Routing In Cognitive Radio Networks: A Detailed Description

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Abstract - The lack of spectrum availability and the need for effective use of the spectrum has led to the novel technology called cognitive radio networks. There are two kinds of users in the network. The primary or licensed users, who make use of the spectrum assigned to them by any governmental agencies. The Secondary or unlicensed users has restricted access to the spectrum. The secondary user is also called as Cognitive user. The basic idea of the cognitive radio network is that the unlicensed or secondary users can make use of the spectrum of a primary user but the secondary user has to vacate the band once the primary user starts transmitting the packets. There is also another option in which the primary and the secondary user can transmit the packets simultaneously. In order to achieve this coexistence, the transmission power of the secondary user must be lesser than a threshold value such that the QoS requirements of the primary user are satisfied.

Keywords : Cognitive Radio Networks(CRN), Primary User(PU), Cognitive User(CU).

I. INTRODUCTION

The Federal Communication Commission (FCC) defines Cognitive radio as, "A cognitive radio is a radio that can change its transmitter parameters based on interaction with the environment in which it operates"[6]. As by S.Haykin, "Cognitive radio is an intelligent wireless communication system that is aware of its surrounding environment (i.e., outside world), and uses the methodology of understanding-by-building to learn from the environment and adapt its internal states to statistical variations in the incoming radio frequency stimuli by making corresponding changes in certain operating parameters (e.g., transmit power; carrier frequency, and modulation strategy) in real-time, with two primary objectives in mind: (i) highly reliable communication whenever and wherever needed and (ii) efficient utilization of the radio spectrum". The cognitive radio concept[8] is shown in the figure 1 below.

[6]The two primary characteristics of cognitive radio are

1. Cognitive Capability and
2. Reconfigurability

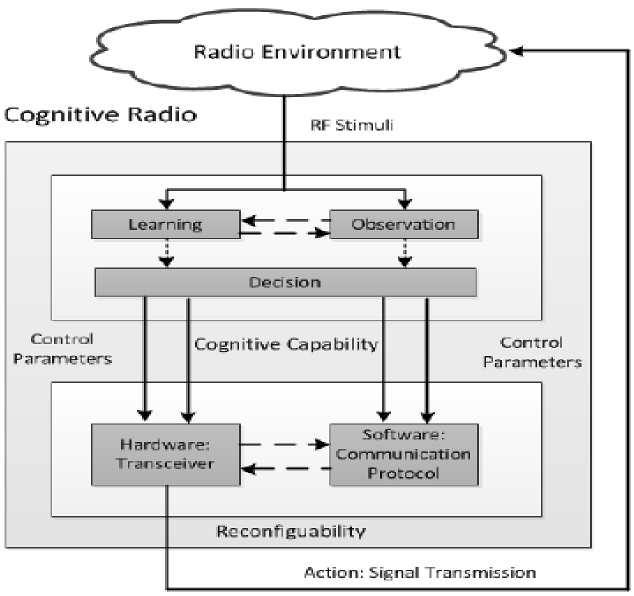

Fig 1: Cognitive radio concept

A cognitive radio network (CRN) consists of wireless nodes equipped with cognitive radios that have the above two mentioned characteristics and the capability to detect and exploit the spectrum holes for their communications. The cognitive radio network architecture[8] is shown in the figure 2 below.

