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On Platform to Enable the Cognitive Radio Over 5G Networks

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Abstract

With the increase in the number of communication devices, the requirement for higher bandwidth is essential. To achieve this goal, research and industrial communities have both suggested that future wireless systems will take advantage of the numerous emerging technologies. Utilization of Cognitive Radio (CR) for the next-generation Fifth Generation (5G) communication technology is the major advancement for getting a higher bandwidth in a cellular communication network. In this paper, we present a comprehensive study of CR from the perspectives of spectrum allocation schemes, impact and role of MAC layer in spectrum sensing and sharing, CR application in multi-hop wireless networks, and challenges associated with channel selection and packet routing in multi-hop heterogeneous CR networks. This paper also presents the analysis, in literature, of a range of intelligent routing protocols that are considered viable for packets routing in CR networks. The need to address the issue of spectrum depletion and the apparent underutilization of available scarce spectrum resources in existing wireless networks is the primary motivation behind this study. Considering the fact that CR technology can potentially maximize the utilization of bulk of the unused communication spectrum bands for the future 5G of wireless network and beyond.

Keywords Cognitive radio · 5G network · Resource sharing · Routing protocols

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1 Introduction

With the increase in the number of communication devices, the requirement for higher bandwidth is essential. Several researchers and mobile operators are working together with the 3rd Generation Partnership Project (3GPP) to achieve higher throughput with greater user capacity [1]. The next-generation mobile network will be stated as the Fifth Generation (5G) and would be expected to commercialize in the next few years [2, 3]. Expecting data rate for the 5G network is around 100 Gbps with a minimum of 1 ms latency along with better user capacity and battery life [4, 5]. In order to achieve the acceptable Quality of Service (QoS), various potential solutions are in progress such as the use of Millimeter-wave frequency band [6, 7], Cognitive Radio (CR) [8], Massive multiple-input and multiple-output (MIMO) [9], Cooperative Network (CN) using Relay Nodes [10], Coordinated Multipoint Operation (CoMP) [11], Wireless Software defines networking (WSDN) [12], Mobile Ad-hoc Networks (MANETs) [13, 14], Device-to-Device (D2D) communication [15], Internet of Things (IoT) [16], Ethernet passive optical network (EPON) [17], Big Data and Mobile Cloud Computing [18]. Moreover, it also uses several power optimizations [19, 20], interference cancellation [21, 22] and scheduling algorithms [23] in the existing technology.

To address the issue of spectrum depletion in the next era of wireless communications (5G and beyond), CR is considered a key component technology to achieve this seemingly strenuous feat [24–26]. Existing bandwidth regulation policy allows the cellular system to operate only on the licensed spectrum with narrow and fixed bandwidth [27]. While available cellular spectrum resources often appear to have been heavily utilized, recent measurements have exposed a large fraction of underutilized frequency bands which are licensed to various incumbent users who do not utilize them resourcefully. In order words, CR is a form of wireless communication in which a transceiver can intelligently detect which communication channels are in use and which are not, and instantly move into vacant channels while avoiding occupied ones. This optimizes the use of available radio-frequency (RF) spectrum while minimizing interference to other users [28, 29]. Hence, CR systems have the potential to massively increase the efficiency of spectrum utilization by providing enabling mechanisms for Software Defined Radio (SDR) devices [30]. It detects the unused frequency bands (also named as spectrum white spaces Fig. 1) in the radio environments and then adapts their transmission to those unused spectra without causing any interference to primary users [31, 32]. In other words, CR allows the secondary users to opportunistically use the underutilized spectrum bands when not in use by the primary users [33]. However, considering the unreliable nature of the opportunistic spectrum, the cost

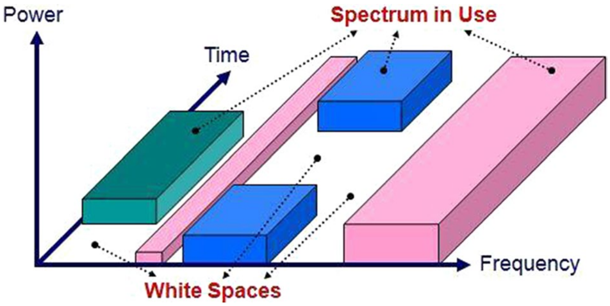

Fig. 1 The concept of spectrum white space

of spectrum leasing or spectrum opportunity is expected to significantly outweigh the cost of acquiring a licensed spectrum [34]. Hence, CR has the potentials to offer an on-demand spectrum expansion in a cellular network at a very low cost as well as the capacity to provide a natural solution to deal with the randomness in mobile data traffic expected to trend in 5G network and beyond [35, 36]. In addition, the opportunistic bands can be utilized during peak hours to handle overload traffic and to provide on-demand opportunistic multimedia streaming at relatively low cost [37]. This is a realistic approach to effectively utilize the available spectrum in new services [38, 39].

