band. Delays occurring due to On-Demand (ODR) routing protocol compromises parameters like switching delays, back-off delays, queuing delays which impact in terms of selecting the path and towards interesting nodes that are indicated by PATH- DP delay and NODE-delay (NDP).

The DP identifies both switching and cumulative delays for these models. It also considers back-off delays based on the channels allocated to the nodes.

In [34], researchers used Swarm Intelligence approach for routing. The model works in cases when the source node neither develops ant

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colonies nor creates route request packets in the data transmission process. Network demand determines the ants' number and details of what the ant colony produces. The source node functions by assuming that N (p) number of ants are transmitted to neighboring nodes and transmit RREQ packets accessible on free channels.
Upon successful delivery of RREQ request packets to secondary node I, ants count is greater than zero. In such cases where the secondary node is not destination node and fails to receive RREQ packets, the satisfying nodes are identified if the following conditions in its neighbor node are identified.
In [35] Gymkhana, researchers concentrated on detecting routes with maximum stability in the routing process. Further, the study identified the routes which can escape network zones, which have variable link stability so as to evaluate network connectivity. The stable link detection process can be observed in three sections-
In order to capture specific parameters related to user path between source and destination is captured through the use of the distributed protocol of AODV- style.
To indicate the PUs is encountered in the given path, a mathematical structure depicting a graph shall be considered.
A closed formula computed using the second smallest eigenvalue of the Laplacian associated with the graph of the part shall be considered.
The algorithm needs to optimize utility functions, which are considered as key parameters for evaluating both length and connectivity of the network path. Analysis of the approach provides information on system efficacy. However, the model faces limitations like high complexity involved similar to other mathematical models. The usability of the models is restricted to large-scale data routing with large reliability requirement. The model needs to be simplified for applying it to cases with small data sizes and relatively low-reliability issues.
Researchers in [36] developed a routing protocol using Spectrum Tree structure- STOD-RP. The framework functions by considering QoS requirements as the primary route metric. Further, the model also considers Primary user's statistical activities as the key evaluation parameter.
In addition, to resume connectivity between multi-hop networks, tree-based routing, the discovery of on-demand route and recovery of spectrum adaptive route are vital. Further, resource consumption costs and link stability factors are also included in routing metrics.
The STOD-RP protocol forms a tree in all the available spectrum bands. The CRN users consider such tree as spectrum tree with one root. Further, the related node has the highest number of such trees. The root node carries some specific information regarding the tree topology. The nodes related to different trees and the nodes with multi-radios are regarded as 'overlapping nodes'. These overlapping nodes can work for different spectrum trees at the same time.
The model proposed in [37] depicted higher reliability as compared to earlier models. The model focused on the protocol to identify path with highest link stability among all feasible options. The identified path is made the primary path for transmission. Further, a second path is also identified based on maximum disjoint with the first identified path. Channel and link stability periods along with switching delays are considered as the key routing parameters for evaluation.
Routing in large-scale networks is studied in [38], which can decrease search space on the basis of node positions. Further, the study also detects most stable routes for secondary users. However, certain challenges like high complexity due to large density of secondary users can occur in this large-scale networks model. Accordingly, to address these complexity issues, ETX count parameter is proposed. This ETX metric primarily varies with link/ channel loss ratio for identifying stable routes. Further, the model is efficient in lowering hops volume in selected routes.
A new protocol based on location is proposed in [39], to assist mobile multi-hop networks. This model also supports routing and channel selection for secondary users. To avoid conflicts, the protocol bypasses primary user activity regions. Assessment of how to avoid primary user coverage area while switching channels is the primary focus of the model.
LAUNCH, another location based protocol is proposed by researchers in [40]. Similar to SEARCH protocol proposed in [39], the LAUNCH uses location information for routing.
However, the key difference between the two studies is that LAUNCH protocol uses stochastic activity of primary users for selecting stable routes. Further, among stable routes, long-lived ones are preferred and are assigned to primary users in their active time.
The LAUNCH protocol inherently decides about the next hop neighbor based on proximity to destination and minimum delays expected in the process.

In [41], an energy aware protocol is proposed. The SER protocol can be used for attaining the balance of energy usage among secondary users. Accordingly, it ensures that reducing energy supplies are not allocated to primary users, forcing them to leave the network.

The RREQ request process in SER is largely based on DSR protocol suggested in [42]. In the DSR protocol, source node contains a few packets to transmit to the destination node. Further, the process relays RREQ request packets in the process to CCC.

Towards selecting the energy-efficient path, routing metric has the maximal minimal nodal residual energy that has lower hop count. Only in cases of availability of common channels of any type, intermediary nodes will participate in the transmission process.

The value of residual nodal energy in the route mEREs is equivalent to the battery energy at the initial levels, in a source node, but when the RREQ propagation process is in progress then the intermediary nodes compare their own residual energy with the battery saver. In addition, SER supports maintenance of route by handling errors in route or failures at nodes via local recovery (RREC) process.

MWRP [43] focus on the routing metric that focuses on the transmission power essential to reach the receiver power for a certain interface. Varied levels of interfaces adapted with varied levels of communication range and also the dedicated demand common control channel (CCC) for communication among SUs. Considering the fact that there is some free space propagation model, the route discovery procedure might be similar to the routing algorithms with link stage, and the new link weight shall be based on the transmission power which is minimized with the most efficient route.

CRP model focus on combining varied CR-specific performance metrics that are proposed in [44] and some of the key metrics that are considered are about the bandwidth availability probability, the differences in the number of bits that are sent over the link and the level of spectrum propagation characteristics, spectrum sensing consideration and the PU receiver protection. Such factors reflect upon the impact of how varied metrics are considered in one technique.

The CRP model primarily includes two stages. In the first stage, CR user identifies the best spectrum and also selects suitable channels available in the band. The above listed metrics are used for identifying these channels. Further, for every class of CR route, optimization function is designed. These routes act as initiative depicted by CR for the participating route.

During the second stage, based on the spectrum choice and physical conditions, ranks are assigned. Ranks determining CR initiatives for subsequent route data are also considered. These initiatives are then mapped to delay function so as to facilitate RREQ request messages. This ensures all preferred users to broadcast this request message much earlier. On the other hand, the destination node emphasizes on final route adhering to the desired routing class outcome.