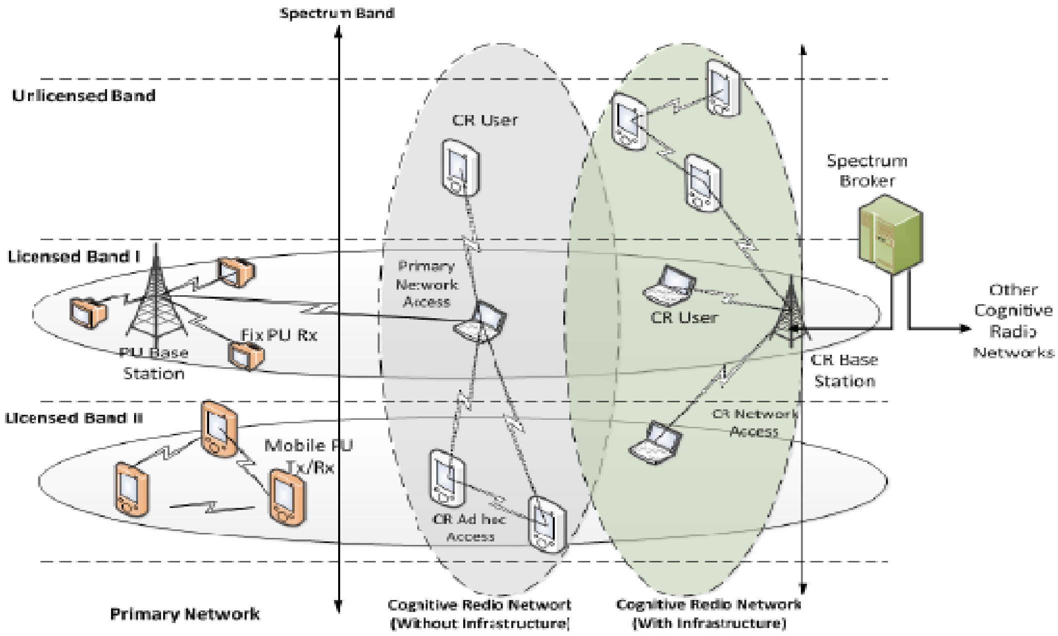

Fig 2: Cognitive Radio Network (CRN) Architecture.

The key issue of Cognitive radio networks is the uncertainty in the availability of the spectrum which poses a great challenge to the network.

II. ROUTING IN CRNs:

The spectrum that is licensed for the primary user is not completely and effectively utilized by them. When the primary user is not transmitting the packets the secondary user can make use of the spectrum. The spectrum that are not allocated to primary user or in other words the spectrum which is temporarily not used is called the spectrum hole. Cognitive radio technique provides the capability to use or share the spectrum in an opportunistic and effective manner. The spectrum hole concept is given in the figure 3 below.

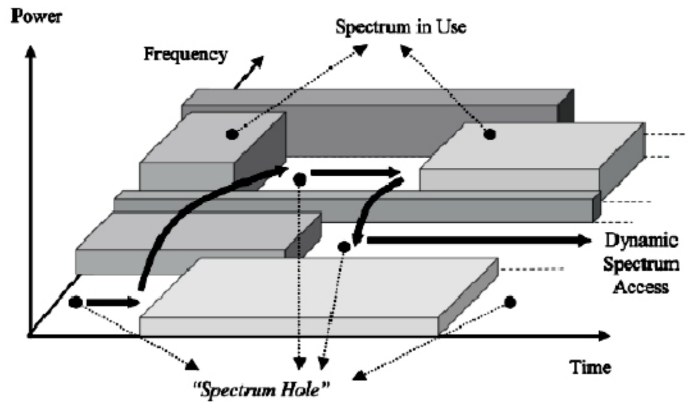

Fig 3: The spectrum holes concept.

As far as routing in CRNs is concern, the user should be aware of the spectrum utility in order to discover and maintain the route. The spectrum knowledge can be obtained in one of the two ways.

1. A central control unit can be maintained which globally collects the spectrum utility information and the secondary user can communicate to this unit to get the global spectrum information of the network.
2. Each secondary user can obtain the spectrum information locally by distributed or local sensing operations.

Now comes the concept of routing,

[2]The routing scheme can be divided into two folds (as shown in fig 4):