It is defined that the 5G-based CR wireless network uses the instrumentality of CR technology to lease the unused spectrum to other unlicensed users within the network [40]. In this case, the 5G cognitive-based cellular network employs two types of Radio Resources (RR); the cellular (licensed) RR and the cognitive (unlicensed) RR [41, 42]. The licensed radio resources are characterized by three main factors i.e., (1) high transmit power, (2) relatively smaller bandwidth, and (3) high reliability [43]. On the other hand, the cognitive RR has low transmitted power, potentially broader bandwidth and low reliability. Essentially, these two different RRs are complementary in nature so, integrated system design is required for efficient utilization of both [44]. Thus, joint utilization mechanisms of licensed and cognitive RRs remain one of the research challenges in 5G-based CR cellular networks [45]. The issue of spectrum availability crisis, especially at those frequencies that can be economically used for wireless communications, is a well-orchestrated challenge. In actual sense, this is a huge misconception supported by a look at the Federal Communications Commission (FCC) frequency chart that indicates multiple allocations across all the frequency bands, especially in the bands below 3 GHz [46, 47]. However, real measurements taken at various times in an urban setting reveal otherwise. It is found that only about 0.5% of available spectrum in the 3–4 GHz frequency band is utilized and in the 4–5 GHz band, the utilization drops to only 0.3% [48]. This is evidence of an abundance of spectrum availability and it shows that the perceived shortage in the spectrum is partially a flaw in the regulatory and licensing process [49, 50]. This obvious discrepancy between spectrum allocation and usage (resulting in spectrum shortage issues) could be effectively addressed by adopting a more flexible spectrum usage approach [51]. As the world is about to welcome yet another generation of wireless communications (i.e., the 5G) in the near future, CR could provide the needed shift in the spectrum regulatory and allocation paradigm for maximum utilization [52, 53].

2 Contribution

In this paper, we have focused on the most urgent issues responsible to facilitate the application of CR in 5G networks. Therefore, this study exposes the readers to the knowledge and technicality and issues that arise while CR network deployment in from the perspective of 5G networks. First of all, the design analysis of the configurations of CR oriented 5G networks based on the fundamentals of wireless Ad-hoc networks in terms of spectrum availability, spectrum diversity, and topology differences are deeply analyzed. In this paper, we focused on spectrum allocation issues such as dynamic availability of spectrum, diversity of frequencies and spectrum changing topology. It also discusses the issue of spectrum depletion and the apparent underutilization of available scarce spectrum resources in existing wireless networks. The design issues for heterogeneous multi-hop 5G oriented CR networks are discussed which includes MAC layer spectrum sensing, neighbor discovery and resource assignment. Moreover, the route selection, fluctuating interferences and switching delay challenges in the network layer are highlighted as well. We also present a comprehensive study routing protocols that are deemed suitable as secure, robust and efficient routing solutions for heterogeneous multi-hop 5G CR networks.

This paper consists of three sections; Sect. 3 presents a discussion on design issues in the CR network as well as a comparative study between a typical Multi-Channel Ad-hoc network and a CR network. Section 4 devotes enough time on discussion about design challenges in the CR network from the perspectives of both MAC and network layers, which also covers routing challenges and preferred spectrum access strategies in heterogeneous multi-hop-5G CR oriented networks. Section 6 discusses various routing protocols suitable for CR networks. Finally, Sect. 6 discusses the conclusion.

3 Design of dynamic spectrum allocation network

While the demand for spectrum is very high within a certain range of frequency bands, studies have revealed a massive underutilization in those range of spectrum [54]. This spectrum availability uncertainty is the key factor that motivated the introduction of a spectrum allocation scheme known as Dynamic Spectrum Allocation (DSA) to increase the efficiency of radio spectrum utilization in Cognitive Radio Networks (CRNs) [55, 56]. Different from fixed spectrum assignment scheme in traditional systems, DSA enables Secondary Users (SUs) to access unoccupied licensed bands which are not currently used by their genuine licensed owners–Primary Users (PUs) [57]. DSA is supported by the recent declaration by FCC to the effect that the sub-900 MHz TV spectrum will be made available for unlicensed services which will allow for more flexible utilization of frequency spectrums [58]. So, a novel design of CR network architecture is suggested based on DSA in Fig. 2, where nodes in such a network are allowed not only to scan for opportunistic spectrum and make use of them when they exist but also can perform intelligently with enough coordination to increase the overall network capacity while protecting the PUs from undoing interferences.

3.1 Multi-frequency Ad-Hoc Network vs Cognitive Radio Network

In CR-based DSA networks, unlicensed users are allowed to pro-actively share the licensed spectrum of PUs provided interferences to PUs are avoided [59]. Although the CR network can operate in multiple frequencies, the modes of its operation are technically and entirely different from those of conventional multi-frequency ad-hoc networks [60, 61]. These concepts will be discussed below.