In [45], authors focused on traffic type for routing. It can be considered as a variant of CRP protocol. The MRSED model switches dynamically among different parameters determining QoS metrics. Unlike CRP model, the MRSED model does not adapt to a cluster of multiple metrics. Instead, three metrics are independently adapted including link stability, load balancing, and delays.

Analyzing early literature, we can conclude that the prime focus of all models was primary users. However, a significant impact was felt on optimizing spectrum allocation and transmission interests of secondary users.

In addition, the existing models rely on only one of the QoS service metrics [34]. Accordingly, more effective strategies are needed like the ones addressed in [44] and [45]. These models considered multiple parameters for arriving at the best route. The proposed model is similar to these models in the aspect of parameter selection.

In the proposed model, the focus is given on achieving optimum QoS using multiple metrics instead of single metric. Further, genetic algorithms are deployed for facilitating the model development [46]. In addition, the proposed model varies from existing models in the process of laying the path between the source node and the destination node. It uses the combination of different channels that can connect with intermediate nodes.

2.2 Benchmark routing strategies

It is worth pointing out that routing in *CRAHNs* is highly challenging because of the stochastic activity of *PUs* that plays a major role in distinguishing them from conventional multi-channel multi-hop ad hoc networks. In the *CRAHNs* , nodes generally have to handle coinciding transmissions of *PUs* that dynamically alter network topology, as well as the availability

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of spectrum opportunities (*SOPs*) . Therefore, some more challenges are always added to *CRAHNs* that include:

- In *CRAHNs* the , not only the location of nodes but also the frequencies of their communication affect the connectivity of network different from multi-channel multi-hop networks in which distance of the nodes from each other is the only factor affecting the connectivity of the network.
- Availability of channels in CRAHNs networks varies from conventional multi-hop wireless networks. Nodes can have partial overlap or can have non-overlapping channels availability. These channels also vary with time-based on the *PU* activity, as well as its effective area.

Due to the challenges above, classical ways of assessing the routes' quality (like delay, throughput, and energy efficiency among others) are not adequate in *CRAHNs* . They ought to be coupled with newer measures which take into consideration spectrum availability and path stability/ *PU* presence and also capture spectrum information and integrating them into the process of routing in *CRAHNs* .

As illustrated in Figure 2, we group the proposed protocols into six major groups:

(1) Protocols employing delay as a routing metric;
(2) protocols selecting most stable routes
(3) Throughput based protocols which strive to ensure the maximization of throughput;
(4) Location-based protocols, which are making use of location information for the construction of routes through the use of nodes which are very close to the destination;
(5) Energy-based protocols which strive to reduce the consumed energy at every node;
(6) Combined, as well as multi-metric protocols, either which is a combination of numerous metrics together or which employ diverse metrics based on certain specific rules for satisfying *QoS* requirements.

The sections below offer a description of the process of route discovery of the surveyed protocols in every category in detail emphasizing on the routing metrics that have been used.

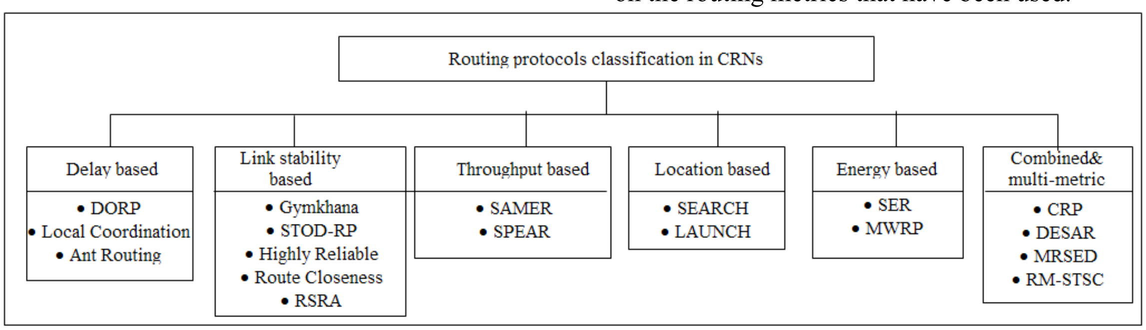

Figure 2: Metric-Based Taxonomy Of Routing Protocols In CRN

2.2.1 Delay-based routing protocols

This part of the report provides an overview of the routing approaches which are measuring the quality of the routing solutions with regards to delays.

End-to-end delays or One Way Delays in the path between source and destination is the most conventionally adapted parameter in designing routing algorithms. However, it faces several cases of multi-hop CRN. Simultaneously, other metrics like delay-aware metrics are proposed in [32], [33], [34]. These studies consider different types of delays including-

1. Switching delay: Occurs with the node in the scheduled route opts for a different frequency band.
2. Back-off delay: MAC protocol brings about back off delay when attempting to solve the hidden-terminal, along with exposed-terminal issues (while operating on similar frequency band).
3. Queuing delay: Queuing delay is primarily based on a node's transmission ability in a particular frequency band.

The sections below offer a brief description of every protocol, which uses delay metric, besides specifying the delay elements which are employed for every one among them.

2.2.2 Combined spectrum assigning and on-demand routing

In [32], a delay based routing model is proposed. A routing protocol functioning on demand and motivated by delays in the system is investigated.

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The approach is generally composed of numerous delay metrics (backoff delay, switching delay, as well as queuing delay) to efficiently and effectively choose the least delay route from end to end, back-off delays at nodes or the path, switching are referred to as Node-Delay and Path-Delay respectively. These are employed in evaluating the collective delay of the path. At the m^{th} relay node, a measuring parameter is designed to represent total delay along the route.

DORP Generally inherits the procedures of Ad-hoc On-demand Distance Vector (*AODV*) . If a given source node *m* desires to convey data to the destination where it is having no routing information for it, it generally broadcasts Route Request packet (*RREQ*) on common control channel (*CCC*) which is generally not subject to the *PUs* interruptions the assumption is used by a number of *MAC* as well as routing protocols in the *CRNs* [43], [47], [39]. If an intermediate node gets *RREQ* , it generally checks the current *SOPs* – which is generally a list of presently available channels. When it is having an intersection with closest *SOPs* , it replaces the current *SOPs* in *RREQ* and passes to the next nodes. On the contrary, when the *RREQ* packet is obtained at the destination, the frequency band is selected from an intersection point of SOP opportunities with minimum DNm, summarizes the choice into RREP packet and relays the packet back to the source. In case of an intermediate node receiving RREP packet, it selects frequency band from the intersection point of SOP opportunities with minimum value of DNm+DPm. Of this, DPm is computed from node m to destination. It then incorporates spectrum choice into the packet and sends back to source. And then, the source node initiates data transmission.

