SURVEY ON COGNITIVE RADIO ROUTING PROTOCOLS

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Abstract
Today's emerging usage of ISM band introduces concept of the Cognitive Radio (CR), they are intelligent transceivers that accommodates dynamic frequency allocation (DSA). Based on challenges in cognitive radio networks there are some approaches categorized into Graph based approaches, Common control channel based and Non-common control channel based approaches are explained in this paper. Also we have explain basic concept and analysis of the each paper and limitations of the papers are described in each category. Discussion of this survey help us to study new era of the cognitive radio routing solutions.
Index Terms: Cognitive Networks, Routing, Survey.

I. INTRODUCTION

Cognitive Radio (CR) Network is a kind of wireless communication network in which nodes are equipped with an intelligent transceiver [1]. This intelligent transceiver can detect the status of all wireless communication channels in it surrounding area. These nodes can shift from one frequency to another frequency dynamically for data transmission. The CR technology is based on the concept of Dynamic Spectrum Allocation (DSA) that controls by Software Defined Radio (SDR) as applied to Spread Spectrum (SS) communications. The users in the CRNs are divided into two classes. The first class of users is called Primary User (PU) and the other class is called Secondary User (SU). The PUs are those users that operate on Licensed Frequency band and SUs are those users that operates in unlicensed Industrial Scientific and Medical (ISM) frequency band specified by Federal Communications Commission (FCC). Research on the devices that use Licensed Frequency band shows that they use its allocated bandwidth is used minimum of *15%* and maximum of 85% [2]. On the other hand, the devices operate is ISM band faced a crisis of bandwidth as there are large number of users in such network.

A) An Overview of CRN

The main goal of the CRNs is to optimize the use of available radio-frequency (RF) spectrum while minimizing interference to other users. It ensures efficient utilization of unused licensed frequency band. In order to achieve this, the available licensed band of PUs is used opportunistically by SUs. To have such opportunistic use of bandwidth, both the PUs and SUs must collocate. The SUs in the CRNs must have the capability of determining its geographic location, identify and authorize its nearby users, encrypt or decrypt signals, sense neighboring wireless devices in operation, and adjust output power and modulation characteristics.

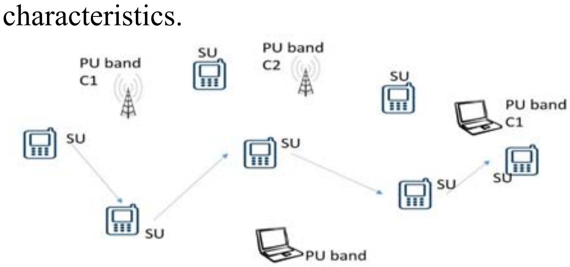

Fig. 1 Typical CR Network [3]

Rest of the paper is organized as follows. Section II describes the parameters for CRN routing evaluation. CRN routing solutions are explained in Section III. The paper is concluded in Section IV.

B) Routing Solution Approaches

In this paper we are categorize cognitive routing solution into five subsection (1) Graph based approaches (2) Common Control Channel based approaches and (3) Non Common Control Channel based approaches. This approaches are categorize as claimed by routing challenges described in the next section.

C) Routing Challenges in CRN

There are three types of network architectures found in the CRNs: Infrastructure, Ad-hoc and Mesh architectures. For our discussion a mesh architecture is considered which is actually a combination of Infrastructure and Ad-Hoc architectures [4]. The architecture enables communication between BSs (or APs) as it is done in Hybrid Wireless Mesh Networks [5] with a formation of wireless backbones by BSs. The mobile stations can access the BSs either directly or through other mobile stations in multi-hop mode of communication. Some BSs are also connected to the wired backbone and they act as gateways. However, the CR nodes access the network in the spectrum hole opportunistically.

The main challenges of routing in CRNs with an architecture described above are listed below:

The *spectrum-awareness* is one of the main challenges in designing routing protocols for CRN. Since CRN devices are allowed to access the network only in the spectrum hole, so the routing algorithm must take into account the availability of spectrums during packet transmission. There must be coordination between the routing module and the spectrum management module of a CR device. Moreover, the routing module must take care of the upcoming PU activities during their transmission.