3.1.1 Dynamic Availability of Spectrum

In fact, one of the unique features of the CR network is the dynamic availability of frequency bands. The need to protect the primary transmissions from interference due to opportunistic access by SUs is one of the reasons that motivated the space–time DSA in CR networks [62, 63]. Hence, while the nodes in traditional multi-frequency ad-hoc networks operate on a pre-defined set of static channels, in the CR network, a certain frequency band may be unoccupied at a certain time in a given place and occupied at another time in the same place [64]. This is what distinguishes the CR network from a typical

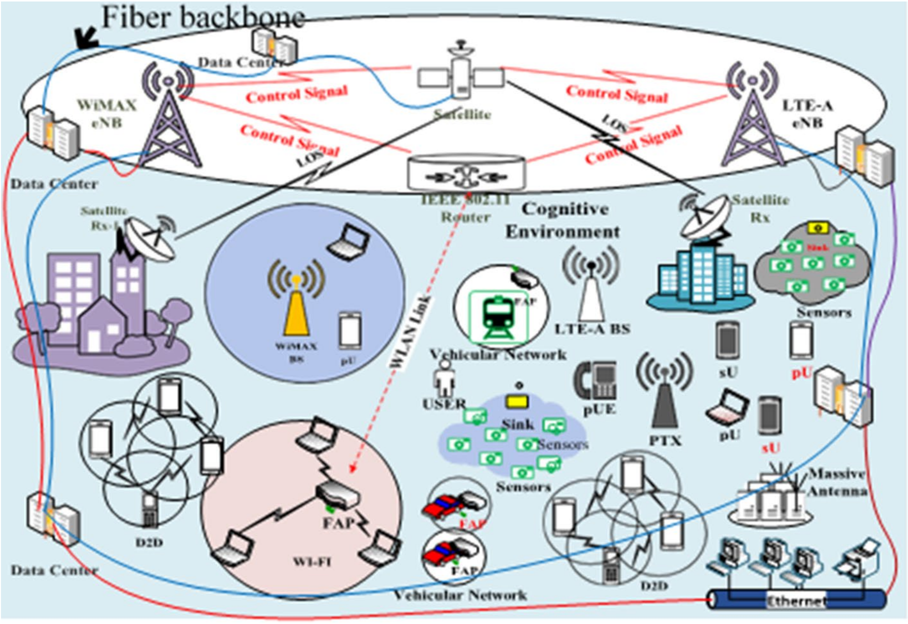

Fig. 2 A suggested heterogeneous Multi-Hop 5G Oriented Cognitive Radio Network architecture CRN comprising of D2D communications, WLAN, Ethernets, sensor networks, vehicular networks, Macro BSs, femtocell access points (FAPs) etc., using LOS satellite communications, WiMAX and LTE-A backhaul as access technologies

traditional multi-frequency ad-hoc network. However, when the global common channel is not available, other neighboring SUs share a separate common available channel. Also, the availability of spectrum is varying continuously, therefore, it is suggested to estimate the availability of spectrum before for efficient transmission [65]. The route selection delivers an important factor in the transmission QoS such as spectrum idle time and spectrum bandwidth. This is due to the switching of the spectrum between PUs and SUs; as the PUs has to abandon the channel before SUs occupy it [66]. The chosen channel spectrum might be unavailable or invalid due to delay in switching and delay transmission which requires an efficient routing scheme to maintain the required QoS for the CR network [67].

3.1.2 Diversity of Frequencies

Another feature that differentiates CR networks from typical multi-frequency ad-hoc networks is that in CR networks there is a diversity of frequency bands potentially available for opportunistic access, including assorted availability of both licensed and unlicensed bands [68]. It includes a set of public safety spectrum in the range of 700 MHz, i.e., 764–776 MHz and 794–806 MHz and another set of frequency bands, used for FM and TV operations, in the range of 54–862 MHz as well as 4.9 GHz and 5 GHz bands [69–71]. However, only a few and fixed number of channels (normally not exceeding 10 at most) can be supported in a typical multi-frequency ad-hoc networks, thousands of channels can be supported in CR network [72]. Moreover, in a typical multi-frequency ad-hoc networks, diversity is not supported as the available channels are mainly from the same contagious band of frequencies with homogeneous physical attributes, for example, the 13-channel IEEE 802.11 multi-frequency ad-hoc networks operating in 2.4 GHz band [73, 74]. Moreover, only 10 channels are essentially used for data transmissions and the other remaining 3 channels are orthogonal to the rest and are used for simultaneous transmission of control signals such as beacons with less noise uncertainty [75]. All the channels in this band of frequency have the same transmission characteristics in terms of radio range, modulation scheme, transmit power, etc.