2.2.3 Local route allocation and spectrum assignment

Yang et al. [33] propose a general framework for multi-hop CRN, focusing on achieving highly efficient routing along with spectrum assignment. This model generally has two parts-

- Joint on-demand scheme which routes algorithm based on band selection, aiming at achieving least end-to-end delay.
- Local coordination algorithm is designed for load balancing across multiple frequencies in intersecting relay node.

Joint on-demand scheme is generally a variant of AODV. In most of the cases, route is determined by the source node which broadcasts RREQ request message containing local state data. The information is then transmitted to intermediate nodes. These intermediate nodes add their own SOPs to RREQ request messages.

When the *RREQ* message gets to the destination, the destination node calculates the total delays in the transmission process by using parameters depicted in Eq. (4). After selecting the optimum available frequency band, the destination sends RREP reply message on the same path of RREQ request message.

The second part, local coordination algorithm is used for providing intersecting nodes for redirecting data. This scheme initiates possibility of modifying routes as RREP is transmitted along return route.

This is capable of improving performance due to the fact that the nodes which carry over a flow may need to switch to different frequency bands incurring larger delay.

2.2.4 Improvements in ant routing algorithm

In [34], researchers proposed novel algorithms for routing based on the principle of swarm intelligence. It is worth pointing out that swarm intelligence is a highly powerful technique which is employed in solving big scale tasks in distributed patterns. The model is developed on the concept of collective behaviors of ants. Despite ant being a small creature, an ant colony is capable of presenting a social organization which is highly structured.

Driven by this organization structure, ant colonies can accomplish complex tasks which are otherwise cannot be performed by individual ants like detecting best route to food sources, as well as sharing the information with the other ants [48]. Currently, swarm intelligence has widely been employed in routing algorithm in the communications networks [49].

In [34] source node generates ant colony besides creating *RREQ* packet when it is having data which is supposed to be transmitted. It should be noted that the amount of the ants is generally influenced by the demands and needs of the network.

After ant colony production, the source node calculated ants count N(p) and transmits to neighboring nodes and resends RREQ request packets over available channels. In the case of a secondary node *i* receiving the RREQ request packet, it finds out nodes, which satisfy a number of conditions in the available neighbor node table.

However, the total ants count should be greater than zero and the receiving node must not be destination node.

2.2.5 Protocols evaluating Link stability

Nodes continuously communicate over the same frequency in a conventional WANET network. Accordingly, the distance between nodes and transmission power used remain the only parameters capable of influencing connectivity in network.

On the contrary, in *CRAHNs* network, as *SUs* face spectrum heterogeneity, different connectivity concepts are observed. Further, in *CRAHNs* , any two nodes can connect to each other provided they remain in radio visibility range and at least one coming channel is available. Accordingly, in *CRAHNs* , *SOPs* communication can impact network connectivity in addition to transmission power and distance between nodes. The section provides an overview of the suggested routing algorithms focusing on identifying multi-hop paths with maximum stability in the *CRAHNs* .

The major objective of Abbagnale and Cuomo [35] was discovering the routes which are the most stable.

The study was successful in calculating connectivity of different paths, data packets in paths that evade network zones that do not guarantee stability and links with high connectivity. The proposal can be detailed in three major parts-

1. A distributed protocol based on *AODV* style- The protocol collects certain specific metrics related to candidate paths between source node and destination node.
2. Simple mathematical structure depicting a graph related to the given path transmitting information from *PUs* .
3. A closed formula which is calculated through the evaluation of the second lowest eigenvalue of the Laplacian linked to the graph of part two.

The algorithm strives to maximize the above utility function. The metric generally accounts for path connectivity, as well as the length of the path. Assessment of the algorithm illustrates how effective the approach which has been proposed is. However, the mathematical model which has been introduced is highly complex and ought to be opted in a few scenarios (like for critical data routing of huge dimensions, which need high-reliability levels, but for smaller data size that may endure in reliability, it ought to be made simple. Or else, a hybrid algorithm may be employed).

Collaboration between the route selection, as well as spectrum decision has also been taken into consideration by [36]. They propose Spectrum Tree based On Demand Routing Protocol ($STOD-RP$) framework which is a combination of: (i) a route metric that takes into consideration both the *CR* user's quality of service (QoS) needs, as well as statistical primary user activities; (ii) proactive routing using tree structure, and on-demand route identification; (iii) spectrum-adaptive recovery for resuming connectivity in the multihop networks. Regarding the routing parameter, it is developed on resource usage as well as on route stability (so as to reflect both the *CR* user’s *QoS* needs and the primary user activities).

In the $STOD-RP$, the *CR* users form a tree in every spectrum band, which is available, referred to as spectrum-tree. Every spectrum-tree is having just a single root. The node belonging to the biggest amount of the spectrum trees or which is having the lengthiest time duration where an available spectrum band is selected as the root. This root node is vital for holding topology information of the spectrum- tree. The nodes with multi-radios and belong to multiple spectrum-trees are termed as ‘overlapping nodes’. They are capable of working in several spectrum-trees simultaneously. Every node is having unique *CRID* in a single spectrum-tree. *CRID* of node X is $CRID_x = A_0A_1......A_n$, in which A_0 is the spectrum band in which the formation of spectrum-tree takes place. It is also *CRID* of the root in the spectrum-tree, n is hop number away from the root. It should be noted that the overlapping node is having numerous *CRIDs* .

It is also noteworthy that the spectrum-tree which has been formulated is employed for both intra-spectrum routings, as well as for inter-spectrum routing. The intra-spectrum routing takes place in one spectrum-tree, whereas the inter-spectrum routing takes place in several spectrum-trees. On the other hand, routing within spectrum is engaged whenever the root confirms that destination node differs from spectrum tree in the perspective of source. The root then assesses all inter-spectrum nodes so as to identify overlapping nodes among different spectrum bands. When the root attempts to detect overlapping nodes, two of the following cases can occur-

- Case I- The root fails to obtain overlapping node: the root shall obtain data directly from source node and can then relay the given data to the destination node through the use of proactive links.
- Case II- The root successfully obtains an overlapping node: In this case, the root chooses the node having lowest queuing size and then transmits route request data to this node. This node obtains route request data between source and destination is to be established by itself. Accordingly, the intermediate node transmits route request data in the first and second trees so as to obtain the best path for source and destination nodes respectively.