Selection of quality route is another major challenge in CRN routing. This is due to dynamic behavior of PUs in cognitive environment. There is no specific pattern of appearance and disappearance of PUs in such environment. Since, the CUs must leave the channel as soon as some PU appears so the SUs must try to use the available spectrum in an optimized way to ensure nominal bandwidth, high throughput and minimized delay.

The *route maintenance* imposes difficulties in designing routing algorithms for CRNs. The PUs may become visible at any occurrence of time thereby forcing the SU to vacate the occupied channel. Releasing the channel causes an unpredictable broken path in the ongoing conversation between CRs. So, a new path must be discovered despite of staying in the same location of a CU. Furthermore, the path discovery process must impose minimal effect on the perceived quality of services to the end users.

II. PARAMETERS FOR CRN ROUTING EVALUATION

In this paper we have consider many parameters that effecting the cognitive routing solutions like end-to-end delay means we have to minimize the delay from source to destination, throughput means from source to destination maximum throughput we have to consider, No. of Primary and Secondary users, required bandwidth, Hop count means number of intermediate nodes we also have to consider, Interference range, latency means time varies between source to destination, Channel switching means consider minimize switching delay, Link quality and link stability according to route failure and route reparation etc.

III. CRN ROUTING SOLUTIONS

1) Graph Based Approaches

Route design in classical wired/wireless networks has been tackled widely resorting to graph-theoretic tools. Graph theory provides effective methodologies to design routing in wired as well as wireless networks. It also helps to theoretically examine the feasibility and flaws of a routing algorithm in a multi-hop network topology. The graph based approach for designing routes multi-hop networks goes through two phases: the graph abstraction and the route calculation. In the graph abstraction phase the physical network topology is converted in to a logical graph. This phase generates a graph structure *G* represented as *G = (N, V, f(V))*, where *N* is the number of nodes (also called vertices) in the graph, *V* is the number of edges, and *f(V)* is the function that assigns a weight to each edge of the graph. The second phase of the approach i.e. the route calculation phase represents a path in the graph between any source and destination pairs. In CRNs there are few protocols proposed which are based on graph theoretic approach. Some of such proposals are discussed in this section.

A. Routing through layered-graphs

The very same two-phase approach to route design has been leveraged also for multi-hop CRNs. The work reported by C. Xin et al. in [6, 7] describes a framework to address channel assignment and routing. They have done a comprehensive analysis using two phased graph theoretic approach in a semi-static multi-hop CRNs.

Basic concept: The authors considered a CR environment where, the PU dynamics are low enough. In such environment the channel assignment and the routing among SUs can be designed statically. They also assume that the secondary or the cognitive devices are equipped with a single half-duplex cognitive radio transceiver. These SUs can be tuned to multiple (say M) available spectrum bands (or channels). One layer of graph among the SUs is formed by each of the available channel.

Analysis: The proposed framework given in [6] is a general one and different routing metrics as applicable can be applied to analyze any network topology. In [7], the authors considered a specific case in order to execute the framework given in [6]. In this paper, the horizontal links are assigned weightage form the traffic load and interference level on those channels. A centralized heuristic algorithm for finding shortest path between SU nodes are also proposed in [7]. However, these protocols [6, 7] have several limitations. Firstly, they follow iterative method of finding shortest path. Only one pair of source and destination is explored at a time. After completion of one path, a new layered graph is constructed from the previously constructed layered graph. The new layered graph is constructed by eliminating all unused incoming horizontal or vertical edges in the previous graph. The weights assigned to edges are also recalculated. The entire process involves considerable computational complexities for route finding. Secondly, the algorithm works only for semi static CRNs, where the topology changes very slowly. In highly dynamic environment its applicability is not discussed in [6] and [7]. Thirdly, the algorithm is centralized and hence need network wide signaling support to generate the layered-graph. This signaling process consumes large amount of channel bandwidth for large network size. Moreover, the iterative algorithm proposed in the paper cannot produce optimal solution as it is based on a greedy approach. Finally, iterative path computation over graph abstractions may not scale well for a network of large size.