1. Routing scheme with Full Spectrum Knowledge
2. Routing scheme with Local Spectrum Knowledge

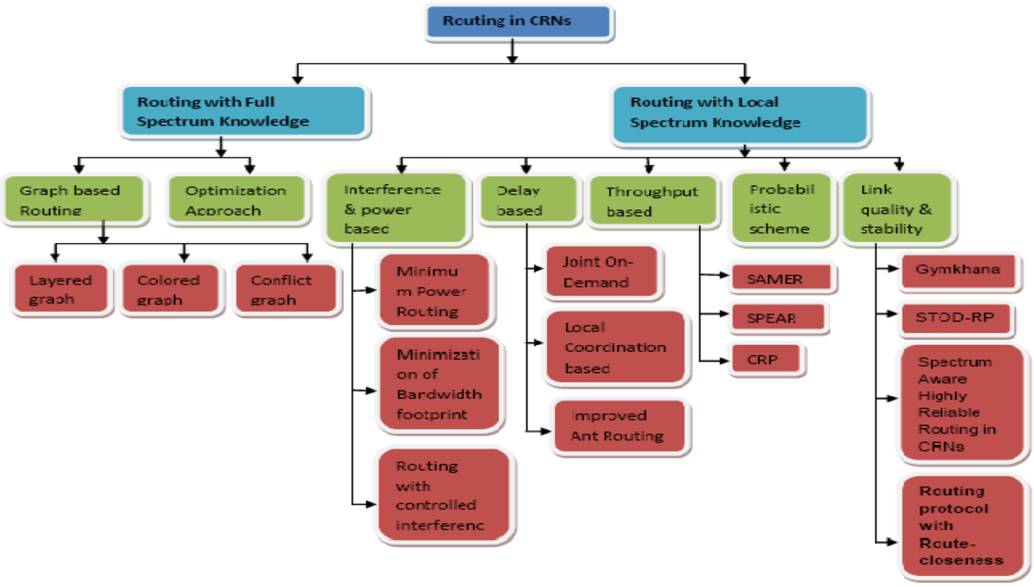

Figure 4: Classification of routing in CRNs.

Routing Scheme with Full Spectrum Knowledge

The availability of spectrum has to be sensed before transmitting the packets. The availability information can be received by all the nodes from the central unit. The FCC has exploited that the white spaces in the spectrum below 900 MHz and around 3 GHz bandwidth can be used by the Cognitive User (CU)[1]. The routing schemes under this category in discussed in the section below.

1. *Graph based Routing*

There are two phases: Graph abstraction and route calculation. In the first phase, the logical graph is created with the physical topology which results in a graph structure G=(N,V,f(V)), N=No. of nodes, V=No. of Edges and f(V)=Function to assign a weight to each edge. Route calculation deals with defining a path from source to destination using mathematical computation.

1.1. Routing through Layered Graph:

The framework is proposed which is based on the creation of the layered graph with number of layers equal to the available spectrum. The framework addresses channel assignment and routing in semi-static multi-hop CRNs. In semi-static CRNs, the PU activity is assumed to be low enough for the channel assignment and the routing among SUs to be statically designed. Each CU device is represented in the layered graph with a node, A, and M additional sub nodes, A1, A2. . .AM, one for each available channel[3].

1.2. Routing through Colored Graph:

A colored graph Gc=(Nc,Vc) is used to represent the network topology where Nc is the vertex set and Vc is the node set. Two vertices can be connected using M number of edges where M is the number of available channels. Centralized Iterative approach is used for route calculation.

1.3. Routing through Conflict Graph:

The routing and channel assignment is dealt separately by finding all available routes between the source-destination pairs and all available channels for each route. The best combination of both is found by running a centralized algorithm on a conflict graph. An edge is drawn between two vertices if the corresponding wireless links cannot be active at the same time. The conflict graph is used to derive a conflict-free channel assignment using a heuristic algorithm to calculate the maximum independent set.

2. *Optimization Routing*

In order to optimize the network, the Mixed Integer Non-Linear Programming (MINLP) formulation is introduced. This aims at maximizing the spectrum reuse throughout the network and minimizing the overall bandwidth usage throughout the network. The link capacity. Interference and routing are considered for this approach. Routing is based on sequential fixing algorithm[3] which starts by setting up and solving the relaxed

LP version of the original problem to obtain the lower bound. Then the assignment variables are sorted in descending order. Then the largest bit is set to 1 and other variable are set to 0. Then, the LP formulation of the problem is solved based on the variables. This procedure is repeated until we get fixed assignment variables.

Routing Scheme with Local Spectrum Knowledge

The spectrum occupancy will not be known completely by all the CUs. They acquire information by local sensing through distributed protocol. As local sensing keeps varying time to time, the routing depends on the metrics that the CUs consider. The following section describes the categories of routing based on different metrics.

1. *Interference and Power based Routing*

The following routing schemes can locally manage the radio resource based on the Partial network information[5].