2.2.6 Reliable routing in CRNs based on spectrum awareness

In contrast to previously proposed solutions, reliability is attained in Song and Lin [37] through the exploitation of the multi-path routing concept. The major design concept falling behind the protocol entails choosing the route which is deemed to be the most stable among every candidate and using the route as primary one and selecting second path that has maximum disjoint from the main path which is referred to as alternative path that is employed when the main path fails due to the detection of *PU* or because of any other type of reasons. The route metric used for evaluation is typically a combination of link stable time (LST) and channel stable time (*CST*) , as well as switching delay for the selection of the path that is the most stable.

The Beltagy et al., [47] exploited the model of multi-path routing to ensure reliability. However, the model introduced a new routing parameter termed as ‘Routes Closeness’. It should be noted that the Routes Closeness metric chooses the paths on the basis of their distance from one another. As the distance between routes increases, PU interruption faced by routes decreases due to the fact that one active mobile *PU* is not capable of interrupting each of them at once. Therefore, choosing non-close routes is capable of minimizing the quantity of interrupted paths and hence, there is always an increase in the levels of reliability of the connection as well as that of throughput.

In the route discovery stage, a new variant of *DSR* protocol, with some specific differences is implemented in order to be appropriate for ‘routes closeness’ parameter. The DSR tries to detect a direct, straight and shortest route between source node and destination node.

However, if the shortest path is inadequate, the protocol tries to setup multiple paths spanning across the entire field. To detect the best route, an algorithm evaluating multiple routes and determining the best one among candidate routes is proposed. The parameter considered for detecting the best root is maximum proximity between routes.

There is a slight different between the work which was done by Gad et al. [38] and the past work that have been done. Its target is not just the selection of stable, as well as highly robust routes for the *SUs* , but also the introduction of a new method for large-scale *CRNs* which minimizes network search space size on the basis of the position of the nodes. Large-scale *CRNs* are facing numerous additional challenges which are not existing in the normal *CRNs* . The major challenge includes the huge density of *SUs* which are capable of significantly increasing the routing algorithm’s complexity. The high density of *SUs* is also responsible for increasing the quantity of the possibilities for given nodes to select the subsequent hop node that results into an increase in the computational complexity. The challenges generally play a major role in motivating the work of the proposed large-scale routing protocol. Further, the protocol uses ETX count metric for selecting most stable routes. It calculates the link/channel loss ratio for determining the route.

It is also aimed at reducing the number of the hops in the chosen route as possible.

A trivial scenario for minimizing the search space is to get the shortest path between the destination and the source (through the use of any shortest path algorithm like Dijkstra). Then, take into consideration one-hop neighbor for every node in the path that has been obtained for the construction of a sub-network with minimal numbers of nodes. When that has been done, the weights are assigned to every link within the sub-network based on the *ETX* metric. The path which is having the minimum cost is chosen. The main problem of the scenario is the very high complexities during the stage of initialization (getting the shortest path) and that it needs full knowledge of the network topology.

However, a highly efficient scenario has been introduced by the *RSRA* . On the basis of the location information of the destination and source nodes, the length of the line which is connecting them may be easily calculated (L_{SD}) .

2.2.7 Throughput based routing protocols

Throughput refers to the average rate of fruitful and effective packet delivery at every second. This part of the report presents the routing protocols which have the target of throughput maximizing.

According to Pefkianakis and Wong [50] Spectrum Aware Mesh Routing (*SAMER*) refers to a solution for routing for *CRNs*, which takes into consideration both the long term, as well as the short term spectrum accessibility. It typically attempts to balance long-term optimality (in terms of hop count), and the shortest opportunistic gain (with regards to higher spectrum availability).

The primary target of the algorithm is to opportunistically utilize network spectrum, by diverting traffic to paths having higher spectrum availability. Simultaneously, the algorithm attempts to achieve long-term stability by remaining in the shortest hop-count path. This plays a role in the maximization of aggregate throughput.

SAMER Generally constructs a forwarding mesh that is always adjusted occasionally based on the dynamics of the spectrum and routes packets opportunistically along the mesh. To ensure efficiency, the mesh is positioned around the shortest path (long term) in terms of hop count. However, the mesh can opportunistically vary in size on a periodic basis to ensure maximum utilization of available spectrum. The paths are connected using the PSA metric. Later, opportunistically, the packets are transmitted across the path available in the given instance and with highest PSA value.

The *PSA* metric's goal is capturing:

1. Local spectrum availability: The availability of spectrum at a node is based on the quantity of the spectrum blocks those are available at i, the aggregated bandwidth, as well as conflict with secondary users.
2. Quality of Spectrum blocks: The quality of spectrum blocks depends on bandwidth and loss rates.

If a node relays a given packet, the subsequent hop is selected locally along the route which is having the optimum *PSA* value with availability of given spectrum. Every spectral resource reservations are often performed over *CCC* prior to the transmission of a packet by the *SU*. In case of very high SU content observed in flows, the same is reflected in bandwidth availability metrics. This in turn modifies the PSA values of the routes. As a consequence, the scheme that is proposed is accounting for *SU* and *PU* activity for ranking the routes. It is also noteworthy that *SAMER* has been established to perform better than the popular hop count, as well as the Expected Transmission Time (*ETT*) metrics, something which ultimately results into higher end-to-end performance. On the contrary, overheads which are linked to forwarding mesh establishment, as well as maintenance have generally not been considered in great depth.

Sampath et al. [51] introduced a multi-hop distributed channel assignment, as well as a routing algorithm which is supporting high-throughput transmission of the packet.

The SPEAR model attempts to address heterogeneity issue of the spectrum. Flow-based models with inherent flexibility observed in link-based approaches are end-to-end optimized and then integrated for handling spectrum heterogeneity.

The contribution majorly comprises three sections which include integration of the spectrum discovery, as well as route discovery for coping up with heterogeneity in spectrum; Effectively organizing allocations of channel based on per-flow by lowering inter-flow interference; building on heterogeneity of local spectrum by allocating different channels to links with flow for the minimization of intra-flow interference.