3.1.3 Dynamically Changing Topology and Incomplete Statistics

The nodes in multi-frequency ad-hoc networks do not need global topology information or the involvement of any centralized infrastructures to operate, therefore, these nodes depend heavily on topology information shared by neighbors [76]. In a multi-frequency ad-hoc setting, nodes exchange topology observations with neighbors through periodic transmission of beacons on a pre-defined control channel [77]. However in CR networks, since there are assorted available frequency bands, the periodic transmission of beacons on the entire channels is considered an inefficient approach [78]. So, in CR networks, complete network topology information is not necessary for the CR nodes to function. However, the dynamic space–time availability of a wide range of frequency bands in CR networks introduces a different challenge of rapidly changing network topology on the PU's spectrum access [79]. Hence, a 5G oriented CR network requires a unique design solution that will be highly adaptive to the rapidly changing radio conditions of the network rather than the traditional spectrum access solution [80, 81].

3.2 Spectrum Depletion Under-Utilization of Available Spectrum Resources

CR technology should have the ability to acquire and acclimate the network environment during wireless transmission. The inclusion of Artificial Intelligence (AI) techniques in the CR network is a promising technology that able to achieve higher QoS to the end-users [82]. Moreover, in order to resolve the issue of spectrum scarcity, a dynamic spectrum access techniques have been used to achieve optimum QoS performance.

An approach in [83] focusing on cognitive radio sensor networks (CRSN) scheme for IoT where the sensors nodes can access the spectrum optimum energy efficiency. It works on energy-aware mode switching techniques along with the cluster-head selection algorithm. The simulation results prove the proposed energy-efficient spectrum CRSN scheme gives efficient results as compared to the dynamic channel selection scheme (DCSS) and dynamic random channel selection scheme (DRCSS) scheme. Another approach focusing on energy harvesting based on cooperative spectrum sensing in a cooperative network [84]. The proposed approach helps to improve the spectrum utilization by using the alternation direction optimization method by adapting the convex issues into two different optimization problems. The results prove the validity of the technique by achieving the joint optimization of sensing time with improved battery life. Moreover, an approach in [85] proposes a spectrum-aware cluster-based energy-efficient multimedia (SCEEM) routing protocol for efficient multimedia routing in CR sensor networks. The cluster head-based algorithm is based on hybrid medium access by combining carrier-sense multiple access (CSMA) and time-division multiple access (TDMA).

A technique focusing on increasing the system throughput in a small sensing time is presented in [86]. The proposed technique Multi-Taper Spectrum Sensing (MTSS) is utilized to sense the available spectrum in the network for two different scenarios i.e., single-user detection and cooperative spectrum sensing detection. The results proved that the proposed model has better results in comparison with conventional spectrum sensing under different scenarios. Moreover, a machine learning-based cooperative spectrum sensing schemes (CSSs) is proposed in [87]. This technique helps to minimize the issue of spectrum occupancy for the sensor nodes. Another approach proposes an AI-based abnormality detection technique at the physical (PHY)-layer in CR by enabling learning Generative Models [88]. This approach is able to detect false signals in the spectrum and make the network self-aware. The results proved that the proposed approach is applicable in both Conditional Generative Adversarial Network (C-GAN) and Dynamic Bayesian Network (DBN) models.

4 Design Challenge in Heterogeneous Multi-hop 5G Oriented CR Network

CR networks can potentially optimize the efficiency of spectrum utilization in 5G networks, however, there are several issues including higher throughput, interference mitigation, and extended coverage, that require absolute consideration in the design of heterogeneous multi-hop 5G oriented CR network [89]. These issues must be addressed as the first step toward successful implementation for design a CR based 5G multi-hop network. For dynamic operation, the 5G CR network should be distributed in nature and multi-dimensionally deployed [90, 91]. Hence, it will face similar challenges that were encountered in single-hop CR networks given that CR-UEs are fundamentally heterogeneous in nature due to their complex user terminals in terms of wireless access technologies, frequency bands, service variety and application types [92, 93]. Therefore, it is expected that the CR-UEs in such a network must have the capacity to handle the challenges arising from multi-hops data propagations in such a heterogeneous setting [94]. For instance, it is not just enough to detect unused frequency bands, but accomplishing efficient end-to-end communication by establishing reliable routs in the midst of the rapidly changing sets of cognitive relay nodes as well as adapting resource sharing through dynamic spectrum assignment among all flows, are also part of the major requirements for the network elements [95]. Since PU signals must be guarded carefully against interference, it is also required that the Quality of Service (QoS) of SU should be guaranteed as well [96]. Contrary to infrastructure-based networking, a self-configurable multi-hop architecture can create expanded-area backhaul networks that allow traffics to be routed directly between peer nodes via relay/forwarding using multiple hops routing strategy [97]. It resulting not only in ubiquitous connectivity but also in increased capacity and expanded coverage [98]. However, a good understanding of the operation of DSA in cognitive mesh architecture is required. Figure 2 is a typical example of the suggested multi-hops 5G oriented CR network comprising of Device to Device (D2D) communications, sensor networks, vehicular networks, etc., using line of sight satellite communications, WiMAX and LTE-A backhaul as access technologies. In DSA, devices have a High Degree of Freedom (DOF) to choose to switch between multiple frequencies, resulting in efficient spectrum utilization and can switch to orthogonal frequency bands when necessary leading to lower radio interference and high system throughput [99]. Hence, a multi-hops heterogeneous 5G-based CR network such as the one presented in Fig. 2 can essentially achieve the followings:

1. Increase the efficiency of spectrum utilization.
2. Enhances the service of area coverage.
3. Reduce co-channel and adjacent-channel interference.
4. Increase ubiquitous connectivity.
5. Increase network throughput by multiple concurrent packet transmissions over different channels.
6. Reduce end-to-end access delay through efficient multi-hop routing.

While design the heterogeneous multi-hop-5G oriented CR network, several issues arises especially in MAC and NETWORK layer [100]. The following subsection is discussing the related issues.

4.1 MAC Layer Challenge in Multi-hop 5G Oriented CR Network

In a multi-hop heterogeneous 5G-based CR network, nodes are allowed to listen to different frequency channels at any given instance in time, which leads to constant fluctuation in wireless channels activities resulting in neighbor discovery challenges in the MAC layer. Few of the MAC layer challenges are discusses in this section.

4.1.1 Neighbor Discovery Co-ordination Challenge

Neighbor discovery duration is expressed as the time duration during which a node discovers its neighbor(s). In a conventional multi-hop wireless network, neighbor discovery is triggered each time a node needs to discover other node(s) within its radio range (i.e., its closest neighbor(s)) for information exchange [101, 102]. Likewise, in CR network, each time a CR-UE turns on or switches a frequency channel, it executes what is called a “listen-and-talk” operation in order to detect any possible PUs transmissions and to discover other potential neighbor (CR-relay) nodes in its radio territory with which to establish a routing path to intended destination [103]. Although each CR- node in the network has a DOF to dynamically select any available spectrum band via the DSA, the CR-nodes are required to carefully sense the channel(s) of all their neighboring relay node(s) and this is known as external channel sensing which potentially increases the number of channels to be scanned in the process [104, 105]. Moreover, because of the rapid changing nature of the nodes in heterogeneous multi-hop CR networks, the CR-nodes can switch to new channels even within the discovery interval [106]. Therefore, a coordination policy in the MAC layer that can maintain a minimum discovery time for the neighbor discovery process is needed for CR network [107].

4.1.2 Resource Allocation and Spectrum Sensing Issues

The 5G-based CRNs comprising of the diversity of access technologies with a multitude of D2D communications, WLAN, sensor nodes, relay nodes, vehicular networks, etc., each operating on different frequency bands from the others and in some cases, using different resource allocation and spectrum sensing strategies [108, 109]. In order to address this issue, multiple transceiver CR prototypes have been designed with ultra-high-speed switching and sensing times in the order of tens of milliseconds which have been tested in [110]. Although it was observed that using multiple transceivers may potentially shrink down the number of switching in the entire communication flows at relay nodes, however, it is energy-consuming to use multiple transceiver radio devices and may also be computationally intensive at the operating systems level due to the interrupt-driven nature of the operating systems of CR devices [111]. Moreover, as suggested in Fig. 2, the heterogeneous Multi-Hop 5G Oriented multi-interface and multi-dimensional CR Network architecture will be adopting cooperative sensing as the spectrum sending scheme, multipath routing protocol and preferred routing strategy due to the dynamic and heteronomous nature of this network.

4.2 Network Layer Challenges in Heterogeneous Multi-Hop 5G CR Network

In conventional wireless networks, each time a node enters a new network, it, first of all, announces its presence by transmitting beacons over all channels and then listens to broadcast announcements (if all) from its neighboring nodes on one pre-defined channel [112, 113]. However, in CR heterogeneous multi-hop setting, the new arriving node has no restrictions on specific channels with which to receive/listen to neighbors' broadcast announcements, thus it is free to use any channel which is available upon arrival for data exchange. This gives rise to several key routing issues in heterogeneous multi-relay/forwarding CR networks [114]. Routing is ultimately a network layer process, and an efficient routing strategy is critical for dynamic routing in heterogeneous CR networks [115]. This section discusses network layer challenges from the perspective of channel/frequency selection decision in Multi-hops 5G CR Network.