1.1. Minimum power routing:

This routing system contains two subsystem namely operation system and communication system. The operation system finds the wireless interface and the CUs communicate via the common link control radio (CLCR) to perform cognitive functionalities. Finally the system finds the path with minimum weight from source to destination. Here route maintenance is not done.

1.2. Minimization of Bandwidth usage:

The routing protocol operates on the metric called Bandwidth Footprint Product (BFP). The footprint denotes the interference area associated with a given transmission power. A node use different transmission power to transmit in different frequency bands. The objective of this routing protocol is to minimize the sum of BFPs of all the nodes. The link scheduling, power allocation and route selection are performed by a conservative iterative procedure (CIP) and an aggressive iterative procedure (AIP).

1.3. Routing with controlled interference:

When the PUs are transmitting data, the CUs must have a transmission power lesser than the threshold in order to satisfy the Qos requirements of the PUs. The CU has a maximum transmission distance. For this purpose two routing algorithms are proposed: Nearest-Neighbor Routing (NNR) and Farthest Neighbor Routing (FNR). NNR has better performance in terms of energy efficiency and FNR has better performance in terms of reliability and channel utilization.

2. *Delay based Routing*

The routing quality is measured in terms of delay. End-to-end delay is the traditional metric. The components are switching delay, back off delay and queuing delay. Following are the protocol that uses the delay metric[4].

2.1. Joint On-demand Routing and Spectrum Assignment:

A Delay motivated On-demand Routing Protocol(DORP) is a delay-based approach where the switching and back off delay along the path or at the intersecting nodes are represented as PATH-delay(DP) and NOE-delay(DN) respectively. DORP inherits AODV which sends RREQ for route discovery and chooses the frequency band based on the delay. The cumulative delay at route m, is calculated using

$$D_{route,m}=DP_m+DN_m \qquad (1)$$

2.2. Local Coordination Based Routing and Spectrum Assignment:

The two parts of this routing are

1. A joint on-demand routing algorithm for frequency band selection to achieve minimal end-to-end delay (section 2.1.).

2. A local coordination scheme for load balancing among multiple frequency traffic in the intersecting relay node.(Implementation in fig 5)

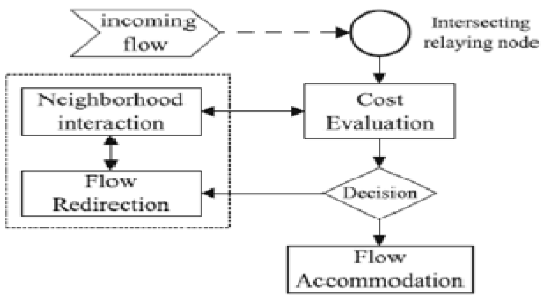

Figure 5: Implementation of Local Coordination

2.3. Improved Ant Routing Algorithm:

It is a on-demand routing protocol without a common control center. This follows Swarm intelligence, a powerful tool to solve large scale optimization problem in a distributed way. Route discovery starts with creation of ant colony and RREQ when there is a data for transmission. The number of ants is based on the network demand. The no. of ants from i to j in RREQ is given by $N(P_j)=m_{i,j}.N(p)$ where N(p) is the no. of ants sent to neighboring nodes.

3. Throughput based Routing

To maximize the success rate of packet delivery per second, the following solutions are proposed[4] .

3.1. SAMER:

Spectrum Aware Mesh Routing (SAMER) builds a forwarding mesh that adjusts periodically based on the spectrum dynamics. It balances both long term and short term spectrum availability. The mesh is centered on the spectrum available and the protocol is based on Path Spectrum Availability (PSA) metric. PSA captures the local spectrum availability and spectrum blocks quality. The packets are delivered through the path with highest PSA value that is available at that point

3.2. SPEAR:

SPEctrum Aware Routing protocol (SPEAR) includes three parts: (i).integration of spectrum discovery and route discovery to cope with spectrum heterogeneity; (ii). Coordination of channel assignment of a per-flow basis, by minimizing inter-flow interference; (iii). Exploiting local spectrum heterogeneity and assigning different channels to links on the same flow to minimize intra-flow interference.