Further, the route detection phase occurs only if a node has data to deliver and it will transmit AODV route request packet to neighboring nodes which have information on channel availability and quality of different nodes.

The SPEAR model engages multiple routes to reach destination for detecting best path unlike AODV model. To handle interflow interferences and intra flow interferences, intersecting nodes store flow timetables. The model parameters are combined and are also employed by the destination for the selection of the optimal route whose reservation is then done through the use of *RREP* message.

2.2.8 Location-based routing protocols

The location of most of the wireless devices, which are presently being used are enabled. It is always anticipated to spread very fast over the coming decades.

It is assigned a key role in keeping work momentum in location-based parameters for CRN networks, mainly in cases where location details of CR nodes can be easily obtained from FCC. The study in [2] depicts *FCC* Geolocation-Databases. Despite the fact that routing which is based on location has been researched already, for ad-hoc type networks, the routing usage in CRNs faces multiple types, as well as newer challenges like the highly dynamic changes in the connectivity of network because of the rapid changes in spectrum opportunity of *CR* nodes as a result of *PU* activity. The other issue entails making the routing protocol to be aware of the various dynamic changes and mutually selecting the route, as well as the channel which will be employed in the process of routing.The section provides an overview of two routing protocols which employ location-based metric in the construction of the given routes.

According to Chowdhury and Felice, [39], *SEARCH* (refers to the routing protocol on the basis of greedy location that is designed for mobile multi-hop *CRNs* . It is worth pointing out that the proposed protocol generally makes routing, as well as decisions regarding channel selection as it also avoids areas of *PU* user activity. The primary functionality of the process which has been proposed entails the evaluation of when the area of coverage of *PU* ought to be circumvented, as well as when altering the given channel is the option which is desired. Firstly, it should be noted that the shortest routes to the destination, based on geographic forwarding and volume of Primary User activity are recorded for each channel. The destination node, then integrates different paths by selecting switching locations of channel so as to minimize the number of hops to destination.

In the case of a need to transmit data, RREQ request is sent by source node on all channel uninfluenced by primary user activity in the given location. The request is then forwarded through intermediate hops to the destination node. It is worth pointing out that *SEARCH* has two modes of operations, which include the *PU* Avoidance and Greedy Forwarding on the basis of RREQ propagation in the greedy shortest path towards destination node. Lastly, the routes on individual channels are joined at the destination point by joint channel-path optimization algorithm.

Greedy geographic forwarding has the ability to decide the candidate forwarders of *RREQ* that ought to be selected as the subsequent hop for the minimization of the distance to destination. *RREQ* Forwarding process has to take place on similar channel. At the same time, the next hop that is chosen should not be in the primary user coverage area in the current transmission path. Further, the selected forwarder must be present in the specified area around the available hop, which is referred to as Focus Region. It should be noted that the focus region refers to a sector of a circle which is positioned on the line, which is connecting a current node to its destination, consisting of an angular range of around 2θ. If the forwarding node is unable to identify any node in the given region, the node is notified as Decision Point by itself. The SEARCH moves to primary user evading stage from the greedy forwarder stage. This classification is done because the emergence of DPs occurs when an active area is observed in its path on the spectrum band.

According to Habak et al.,[40], *LAUNCH* refers to a location-based routing protocol that makes use of location information in order to offer guidance to the process of route discovery. Unlike the *SEARCH* protocol, the *LAUNCH* protocol uses stochastic activity of Primary Users in the process of selecting which are the most stable. Additionally, it does not just handle the *PUs* when active, however, the protocol also selects the routes which are highly stable. Further, long-term routes are preferred over short-lived routes. *LAUNCH* Generally makes greedy decision for the selection of the next hop neighbor which satisfies a number of conditions:

- It is in proximity to destination (which ensures that the packer is close to destination)
- Least predictable delays estimated between any two nodes

LAUNCH Simpler in comparison to *SEARCH* and at the same time, it is not having every detail that is presented in the *SEARCH* . However, it offers a good performance assessment through assessing the various effects of altering the density of *SUs* , data rate, *PUs* number, *SUs* mobility, *PUs* heterogeneity, as well as the number of the channels.

2.2.9 Energy based routing protocols

When taking into consideration a network having portable, as well as battery-powered devices, it should be noted that energy conservation is of great significance and challenging. In the *CRAHNs* , energy management of the nodes is highly significant because of the extra particular tasks that they have in comparison to the non-cognitive radio networks. This section provides explanation of the routing protocols which are targeting minimization of the energy that is consumed.

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According to [41], *SER* refers to an energy-aware routing protocol for *CRAHNs* which is mainly aimed at balancing the consumption of energy between them *SUs* . Hence, it prevents the critical users from depleting energy supplies, as well as dropping out from the network.

RREQ Broadcasting procedure of *SER* is founded on *DSR* protocol [42] if a source node is having packets that it needs to send to the destination node. *SER* Also offers a process of route maintenance through the use of the local route recovery (*RREC*) as well as route error (*RERR*) if any failure takes place at the nodes (because of depletion of energy or because of mobility).

According to Pyo and Hasegawa [43], in *MWRP* the routing metric refers to the transmission power needed in order to get to the receiver over a given interface. Diverse interfaces are employed in accessing diverse Wireless Systems (*WS*) like *WLAN* or cellular. Every interface is linked to a diverse communication range. A devoted common control channel (*CCC*) is employed for the purpose of communication among *SUs* . Assuming the free space propagation model, the link's weight can easily be defined.

It is worth pointing out that the procedure for route discovery is just same to link state routing algorithms. The new link weight, which is based on transmission power is reduced for the selection of the route which is the most efficient.

2.2.10 Combined and multi-metric routing protocols

Whereas numerous routing protocols use just one metric as presented in past sections, there are other routing protocols, which are combining numerous metrics into a single metric for the augmentation of some constraints to the route which has been chosen. Other protocols are using multi-metric approach which dynamically switches among different routing metrics for the satisfaction of the *QoS* requirements or to provide better performance for diverse network conditions.This section presents a number of these protocols.