B. Routing through colored-graphs

A similar graph theoretic approach is also proposed in [8] by X. Zhou et al. They have used colored multigraph to design the topology of available spectrum for cognitive devices. The authors have emphasized on maximizing the network capacity and minimize interference among neighboring nodes.

Basic concept: The colored graph denoted by *Gc = (N,V,W),* where N is the set of vertices that represents CU, and V denotes the set of edges that connects two SUs with available channels. *W* denotes the weights assigned to an edge. There may be M number of edges connecting two vertices where *M* is the number of available channels between the two nodes. Each channel is represented by an edge with different color. In the paper authors assumes the value of *W*=1 for all edges in the initialization phase of the process. The two nodes in the topology may communicate with each other directly if they have common available channels. Two nodes with a common channel are termed as potential neighbors. There exists an edge with color *k* between two nodes if and only if they are potential neighbors and have channel Ch_k as available channel in common. One example discussed in [8] is reproduced here for better understanding of the graph coloring method.

Analysis: The algorithm suggests that it ensures optimization in terms of hop count and adjacent hop interface. However, the optimization of Adjacent Hop Interface (AHI) measured in terms of largest number of continuous adjacent edges with same color is not accurate. This approach has the same drawbacks as in [6] stated above. The proposed solution approach is centralized and heuristic which leads to suboptimal routing solution.

C. Routing through conflict Graph

The work stated in [9] is a routing and spectrum selection through conflict-graphs. They have modeled routing and spectrum assignment as different activity in a single transceiver half duplex cognitive radios network. They have shown all available routes between source and destination pairs for a given network topology. They also suggest the assignment patterns of available channels using a conflict graph. Considering each wireless link as a vertex in the conflict graph, the paper suggests a combination of routing and channel assignment. An edge stay alive between two vertices if the corresponding link cannot be active concurrently.

Basic concept: The proposed algorithm for route construction and channel assignment is centralized in nature. The algorithm derives a conflict-free channel for nodes by calculating the maximum independent set in the conflict graph. The down side of the algorithms is its supposition of having apriori knowledge concerning available spectrum bands, neighboring nodes, etc. Centralized computation on the other hand imposes another limitation of the accuracy and overhead for information by centralized unit. Moreover, the problem of defining the most efficient conflict-free scheduling can be reduced to a problem of calculating the maximum independent set on a properly defined ‘‘conflict graph”, which is known to be NP-Hard [3].

Analysis: The paper only focuses on interference avoiding in theory, which is not practical for high computing complexity in practice [14 Personal Communication].

2) Common Control Channel Based routing

A. Spectrum aware routing

A distributed routing protocol for CRN mesh network that addresses hidden and exposed primary nodes. Each SU prepares a list of available channel in advance. Channel list is sorted in ascending order according to the channel usage ratio by PU. As claimed by authors, route failure probability is less as an SU selects alternate channel if PU appears suddenly. Delay is used as a metrics for route computation instead of hop count. Capacity of a channel is computed considering noise into account. **Common Control Channel.**

Proposal made in this paper [10] is an implementation of AODV protocol for CRN. However, the paper suggest to uses a low rate channel in the frequency range of 902 MHz for energy efficient CCC for managerial packet transmission among SU devices. The paper claims that 2.4 Ghz frequency band if used for CCC produces interferences with other devices that uses this frequency and affective only for short distance communication. Further, 2.4GHz band for CC consumes higher energy and hence not suitable for energy sensitive environment. They have provided algorithm for selecting CC and then the selected CCC is used for routing following AODV protocol. The AODV routing through disseminating route control messages (channel path selection) and CR co-operation exchanges in 902 MHz CCC which lessen aggregate network transmit power by reduced end-to-end channel-hop count. In the paper four things are addressed. It ensures energy efficient channel-route selection by reducing the hop count through long range control broadcast, it minimizes aggregate transmit power consumed by all CR nodes on the path, reduces end-to-end data transmission delay, efficient channel-route back-up to protect against spectrum mobility which save node transmit power with respect to retransmissions. Experimental results show that the performance of the proposed AODV protocol outperforms compared with existing CCC based CRAODV routing protocols.