3.3. CRP:

CR routing protocol for ad hoc networks (CRP)[11] considers large number of metrics namely probability of BW availability, spectrum propagation characteristics, variation in no. of bits sent etc. It has tow routing classes: class 1 provides higher significance to CR performance while meeting minimum PU interference avoidance; class2 prioritizes PU protection over achieving low end-to-end latency for CR users. The route set up has two stages namely spectrum selection stage and next hop selection stage.

4. Probabilistic scheme Routing:

As the PUs activities are difficult to judge, the spectrum aware routing decisions can be made in a probabilistic manner such that it satisfies the bandwidth demand. The probability metric is defined as the probability distribution of the interference received at the CU in the channel.

5. Link quality & Stability based Routing:

This section proposes routing solution that focuses on designing stable multi-hop routes in CRNs[4].

5.1. Gymkhana :

It can be explained in 3 parts:

1. A distributed AODV-style protocol to collect parameters related to candidate path from source to destination.
2. A mathematical structure representing a graph associated to a given path.
3. A closed formula, computed by evaluating the second smallest eigenvalue of the laplacian associated to the graph of part 2.

The RREQ has 2 lists: the list of nodes encountered in path k with unique ID and the list of influence vectors of nodes in the path. The example graph is shown in the figure 6. It has two edges: Horizontal Edge and Vertical Edge

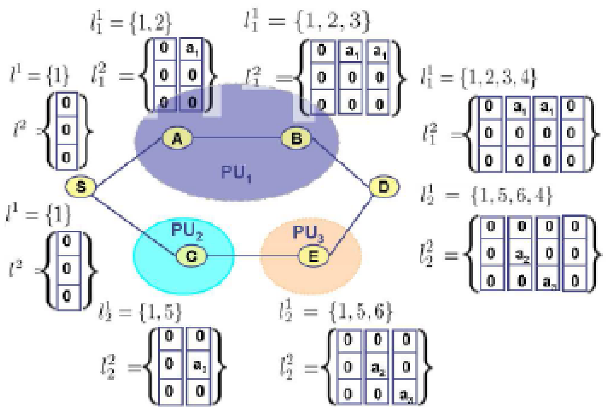

Figure 6: Example of Gymkhana Protocol

5.2. STOD-RP:

The Spectrum Tree based On-Demand Routing Protocol(STOP-RD) combines: (i). a route metric which considers both CR user's QoS requirements and statistical PUs activities; (ii) tree-based proactive routing and on-demand route discovery; (iii) spectrum-adaptive route recovery method for resuming communication in multi-hop CR networks.

CR users form a tree in each available spectrum, called spectrum-tree. Each spectrum-tree has one root. The node that belongs to multiple trees are called “overlapping”. Intra-spectrum routing occurs in a single spectrum-tree, while inter-spectrum routing occurs in multiple spectrum-trees by sending Spectrum Route Request (SRREQ). During inter spectrum routing, the root may find an overlapping node or may not find an overlapping node. When there is no overlapping node, the node with the shortest queuing size is chosen.

5.3. Spectrum Aware Highly Reliable Routing in CRNs:

The most stable path is chosen as the primary path among all the candidates. Another path disjoint of primary path is chosen called the alternative path. An ON/OFF mechanism for primary user is used where ON represents that the PU is active and makes use of the alternative path. When the alternative path is not available, a new path discovery process takes place. This protocol also provides a path maintenance mechanism.

5.4. Routing protocol with Route-closeness metric:

This protocol also exploits multi path routing with a different metric called “Routes Closeness”. Routes closeness deals with how far the nodes are from each other. The more the routes are far from each other the less the PU interruption between them. This increases the connection reliability and throughput. DSR protocol with some difference is used for route discovery phase.

III. CONCLUSION

The Routing scheme with full spectrum knowledge suffers from the weakness of centralized in nature and acquiring full knowledge of spectrum usage and channel availability [9] which consumes excess time. In Practical network, full knowledge is not achievable. When the spectrum knowledge is local within the neighboring nodes, various metrics such as bandwidth, power, interference, spectrum characteristics, number of bits transmitted are considered. Among all the routing protocols discussed above, CR routing protocol for ad hoc networks (CRP) takes the large number of metrics.

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