4.2.1 Suboptimal Route Selection

One of the major routing challenges in highly dynamic and CR networks with a wide range of frequencies is the absence of proper coordination between spectrum decision and route selection [116]. Different from traditional ad-hoc networks, the optimal route or neighbor in this type of network may not be the closest functional neighbor in terms of radio range (or delay) [66]. Choosing the closest node may result in a suboptimal route, as illustrated in Fig. 3, where node (S) wants to communicate with node (D). In this scenario, node (B) appears to be the closest functioning neighbor to the node (S) in terms of radio range. However, considering that fact that channel (B) is currently occupied by a PU coupled with the issue of dead-end at node (E) in the direction of node (B) (i.e., no direct link to D from E), making it impossible for (S) to communicate to (D) via this route, i.e., via (S→B→C→E), hence, node (S) chooses to take the longer but optimum route which is (S→A→T→J→K→M→P→Q→D) to reach node (D). Note that node (S) could have of course taken other shorter (fewer number of hops) channels such as (S→A→R→L→P→Q→D) or (S→F→G→O→Q→D) to go to the same destination (D) but those two channels were not selected due to some foreseeable factors such as channel condition, spectrum availability, interference, and so on. Hence, both the distance between the source CR-node (S) and the relay (neighbor) nodes and their operating frequency bands are key factors in deciding route selection and network connectivity [117]. Relay nodes may dynamically route and switch between frequency channels simultaneously depending on spectrum and routing status of the channel, that way, dynamic routing can be created even within the same topology [118]. Hence, a concrete coordination between multi-frequency scheduling made at both the source CR node and relay node and selection of optimal routes amidst such a multi-flow network is required.

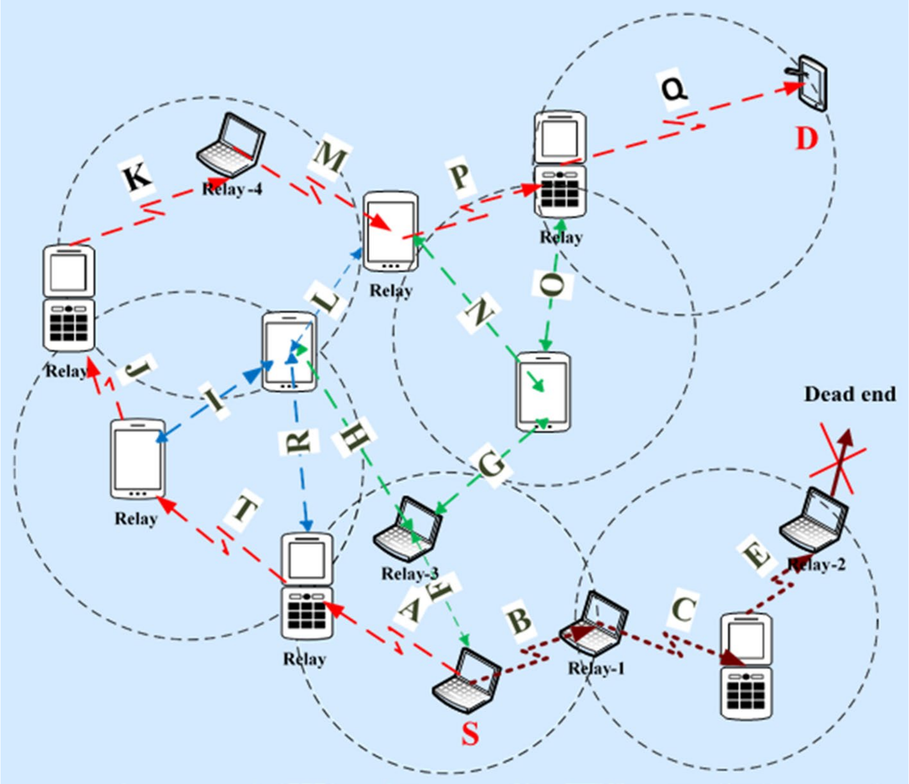

Fig. 3 Optimum route selections in heterogeneous multi-hop cognitive radio networks

4.2.2 Fluctuating Interference

In a cognitive radio base heterogeneous network, small cells are employed in order to increase the diversity and capacity of the network. However, when small cells are operated in the same frequency band, the network is suffering from several adjacent and co-channel interference which reduces the overall network performance [119]. Multi-hop routing needed to calculate the best route which can get the optimal SINR before the transmission. However, due to the rapid changes in the environment which causes the interferences, it leads to varying the throughput of the CR nodes. Moreover, in order to serve all the desired users, relay nodes operating frequencies are continuously switching between various frequency bands. It also causes an additional switching delay which increases more when we are operating in a highly dense urban network.