The *CR* routing protocol (*CRP*) that combines numerous key *CR* -specific performance metrics have been proposed by Chowdhury and Akyildiz [44]. The metrics, which are taken into consideration during the stage of route setup include: (1) probability of availability of bandwidth (2) differences in the quantity of the bits which are relayed over the link, (3) the characteristics of spectrum propagation (4) protection of *PU* receiver as well as (5) considering spectrum sensing. Accordingly, it can be listed as a part of some cases which take into consideration these huge quantities of metrics in a single technique. The major contributions of *CRP* include:

1. Explicitly protecting *PU* receivers: It is noteworthy that for unidirectional transmission like television broadcast, the *PU* transmitters are not suffering from the interference, which is brought about by *CR* network. However, transmissions of the *CR* users might have various impacts on *PU* receivers which can't be detected very easily. *CRP* Offers protection to the *PU* receivers through shunning the regions in which devices like such might possibly be available.

2. Enabling numerous classes of routes: It is worth pointing out that protecting *PUs* brings about degradation of performance for *CR* network due to the fact that avoiding regions of the *PU* activity brings about selecting longer paths with the sole aim of minimizing interference to *PUs* . Based on the preferred protection level for the *PUs* , as well as *CR* user's end-to-end latency needs, a number of routing classes can be employed. *CRP* Offers two routing classes; class1 offers greater importance to the end-to-end latency. At the same time, they meet the minimum *PU* interference avoidance. On the other hand, class 2 is prioritizing *PU* protection over attaining low end-to-end latency for the individuals using *CR* .

3. Scalable, joint route-spectrum selection: Due to the fact that all spectrum band might be made up of numerous channels of different bandwidth, transmitting the route requests in every channel of the diverse bands is adding significant overhead. *CRP* Is using common control channel (*CCC*) .

Features of the selected spectrum by a given user of *CR* are always mapped in order to delay a function on common control channel. This is always independent of the quantity of the possible spectrum bands.

In the *CRP* , route setup is always following two main phases. For the first phase (which is the spectrum selection phase), every user of *CR* points out the best spectrum band as well as the favorite channels in the given band. In most cases, this is often carried out through the use of numerous distinctive *CR* parameters mentioned above which are given appropriate weights in optimization structure for spectrum selection. The optimization function is then developed for each class in the CR route. The route also serves as a measurement of initiatives represented by CR user in the specific route. The next phase (hop choosing phase) is in such a way that the candidate *CR* users are ranking themselves based on the spectrum's choice as well as the local network together with the physical conditions. The ranks generally influence the *CR* users initiating information of subsequent routes. The initiative is typically tagged with delay functions engaged in RREQ request message forwarding. Accordingly, preferred users can be able to broadcast RREQ message earlier. Further, destination node typically chooses the final route capable of meeting all goals of preferred routing.

It is also worth pointing out that maintenance of the route is also offered in *CRP* . It is having a proactive, as well as a reactive element. It is assumed that the architecture of the network is made up of stationary *PU* transmitters that are having locations which are known and maximum range of coverage similar to Television towers.

CR users are mostly mobile and aware of locations but have limited information about PU receivers. Further, during proactive maintenance process, all CR users compare own location with known PU transmission locations. If *CR* nodes proceed towards PUs, in case of current route failure, a new path is detected proactively to retain connectivity.

A mix of delay, as well as energy-aware metrics is always proposed in the *DESAR* [52]. It takes into consideration both path delay, as well as node energy in the selection of a highly efficient path. *DESAR* Generally a highly reactive protocol which is founded on *AODV* protocol. Just like several other *CRNs* protocols, which are based on *AODV* , *DESAR* generally applies the major procedures of *AODV* protocol with the needed modifications of spectrum management in order to fit in the context of *CRNs* .

It is worth pointing out that what is distinguishing *DESAR* from other protocols is the blend between a delay, as well as energy-aware metrics. Delay metric refers to a mix between backoff delay, switching delay, as well as queuing delay. It is the same metric that is employed by the delay-aware protocol (*DORP*) that is proposed by [32]. It however, also identifies the energy that is consumed by nodes at time t, which is also dependent on the number of packets which are not only transmitted but also which are received.

Hence, the combined metric can easily be determined by adding the delay, as well as the energy metric at every node along the path. It is also noteworthy that the path having the least cost is chosen as the candidate path for transmitting the data that is pending.

On the basis of traffic types, MRSED protocol with service differentiation [45] generally switches dynamically among diverse metrics so as to satisfy *QoS* needs of the diverse types of traffic. Different from the past *CRP* protocol, the *MRSED* generally does not combine numerous metrics together into a single metric. On the contrary, it is switching between three diverse metrics during runtime. Just a single metric is employed in the selection of a route for a given flow. The three metrics which are employed in the *MRSED* protocol include: link stability, delay, as well as load balancing metric.

It is also worth pointing out that *MRSED* is consisting of three major modules which generally includes: Route Discovery Module, Spectrum Sensing Module, as well as Route Maintenance Module. The Route Discovery Module generally incorporates three sub-modules which include: Routing Metric Selection/ Calculation, Route Discovery Initiation, as well as Route Decision Sub-module. Every detail of every module has been described in the following section.

1. Spectrum Sensing Module: This refers to an external module which is charged with the responsibility of sensing the spectrum besides informing every secondary user with the available *SOPs* .
2. Route Discovery Module: It should be noted that the main function of Route Discovery Module entails discovering every possible paths between the source node, as well as the destination node through propagating *RREQ* via intermediate nodes, calculating the cost of every one of them, as well as choosing the route that is having the least cost. It entails three sub-modules which includes: Route Discovery Initiation which is conducted by the source node when there is no valid routing entry which is found for the transmission of data; Routing Metric Selection/Calculation where the suitable metric which will be employed in assessing the route is chosen based on various predefined *CRQoS* requirement rules. It is also calculated through the use of statistical *PU* activities, as well as local node

information. Lastly, in Route Decision Sub-module, destination node always waits for some time after getting the first *RREQ* for the collection of more *RREQs* . It then assesses the list of the candidate routes besides selecting the route with the least cost.

3. Route Maintenance Module: This is charged with the responsibility of recovering route failure because of *PU* appearance or because of issues to do with mobility. If a node which is part of already established route is impacted by *PU* appearance, the Channel-Switch (*CSWTCH*) as well as the Channel-Switch-Reply (*CSWTCH* – Re*ply*) packets are exchanged between the node as well as the neighboring nodes in order to replace the channels which are affected with the most suitable channel for each of them. For the mobility issues, link layer feedback is got when a given node is not successful in delivering data packets to the next hop nodes. It then sends Route Suspend packet to the upstream direction for the provision of information to the source in order to suspend the present session. When the failed link is not recovered after a specified time, new process of route discovery is made by the source.