The protocols measures the energy required to transmit a packet according to Friis model which assumes transmission as a free space. However, in reality the transmission environment is full of obstacles and hence other models like two ray ground propagation is of more realistic. But the paper does not give any proper justification to the working of their proposal in presence of obstacles. Although the paper claims that the hidden station problem could not affect the transmission due to long range transmission of low frequency CCC, no concrete proof is found in the work. Moreover, hidden station problem could be avoided only during control packet transmission but not during data transmission unless a special care is taken as explained in [10].

B. Spectrum Aware On-demand routing in CRN

There is one more protocol found proposed in [11] by Geng Chang and his associates. This protocol suggests routing mechanism for CRN which is based on how to dynamically switch the frequency band for either per flow throughput assurance or global spectrum utilization. In this paper, they propose approach to reactively route computing and frequency band selection. They focus on the scenario of multi-hop CRN, and assume that each node has a traditional wireless interface in addition to the spectrum agile transceiver to form a **Common Control Channel (CCC),** such that protocol messages received by nodes despite of inconsistency of Spectrum Opportunity (SOP). They further assume that nodes are able to provide routing protocol with their spectrum sensing information through cross layer designs, thus SOP information is shared between MAC and network layer.

Basics Concept: To smooth away the inconsistency of SOP, they modified AODV to form a implementation on the control channel for interchanging SOP detail among network nodes. The protocol should also recognize traversing flows at each node and calculate the frequency bands taken. The active flow information will be used for multi-flow multi-frequency scheduling.

Spectrum switching introduces switching delay while transmission on the same frequency band brings backoff delay, thus when facing multiple flows' relay demands, a node has to follow switching order to assure all the traversing flows while reducing the two delays. They propose a scheduling scheme that polling by the active frequency bands, the spectrum agile transceiver tunes to a particular frequency band once in a polling rotation, processing every correlated flows. Although the inconsistency of SOP can be solved by the proposed on-demand routing and the impact of other existing flows are mitigated by multi-flow multi-frequency scheduling, there is still delays of along the path left unknown. They apply interaction between on-demand routing and scheduling, let scheduling module adaptively select appropriate frequency band, and the selection result be piggybacked by the routing module. On the other hand, routing module provides SOP information, based on which the scheduling could establish queueing system for the traversing flows. In such a way, the delay of nodes amid the path are gathered and reused as feedback to compute the path-long delay.

Analysis: It also evaluates the side effects of existing flows to the route. Adding switching delay and backoff delay. They also derive cumulative delay based on path delay and node delay. It also evaluates the side effects of existing flows to the path. Adding switching delay and backoff delay. They also derive cumulative delay based on path delay and node delay. In this case only switching and backoff delay are taken into account while queuing delay is not considered.

C. Joint On-demand routing and spectrum Assignment in CRN

There is one protocol found proposed in [12], Geng Cheng and his associates propose a joint interaction between on-demand routing and spectrum scheduling. A node analytical model is suggested to narrate the scheduling-based channel assignment progress, which ease the inter-flow interference and frequent switching delay. They also use an on-demand interaction to obtain a cumulative delay based routing protocol.

Basic Concept: They present the Node Analytical Model (NAM) in CRN node, and suggest that nodes communicate under reactive routing protocol for SOP details dissemination. The NAM adaptively choose legitimate frequency bands, and the result is piggybacked through the routing messages. Another point of view, routing messages contribute SOP detail, based on which the NAM could set up queueing system for the traversing flows. The delay of nodes amid the path are collected and reused as feedback to compute the path-long delay.