These issues are not arising in the previously uses conventional multi-channel network, as the network is operating in a single-channel spectrum band with similar physical characteristics. However, the CR based 5G heterogeneous network has to suffer these issues which will affect the power and spectrum efficiency, coverage and transmission delay [120]. The legacy radio nodes are designed to function over these channels with static propagation characteristics and unable to work on different channels with any other physical characteristics. In conventional multi-hop routing, the routes with the best

Single-to-Interference-plus-Noise-Ratio (SINR) need to be established for to-and-from communication before the start of data transmission [121]. However, in a 5G multi-hop CRNs, there is no need for channel/route establishment prior to data transmission as interference from neighboring transmitters may change very fast during transmission and the CR-nodes within the interference range are expected to dynamically switch to other channels to rapidly adapt their frequency bands of operation to newly available channels [122].

4.2.3 Switching Delay at Relay Nodes

In heterogeneous multi-hop CR networks, if a relay node finds itself in a position where it has to serve so many communication flows, each of which operating at different frequency spectrum [123]. The relay node may be forced to constantly switch from one operating frequency to another in order to serve all the flows thereby incurring additional switching delay at that particular relay node [124]. This delay may become intolerably high as the diversity of the operating frequency spectrum of all communication flows in the network increases, which can result in a bottleneck operation in the network due to the relay nodes [125]. This scenario is illustrated in Fig. 4, where node R1 found itself in a position where it has to accommodate four different communication flows (S1→D1, S2→D2, S3→D3, S4→D4). R1 receives packet flows from S1 on the black spectrum and transmits to D1 on the red frequency band. R1 receives packets from S2 on the black frequency band and transmits to D2 on the blue frequency band. R1 receives packet flows from S3 on the yellow spectrum and transmits to D3 on the green frequency band. R1 receives packet flows from S4 on the red spectrum and transmits to D4 on the black frequency band. This means for the relay node R1 to serve all four communication flows, it has to switch between multiple frequency spectrums, in this case, red, yellow, blue, black and green bands. Thus, it results in enhancing the switching delay at R1 and this constant frequency switching and re-synchronization cause intermittent data transmission, which reduces the data throughput.

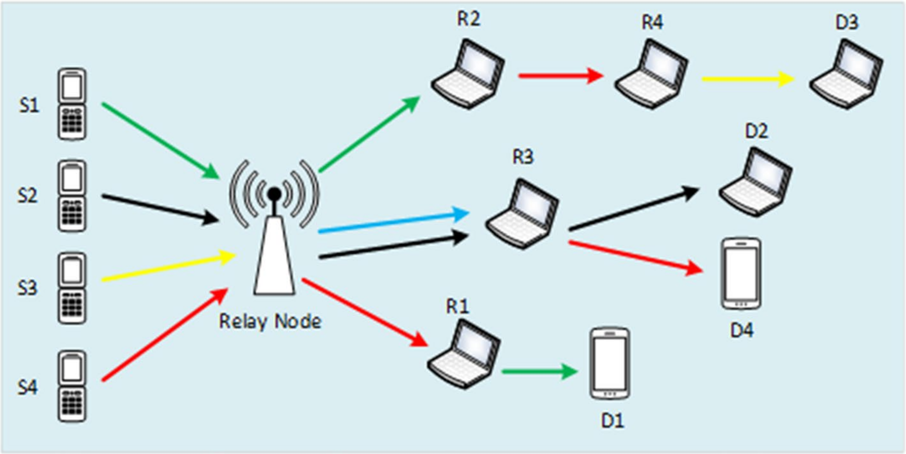

Fig. 4 Switching delay incurred at CR relay node R1 due to multiple data flows with different operating frequency bands

5 Routing Protocols in Cognitive Radio Network

The study of routing protocols in CRNs have gained significant research attention over the past couple of years as the concepts of CR and CRNs become more significant and increasingly popular. The bulk of routing protocols used in the conventional wireless networks such as reactive, proactive, multicast and hierarchical approaches are not considered viable enough for routing in CRNs due to the unique but complex nature of CRN such as the multi-hop configuration, heterogeneity in frequency spectrums and high-speed data rates. Therefore, simple routing metrics like congestion, hop count, delay, etc., are not enough for routing decision making in CRNs [126]. For this reason, a wide range of routing protocols have been investigated in literature for CRN and have been classified into local coordination-based, multipath-based, spectrum aware-based, reactive source-based and tree-based routing strategies depending on the protocol operation [127]. We study in this section, those routing protocols to uncover the suitable ones for routing in rapidly changing heterogeneous CR oriented 5G networks.