2.2.11 Routing management algorithm based on spectrum trading and spectrum competition in CRNs (RM-STSC)

The other multi-metric protocol which makes use of numerous metrics for the satisfaction of *QoS* needs has been introduced by [53]. It is founded on spectrum trading, as well as spectrum competition while offering support to diverse *QoS* levels for the secondary users. At the same time, it proposes a fresh idea of defining a profile for every *SU* to offer a highly effective communication level between the *SUs* as well as the *PUs* . Other than the *QoS* metrics, it is also defining some more constraints connected to link stability. The proposed protocol may be divided into two phases: the path selection stage as well as the spectrum trading and competition stage. The first phases' major objective entails managing the spectrum between *SUs* and *PUs* . The second phase is mainly aimed at giving the *SU* chance of specifying its level of *QoS* and also to choose the needed path accordingly.

It is also worth pointing out that spectrum trading takes place between *SUs* and *PUs* where a *PU* trades the unused spectrum to *SUs* for the maximization of revenues. The *SUs* mainly aimed at selecting the spectrum, which satisfies the *QoS* defined level. Generally, this is accomplished through the use of a price function which is dependent on the size of spectrum traded to *SU* , unit price of spectrum traded as well as *QoS* function. Spectrum competition takes place among *PUs* . Due to the fact that there are several *PUs* which provide a spectrum to various *SUs* , *PU* is generally in competition with the other *PUs* through the provision of a price, which is highly suitable for the secondary users.

In the second phase, (the path selection phase), *SU* which is having data to be sent commences its path request through sending the needed level of *QoS* to each of the sensed *PUs* . Every sensed *PU* checks spectrum availability computes the price of every spectrum band and then sends it to *SU* . *SU* Chooses the least price for requested level of *QoS* . Lastly, the *PU* then allocates the selected spectrum band and then relays the path address to *SU* . Concerning the routing metrics, as well as the *QoS* levels, there are three main *QoS* classes provided by the protocol, which has been proposed. They include:

- Class 1 (Delay): Generally, this is the least level of *QoS* and it generally contains the delay as a metric. Here, the delay metric entails propagation delay, as well as queuing delay.
- Class 2 (Delay and Link Robustness): Generally, this is the middle level of the *QoS* combine's two metrics; delay metric of the past class and the link robustness metric. It is worth pointing out that link robustness metric majorly depends on the *PU* presence.
- Class 3 (Delay, Link Robustness, and Expected Transmission Count (*ETX*)): This refers to the greatest level of *QoS* that combines three metrics; metrics of the past two classes besides the Expected Transmission Count metric. The application of the *ETX* capable of enhancing throughput of the chosen paths.

3 DISCUSSION AND OPEN RESEARCH ISSUES

Based on the surveyed protocols, it can clearly be noted that great efforts have been made in the recent past so as to design highly effective, as well as highly efficient routing protocols for the *CRNs* . On the contrary, there exist certain

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limitations and drawbacks in certain protocols which still require additional contribution.

Table 1 gives a summary of the major features of every protocol. Some common characteristics can be shared between different routing approaches. These features are summarized by surveys. One key characteristic is that both the approached combine spectrum selection with routing on all links of path.

In addition, it is worth pointing out that the protection of *PUs* the way it is a highly significant and a major element that ought to be taken into consideration when it comes to the multi-hop *CRNs* . It is also worth pointing out that all solutions protects *PUs* ' continuous communication. However, just very few of them are having the capacity of reconfiguring the path when the *PU* active. At the same time, we observed that just a few solutions have taken into consideration the mobility of the *SUs* , and designing a highly efficient route maintenance process for the recovery of the paths, which are affected by the *PUs* presence. Additionally, *QoS* provisioning is generally not supported by a huge chunk of them. This survey concludes by pointing out that open research issues, as well as routing-related areas which require additional contribution are discussed in the sections which follows.

It is worth pointing out that for the emergency applications, the nodes are not capable of losing the connection during the point at which the transmission is taking place. In case there is an emergency in the chemical factory, all the workers have to be provided with advice immediately concerning the leakages via a network that is capable of multi-casting information in a manner that is highly reliable. Therefore, introducing several routes in a case like that is highly significant. In [54], simple analysis is carried out in order to research the effect of multiple routes on the strength of the routing protocol. It can be noted that the addition of a route to the path that is between the nodes generally plays a major role in increasing dependability by a given degree and besides, it minimizes to a great extent the possibility of failure.

Table 1: Summary Of Routing Protocols In Multi-Hop Cognitive Radio Networks

Protocol	Routing metric	Single or multiple transceivers	Dedicated control channel	Route maintenance efficiency	Single or multi-path	Simulation Env.	QoS
DORP [32]	Delay	Two	Yes	-	Single	GIoMoSim	No
Local coord [33]	Delay	Single	Yes	-	Single	Matlab	No
Ant routing [34]	Delay	Single	No	Fair	Single	OPNET	No
Gymkhana [35]	Link Stability	Single	No	-	Single	Mathematical model	No
STOD-RP [36]	Link Stability	Single	No	Good	Single	NS2	No
Highly reliable [37]	Link Stability	Two	Yes	Fair	Multi	NS2	No
Route-closeness [47]	Link Stability	Single	Yes	Fair	Multi	NS2	No
RSRA [38]	Link Stability	Single	No	-	Single	-	No
SAMER [50]	Throughput	Single	Yes	-	Single	Qualnet	No
SPEAR [51]	Throughput	Two	Yes	Fair	Single	Qualnet	No
SEARCH [39]	Location-based	Single	No	Good	Multi	NS2	No
LAUNCH [40]	Location-based	Two	Yes	Good	Single	NS2	No
SER [41]	Energy-aware	Single	Yes	Fair	Single	Custom Simulator	No
MWRP	Energy-	Multi	Yes	-	Single	NS2	No

[43]	aware						
CRP [44]	Combined metric	Single	Yes	Good	Single	NS2	Yes
DESAR [52]	Combined metric	Single	No	-	Single	NS2	No
MRSED [45]	Multi-metric	Two	Yes	Good	Single	NS2	Yes
RM-STSC [53]	Multi/Combined metrics	Single	Yes	-	Single	-	Yes