Analysis: The proposed On-demand Routing cooperates with node's Spectrum Assignment Module and execute Path Cumulative delay based choose frequency band. Which alleviates the impact of traversing flows on the path, it accounts backoff delay and switching delay, and choose appropriate frequency bands with minimum route wise cumulative delay. They assume that each node is equipped with a traditional wireless interface in addition to the Cognitive Radio transceiver. Also that every node is able to Provide the routing module with its SOP information. This can be carried out by addressing cross-layer design, sharing spectrum sensing result between network layer and MAC layer.

D. Minimum Weight Routing based on a Common Link Control Radio

There is one protocol found proposed in [13], Pyo and Hasegawa is to discover minimum weight paths in cognitive wireless ad hoc networks. For helping neighbor discovery and routing in the cognitive wireless ad hoc networks, they introduce a common link control radio (CLCR) so it is a standard active wireless system of cognitive terminals. Additionally they propose a novel cognitive ad hoc routing protocol based on a common link control radio (CLCR) said to be a minimum weight routing protocol. They show that the proposed routing protocol can greatly reduce communication overhead in cognitive wireless ad hoc networks.

Basic Concept: The operating system is responsible for selecting the wireless communication interface to be used at a given time. Different interfaces are used to access various Wireless Systems (WS) such as cellular (e.g., CDMA, TDMA and FDMA) or WLAN (i.e., IEEE 802.11 b/g). Each of the interfaces is associated with a different communication range, as well. The use of a **Common Control Channel (CCC)** plays a central role in the work. A dedicated interface, referred to as Common Link Control Radio (CLCR) is used for communication between CR terminals to sustain cognitive radio network related functions. The two main functions using CLCR interface are the neighbor discovery and path discovery and establishment. To discover a large neighborhood, CLCR uses a high transmission power to reach out all the potential neighbors. Nodes share with each other their connectivity over different radio interfaces when they exchange messages through the CLCR. The signaling to establish paths between two end points also happens over the CLCR. The weight of a link is defined as a function of the transmission power of the different WSs an SU may use to communicate with a neighbor node.

Analysis: The proposed routing protocol locally finds the path to minimize the routing weight between a source and a destination. The route discovery procedure is very similar to link state routing algorithms where this newly introduced weight is used. The model does not take into account the primary users, their behavior, or the interference caused by/to other CR nodes. However, such information is implicitly incorporated into routing decisions during neighbor discovery stage. The performance of the proposed system is highly dependent on the neighbor discovery procedure and its refresh rates as there are no other maintenance or recovery procedures defined in the routing protocol to react to PU activity. Furthermore, the power-level based cost metric is not sufficient to address challenges of multi-hop cognitive radio networks.

E. Optimal Spectrum Sharing for Multi-hop SDR Networks

This is one protocol proposed in [14], Hou et al. focus on the problem of designing efficient spectrum sharing techniques for multi-hop CRNs. give a formal mathematical formulation with the objective of minimizing the required network-wide radio spectrum resource for a set of user sessions. Since such problem formulation falls into mixed integer non-linear programming (MINLP), which is NP-hard in general, they develop a lower bound for the objective by relaxing the integer variables and linearization. Subsequently, they develop a near optimal algorithm to this MINLP problem. This algorithm is based on a novel sequential fixing procedure, where the integer variables are determined iteratively via a sequence of linear programming. They use **Common Control**

Channel (CCC) for all the nodes in the network to exchange local state information.

Basic Concept: They introduce a Mixed Integer Non-Linear Programming (MINLP) formulation whose objective is to maximize the spectrum reuse factor throughout the network, or equivalently, to minimize the overall bandwidth usage throughout the network. The proposed formulation captures all major aspects of multi-hop wireless networking, i.e., link capacity, interference, and routing. The authors start off by solving a linear relaxation of the MINLP formulation. Namely, the binary variables which bind each user to transmit over a given sub-band are relaxed to linear values. The resulting formulation is linear (Linear programming, LP), thus it can be easily and effectively solved in polynomial time. The result obtained solving the LP relaxed version of the original problem provides a lower bound on the overall bandwidth usage throughout the network. To complete the characterization of the MINLP solution, the authors further propose a centralized heuristic based on the concept of ‘‘sequential fixing”.