5.1 Local Coordination-Based Routing/Spectrum Allocation Scheme

In heterogeneous CRNs with multi-hops propagation disposition, local coordination-based routing which is considered as on-demand routing and spectrum allocation protocol is proposed by [128]. It is based on exchanging spectrum information locally and for interacting with multi-spectrum assignments at each node to overcome the inconsistency of spectrum opportunity and utilization. This protocol is capable of identifying all transmission flows, specifically, at every node and calculates the aggregate of frequency band required at each node which is used for multi-frequency multi-flow scheduling coordination [129]. The coordination-based routing/spectrum assignment scheme is used for load balancing on communicating nodes for both multi-traffic multi-frequency CR transceivers and for traditional wireless interface ensuring that routing messages are fairly distributed at each node [130]. The advantage of this routing technique that it offers improved end-to-end delay and good adaptability for spectrum diversity as compared to the traditional bare routing [131].

5.2 Spectrum Aware Mesh Routing

This is a variant of dynamic spectrum-aware routing scheme which allows CR systems to accurately detect and efficiently utilize unused frequency bands by routing data traffic over those routes with sufficient available spectrum. In [132] spectrum aware mesh routing scheme is proposed for mesh CRNs which capitalizes on the pools of available channels to balance between short-distance and long-distance routes. This scheme exploits spectrum availability in calculating routing metrics for long-distance routes [133]. A balance between short-distance and long-distance routes is achieved by creating a set of meshed scripted forwarding routes such as; candidate forwarding mesh, dynamic candidate routes, and opportunistic forwarding routs and this script is updated periodically to provide alternative routes to every other node/destination [134]. Therefore, packets are routed toward destinations over the mesh network and routing decisions are made in cognizance with the PHY and MAC layers [135]. In a summary, the spectrum aware mesh routing protocol has a track record for high end-to-end throughput by using short-distance and long-distance for stable opportunistic spectrum utilization and can dynamically utilize variations in spectrum availability for forwarding mesh [136, 137].

5.3 Reactive Source-Based Routing (RSBR)

The unique feature of the RSBR routing protocol is that it allows the source node to specifically predetermine how packets are routed over the network [138]. The source node, at the start, computes multiple paths to the destination and packets are routed to the destination using the best path [139]. The main advantages of this routing technique are that this routing protocol has the ability to handle simultaneous transmissions over multiple channels while avoiding CR-to-Primary Radio interference.

5.4 Tree-Based Routing (TBR)

The TBR routing protocol creates a sort of tree-structured network by configuring a root and branches [140]. This routing scheme is a form of centralized routing strategy where a single network entity called base station controls the routing across the entire network resulting in the rapid establishment of network topology and routs among CR relays by configuring cognitive relays as root [141]. TBR routing protocol employs a set of cognitive aware link metrics for global end-to-end routing decision metric and path selection decisions are made based on the local and global schemes. Finally, an average end-to-end delay which is 5 times smaller than any hop count based routing techniques is achievable [142].

5.5 Multipath-Based Routing (MBR)

As the name suggests, the MBR routing protocol discovers and computes multiple paths to every other destination/node, then the best path among the discovered route is chosen based on routing decision metrics [143]. Multi-path routing technique has many advantages including; high fault tolerance against rout failure as multiple routes to every node are available; improved spectrum incoherency; construction of multiple routes to minimize contention and interference; effective utilization of network resources resulting in higher end-to-end throughput than other routing schemes and finally; it protects the primary users against dynamic interruption [144].

6 Conclusion

The next-generation 5G communication network required a higher bandwidth in order to achieve a greater data rate. This can be achieved by utilizing the CR technology in an adaptive and intelligent manner. It helps transceiver to automatically detect available channels in a wireless spectrum and change transmission parameters enabling more communications to run concurrently and also improve radio operating behavior. While designing the CR network, several complications such as spectrum management need to be mitigated which should detect and share the best available unused spectrum without creating harmful interference. Therefore, this study exposes the readers to the knowledge and technicality and issues that arise while CR network deployment from the perspective of 5G networks. The spectrum allocation issues such as dynamic availability of spectrum, diversity of frequency and spectrum changing topology are focused. It also discusses various design related issues in multi-hop heterogeneous CR networks, which include MAC layer spectrum sensing and assignment as well as channels and routs selection and fluctuating interferences challenges in the network layer. We also present a comprehensive study of a set of routing protocols deemed suitable for heterogeneous multi-hop 5G CR networks. As an open issue for future research in CR technology, multiple transceiver radio devices should be further investigated in order to improve both the computational efficiency and power management as well as enhance the transmissions capability over multiple channels.

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Compliance with Ethical Standards

Conflicts of interest On behalf of all authors, the corresponding author states that there is no conflict of interest.

Ethical Approval This article does not contain any studies with human participants or animals performed by any of the authors.

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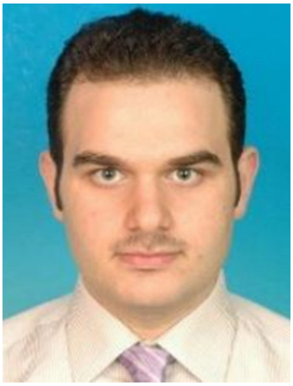

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