As can be observed in Table 1, only few routing protocols for *CRNs* consider issues arising from different routes. A huge chunk of them either make use of a single path or they use two separate paths, which include the primary path, as well as the alternative path so as to attain a routing that is significantly reliable. It is also worth pointing out that the alternative route is used solely if the data packets cannot be delivered via primary path. Generalizing the consideration brings about the usage of numerous paths (not just two paths) based on the reliability level which is needed by *CR* network. All of them should be as separate as possible. Simultaneously, they should be not in proximity to each other because selecting non-close routes typically makes them less exposed to Primary User activities in the same time-period.
They are different from the conventional networks in which topological changes are as a result of node mobility. In the *CRNs* , the topological changes take place because of changes in the *PU* activity too that might affect numerous links at once.
In addition, channel availability in *CRNs* also varies from the conventional multi-channel and Multihop wireless networks. Partial overlapping can be present at the nodes, as well as overlapping sets of the available channels which varies with time. Therefore, irrespective of the stability, as well as the efficiency of routing protocol, established route being impacted by the *PU* generally inevitable. Hence, the development of a highly efficient route maintenance process generally becomes highly significant besides being a task which is non-trivial. Highly efficient techniques for re-routing are highly necessary for overcoming routes which are corrupted by the presence of activating *PU* . As Table 1 reports, just a few solutions have taken into consideration a good route maintenance process. A good number of them are just applying fair techniques for route maintenance like trivial switching to the other channels or rerouting to the other routes without considering the quality, as well as the efficiency of the new route. Based on [55], cross-layering protocol for the route maintenance in *CRNs* is introduced. It generally introduces a novel, as well as a different tool for route maintenance through taking into consideration the physical layer information for the prevention of switching to the routes which are less efficient if a *PU* is very active. It enables multiple *SUs* to supportively move data while nulling out the transmission at the current primary user. Hence, areas which are not allowed for (because of presence) may be penetrated with the existing routes with little changes. On the contrary, the area of route maintenance in thestill requires additional contributions.
It should be noted that the quality of Service refers to the capacity to offer dissimilar priority to diverse data flows, applications, or users, or so as to pledge a given performance level to the flow of data [56]. Resource constraints like spectrum bandwidth, as well as dynamic network conditions with time because of interfering with the, generally increase the need for an appropriatefor diverse applications adapting, and primarily for multi-media applications running on real-time basis. This is largely due to their delay sensitiveness and limited resources in the network.
In [56], the results of survey conducted on provisioning specific to multimedia transmissions in network convey that the various kinds of differences as to why there is the need for a proper system over cognitive radio. This has been provided below:

- Spectrum bandwidth constraints, as well as dynamical alteration of the network topology.
- In the case of video transmission, losing some of some highly significant frames might lower the quality of the video for receiver to a great extent.
- Delays which are brought about by sensing, as well as by the switching activities of the channel might result into some of the video frames missing their deadlines.
- When arrives, with the multimedia traffic might be impacted in comparison to the ones with the archetypal data traffic.

As illustrated in Table 1, just two of the protocols which were surveyed take into consideration the issue of or the service differentiation. They include the[44] as well as [45]. Protocol generally defines two traffic classes, and one of them is favoring the minimization of end-to-end latency for the while the second provides high priority to the protection. Contrary offers diverse service for different traffic kinds. It makes use of different routing metrics based on the type of traffic for the satisfaction of the diverse needs of every traffic hence increasing the efficiency of routing. Additionally, a general cross-layer framework for theprovisioning inhas been proposed by [57]. It is obvious thatprovisioning in thestill require additional contributions.

Mobility falls among one of the major challenging points in networking research. In, mobility of the(receivers and transmitters) as well as (receivers and transmitters) might be considered with diverse challenges for each. Various research activities in theemphasized mainly on the static networks. Very minimal research has been targeting mobility in the field of and a number of them just take into consideration mobility as stated in [45] as well as in the other surveyed protocols. [58] Also played a major role in discussing the main issues, which have been posed by mobility in at the diverse layers of protocol stack. It has also offered various kinds of discussions of a case study which focuses on routing in the cognitive Ultra-Wide Band networks. The impact of twomobility models on spectrum sensing, and not routing, in has been researched in order to establish the parameters which are affecting the spectrum sensing functionality as stated in [59]. It is highly obvious that research in the area ofstill require additional contributions to research the impact of mobility of and.

4 CONCLUSION

CR technology has emerged as a promising solution for efficient spectrum usage. The technology enables utilization of previously unused licensing frequencies by allocating these bands to secondary users. By incorporating the prerequisite of non-interference with primary users ensures that the primary purpose of PU transmission is unaffected. This non-interference requirement builds spectrum sensing and spectrum scheduling as important functions in CR systems. Of multiple sensing techniques proposed, QoS aware spectrum sensing is crucial dimension of the channel scheduling in cognitive wireless ad hoc networks. However, the major constraint of this direction is divergent impact of different QoS metrics.

Cooperative Spectrum sensing, which opts for a distributed path identification model, is recognized as a scalable and optimal model for implementing in Wireless cognitive networks.

On the other hand, the CSS is susceptible to sense false data attacks as the model is based on distributed channel detection. Both in the presence or absence of primary user data, corrupt secondary users can deform RSSs and share among other Secondary Users intentionally. Then, these effects of error-prone results are transmitted throughout the cognitive network. Further, openness of programmable SDR devices equips intruders to easily launch such attacks by easily accessing bottom layers like PHY/ MAC layers. Achieving Qos in sensing during these attacks is very difficult because of inadequate coordination of PUs and SUs along with unpredictable nature of signal propagation in the wireless channel. Accordingly, the need for efficient protection mechanisms for wireless networks is strongly required. To address this issue, this manuscript proposes a novel strategy aimed at achieving QoS-aware spectrum sensing for optimization of route scheduling with an added protection to function in cases of malicious attacks.

This paper has mainly discussed the unique spectrum sensing and routing challenges of the Cognitive Radio Ad hoc Networks. The report has also surveyed the current routing solutions when it comes to Cognitive Radio Ad hoc Networks. A taxonomy of surveyed routing protocols based on the routing metric has been presented which grouped the protocols into six major categories: delay based, energy-aware, link stability based, throughput based, location based, as well as combined or multi-metric protocols, which either combine numerous metrics together or which employ diverse metrics based on certain rules. Lastly, potential directions which out to be taken by future researchers have also been discussed by the paper.

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