Analysis: The proposed framework is effective in capturing many aspects of networking over multi-hop networks and that the proposed solutions approaches are proved to provide nearly optimal solutions to the joint scheduling/routing problem for multi-hop CRNs. On the down side the proposed scheduling/routing algorithm has to run at a central entity which has perfect knowledge of the network topology (presence, position and traffic pattern of the primary users, presence and position of the secondary users). Moreover, traffic splitting is allowed throughout the secondary network. As expressed above, the assumption of having split traffic between secondary users may be unfeasible in practical secondary networks. Finally, the interference is modeled through the concept of interference range, which automatically excludes effects related to interference accumulation from multiple transmitters far away and the definition of link capacity is based on the assumption that the surrounding interference is Gaussian.

3) Non Common Control Channel Based Routing

A. SEARCH: A location based Routing

K. R. Chowdhury et. al proposes another routing protocol called SERACH in their work described in [15]. This protocol is based on the geographic routing paradigm. SEARCH is a completely distributed routing solution that accounts for PU activity, mobility of the CR users and jointly explores the path and channel choices towards minimizing the path latency. It reflects on the true channel delay by conducting the route exploration in the actual channels used for data transfer. **(Do not rely on CCC)**

Basic Concept: In the discussion the authors assume that the source and all forwarding nodes know the GPS position of the destination.

Analysis: However, the proposed protocol does not take the stochastic activity of PUs into account for the formation of route. So, in some times the algorithm select unstable routes from source to destination. In addition, route selection is performed at the destination, which introduces initial delay at route establishment.

B. SAMER:

There is one protocol found proposed in [16], I. Pefkianakis and his associates propose SAMER, a routing solution for cognitive radio mesh networks. SAMER opportunistically routes traffic across paths with higher spectrum availability and quality via a new routing metric. It balances between long-term route stability and short-term opportunistic performance. SAMER builds a runtime forwarding mesh that is updated periodically and offers a set of candidate routes to the destination.

A new routing solution for CRN that addresses both above issues. The design of SAMER seeks to utilize available spectrum blocks by routing data traffic over paths with higher spectrum availability. In SAMER, routes with highest spectrum availability are selected as candidates. Therefore, SAMER computes its long-term routing metric based on spectrum availability and is more or less a “least-used spectrum first” routing protocol. Moreover, it tries to balance between long-term route stability and short-term route performance via building a runtime forwarding route mesh. Once a route mesh that offers a few candidate routes is computed, the runtime forwarding path is determined by instantaneous spectrum availability at a local node. This can lead to short term opportunistic performance gain. It does **not relay on CCC.**

Basic Concept: SAMER takes a two-tier routing approach and balances between long-term optimality (in terms of hop count) and shortest opportunistic gain (in terms of higher spectrum availability). SAMER has main two components:

1) Dynamic Candidate Mesh: Every node in the network computes a cost to the destination D (for each destination each node computes a different cost). This cost reflects the spectrum availability of the highest spectrum path whose length is less than H hops. Also every node builds a set of candidate forwarding nodes to D, by including all its neighboring nodes whose cost to D is less than a threshold C. So the mesh is built around the shortest in hop count path and is dynamically adapted to spectrum changes.

2) Opportunistic Forwarding: SAMER opportunistically forwards packets across the links with the highest spectrum availability. Upon a reception of a packet a forwarding node chooses from the links included in the candidate set, the one with the highest spectrum availability. For computing spectrum availability they use PSA metric.

Analysis: The routing metric of SAMER explicitly considers both route quality based and high spectrum availability. The ultimate goal is to provide optimal spectrum aware routing in the long term. Though SAMER avoids highly congested and unavailable links. However overhead associated with mesh establishment and maintenance have not been considered in depth. Details of channel access, deafness due to the separation of signaling and communication channel, and contention resolution among SUs have not been discussed.

C. SPEAR: SPEctrum Aware Routing

There is one protocol found proposed in [17], Ashwin Sampath and his associates proposed SPEctrum-Aware Routing Protocol (SPEAR), a robust and efficient distributed channel assignment and routing protocol for dynamic spectrum networks based on two principles: integrated spectrum and route discovery for robust multi-hop path formation, and distributed path reservations to minimize inter- and intra-flow interference. Through simulations and testbed measurements, They show that SPEAR establishes robust paths in diverse spectrum conditions and provides near-optimal throughput and end-to-end packet delivery latency. SPEAR performs extremely fast flow setup and teardowns, and can maintain interference-free flows in the presence of variance in channel availability. It does **not relay on CCC**

Basic Concept: They propose SPEctrum-Aware Routing (SPEAR), a new routing protocol for high-throughput multi-hop routing in dynamic spectrum systems. The unique properties of SPEAR include:

- Integrate spectrum discovery with route discovery to cope with spectrum heterogeneity, and obtain optimal usage of available channels.
- Coordinate channel usage explicitly across nodes to optimize channel assignment on a per-flow basis, and to minimize inter-flow interference and interference.
- Exploit local spectrum heterogeneity and assign different channels to links on the same flow to minimize intra-flow interference.

Analysis: SPEAR combines two simple yet powerful features: integration of spectrum and route discovery to establish communications across areas of varying spectrum availability, and distributed path reservation to minimize inter and intra-flow interference. Extensive simulations confirm the efficiency of SPEAR and demonstrate its capability to provide high-throughput, robust multi-hop communications. SPEAR is ideal for communications under unknown and dynamic spectrum conditions, i.e. disaster recovery or military operations. Though SPEAR assumes each device has one dedicated control radio and one data radio and they assume a traffic model consisting of unidirectional UDP traffic.

G. Probabilistic Path selection in Opportunistic Cognitive Radio Networks

There is one protocol found proposed in [18], H. Khalife and his associates present a novel routing approach for multichannel cognitive radio networks (CRNs). Their approach is based on probabilistically estimating the available capacity of every channel over every CR-to-CR link, while taking into account primary radio (PR). Their routing design consists of two main phases. In the first phase, the source node attempts to compute the most probable path (MPP) to the destination (including the channel assignment along that path) whose bandwidth has the highest probability of satisfying a required demand D. In the second phase, they verify whether the capacity of the MPP is indeed sufficient to meet the demand at confidence level δ. If that is not the case, they judiciously add channels to the links of the MPP such that the augmented MPP satisfies the demand D at the confidence level δ.

Basic Concept: A probability-based routing metric is introduced; the metric definition relies on the probability distribution of the PU-to-SU interference at a given SU over a given channel. This distribution accounts for the activity of PUs and their random deployment. This routing metric is used to determine the most probable path to satisfy a given bandwidth demand D in a scenario with N nodes that operate on a maximum of M orthogonal frequency bands of respective bandwidths $W_1, \ldots, W_M$ (in Hz). A source-based routing protocol is proposed for the path selection. The source is able to compute the most probable path to the destination. A subsequence phase is dedicated to compute the available capacity over every link in the selected path and augmenting this capacity till the total capacity available on the path is greater than the demand D.

Analysis: However, the fully opportunistic approach makes sense if PUs are highly active, then the availability of SOPs to sustain a full communication session in a single SOP becomes impossible. A possible solution for SUs is to transmit over any available spectrum band during the short SOPs in a fully opportunistic way. In this case every packet of a given flow can be sent on a different channel by exploiting the intrinsic intermittent CRN channels availability. The selection of a channel to be opportunistically used can be made by tracing back the history of the channel itself, as sensed by a given node. It is to be noticed that, oppositely with respect to probabilistic approaches. Here a node first looks at the available channels and then selects on the basis of a history. On the contrary probabilistic approaches select a path composed by a set of channels on the basis of the history.

IV. Conclusion

From this paper, we have presented analytical comparisons of the existing cognitive radio routing protocols and categorized according its challenges and issues. We have also discussed advantages and limitations of the routing protocols. For the future research work this paper might be useful in current field of cognitive radio networks and also motivate them toward further design of cognitive radio networks.

REFERENCES

[1] J. M. Iii, “Cognitive Radio for Flexible Mobile Multimedia,” pp. 435–441, 2001.

[2] Fcc and Fcc, “ET Docket No. 02- 135 November 2002 Federal Communications Commission,” Communications, Issue no. 02, 2002.

[3] M. Cesana, F. Cuomo, and E. Ekici, “Routing in cognitive radio networks : Challenges and solutions,” AD HOC NETWORKS, no. 2010.

[4] K. Chen, Y. Peng, and N. Prasad, “Cognitive radio network architecture: part I--general structure,” Proceedings of the 2nd International Conference on Ubiquitous Information Management and Communication (ICUIMC), pp. 114–119, 2008.

[5] I. F. Akyildiz, X. Wang, and W. Wang, “Wireless mesh networks: a survey,” Comput. Networks, vol. 47, Issue no. 4, pp. 445–487, 2005.

[6] C. Xin, B. Xie, and C. Shen, “A novel layered graph model for topology formation and routing in dynamic spectrum access networks”, in proc. of IEEE DySPAN, pp. 308-317, 2005.

[7] C. Xin, L. Ma, and C. C. Shen, “A path-centric channel assignment framework for cognitive radio wireless networks,” Mob. Networks Appl., vol. 13, no. 5, pp. 463–476, 2008.

[8] X. Zhou, L. Lin, J. Wang, and X. Zhang, "Cross-layer routing design in cognitive radio networks by colored multigraph model," Wirel. Pers. Commun., vol. 49, no. 1, pp. 123–131, 2009.

[9] Q. Wang and H. Zheng, "Route and spectrum selection in dynamic spectrum networks," 3rd IEEE Consum. Commun. Netw. Conf. CCNC, vol. 1, pp. 625–629, 2006.

[10] S. Anamalamudi, C. Liu, and M. Jin, "Energy efficient CCC based AODV routing protocol for cognitive radio ad-hoc networks," J. Commun., vol. 9, no. 2, pp. 107–117, 2014.

[11] G. Cheng, W. Liu, Y. Li, and W. Cheng, "Spectrum aware on-demand routing in cognitive radio networks," 2nd IEEE Int. Symp. New Front. Dyn. Spectr. Access Networks (DySPAN), pp. 571–574, 2007.

[12] G. Cheng, W. Liu, Y. Li, and W. Cheng, "Joint on-demand routing and spectrum assignment in Cognitive Radio Networks," IEEE Int. Conf. Commun. (ICC), pp. 6499–6503, 2007.

[13] C. W. Pyo and M. Hasegawa, "Minimum weight routing based on a common link control radio for cognitive wireless ad hoc networks," Proc. Int. Conf. Wirel. Commun. Mob. Comput. - IWCMC, pp. 399-404, 2007.

[14] Y. T. Hou, Y. Shi, and H. D. Sherali, "Optimal spectrum sharing for multi-hop software defined radio networks," Proc. IEEE InfoCom, pp. 1–9, 2007.

[15] K. R. Chowdhury and M. D. Felice, "Search: A routing protocol for mobile cognitive radio ad-hoc networks," Comput. Commun., vol. 32, no. 18, pp. 1983–1997, 2009.

[16] I. Pefkianakis, S. H. Y. Wong, and S. Lu, "SAMER: Spectrum Aware Mesh Routing in Cognitive Radio Networks," 3rd IEEE Symp. New Front. Dyn. Spectr. Access Networks (DySPAN), pp. 1–5, 2008.

[17] A. Sampath, L. Yang, L. Cao, H. Zheng, and B. Y. Zhao, "High Throughput Spectrum-aware Routing for Cognitive Radio Networks", Proceedings of the International Conference on Cognitive Radio Oriented Wireless Networks and Communications (CROWNCOM), May 2008.

[18] H. Khalife, S. Ahuja, N. Malouch, and M. Krunz, "Probabilistic Path Selection in Opportunistic Cognitive Radio Networks," Global Telecommunications Conference, 2008. IEEE GLOBECOM 2008, pp. 1–5, 2008.