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Survey: Routing Protocols in Cognitive Radio Mesh Networks

T. Pavan Kumar[#1] E. Suresh babu[#2] B. Venkata Ramana[#3]B. Sai Shashank [#4]

Department of Computer science and engineering,
K L University, Guntur, India

Abstract **-Cognitive radio is the upcoming and promising technology that solves the issue of spectrum allocation by allocating the required space to both primary and secondary users accordingly, without any interference by understanding the environment of the spectrum. In present scenario there is more demand for usage of wireless technology and also for spectrum usage, so a device like cognitive radio could be able to solve all issues and helps for better functioning of these technologies. Routing in cognitive radio is very difficult and a challenging task due to the dissimilarity in channels present and the flow of data. In this paper we have outlined on basic concepts of CRN including its architecture and its functionalities. We have surveyed on some traditional routing protocols in cognitive radio network based on their classification and operation. Our scope of work will make you better understand on operations of various routing protocols and their advantages.**

Keywords: **Cognitive Radio, CRN, Spectrum, Routing, Security**

I. INTRODUCTION

Now a day's wireless and radio communications are used rapidly and its area has been developed enormously and intended to be more developed in the nearby future. Nearly 3.5 billion devices are using the wireless technologies and the number is expected to increase 50 percent more than today. We know that the gadgets like laptop, automobiles, TV, cell phone and tablet PCs which use this wireless technology are very smart in performing their function which also help us in our daily routine, and make our work very easy. This usage of these many devices make for more demand of spectrum. However some of the known and most popular spectrum bands are allocated and still not utilized effectively. These factors and requirements make us to move towards a new radio technology which satisfies all these requirements for the better functioning of this communication system and spectrum utilization. That device must be able to meet all the requirements of the wireless communication system and must minimize the draw backs in that network. So the promotion of the idea of cognitive radio have been precisely increased over these days it possess all the requirements mentioned by the wireless communication system. It also promises the removal of the limitations in the current communication system with the help of its observation, act and learn in order to improve the performance of the network.

Cognitive radio technology has the ability to understand the spectrum and take decisions on its own depending on the conditions and try to see that the spectrum is utilized in more efficient manner. In later sections we have shown the CR functionalities, its architecture, how it understands its surrounding environment, how it allocates spectrum which helps for the better understanding on this technology.

II. OVERVIEW OF COGNITIVE RADIO TECHNOLOGY

The concept of cognitive radio was proposed by Mitola III. Federal communication commission (FCC) formally defined Cognitive radio as an intelligent radio that utilizes the maximum available band-width to the unlicensed users in efficient manner. Cognitive radio acts as a Trans-receiver which can intelligently detect the channels which are both use and not in use and always searches the vacant channels and provides for the unlicensed users. The primary factor that helps CR to perform better in various situations is its operating frequency, in which cognitive radio is capable of changing the frequency and act according to it. Based on the information it gets from its surroundings it determines the most appropriate frequency is selected and communication is done according to the frequency available and frequency determined. The parameters in CR like capability and configurability makes the radio to act as smart and hence the name cognitive radio. Cognitive Radio networks are an intelligent upcoming multiple hopped technology where nodes change their transmission and receiving parameters for the communication purpose and also not to interfere the licensed users. In cognitive radio nodes dynamically change their parameters according to the environment, secondary users sends the information from the CR and utilize the unused spectrum holes that are not used by primary users at that time, so from this we can understand that the main goal of CR is to increase the utilization of spectrum which is a scarce but also acts as a down utilized resource as presented by FCC. Study of Cognitive engine helps us to better understand the functionality of Cognitive radio. The cognitive engine works according to the principle of cognitive cycle. It consists of several steps like analyzing the radio frequency stimulate from the other environment and detecting the spectrum holes. It also includes functions like transmission power control and managing the spectrum so that efficient spaces are utilized and allocated to the unlicensed users and also to ensure interference free opportunistic spectrum access. The cognitive engine performs the functions like sensing, analyzing, learning, decision making and reconfiguration. These kind of networks have two kind of users one is primary (licensed) and other is secondary (unlicensed or cognitive) users. Primary users have the right to use the spectrum first. On the other way secondary users can utilize the spectrum only if it is available and not used

by licensed user at the moment. Based on the radio frequency stimulate the usage of the spectrum can be divided into three categories: Black Spaces, Grey Spaces and White Spaces.

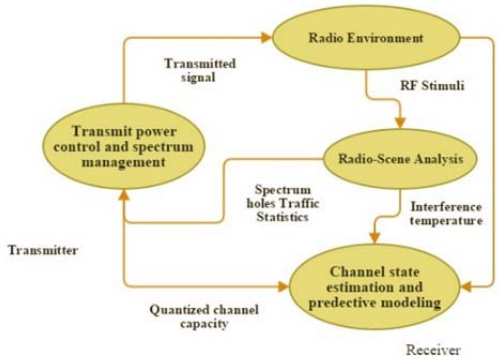

Fig 1: Representing Cognitive Cycle

A. Cognitive Radio Architecture:

Cognitive Radio Network can be able to sense the networks and channels available near to it based on the different parameters like spectrum sensing in order to improve the utilization of the spectrum. Cognitive Radio Network can be regarded as combination of many communication systems. This architecture helps to improve the utilization of the spectrum and also helps to improve the performance of the network. Generally, users think that if the network is able to satisfy the demand without the interference of the two users6 then the network is said to be functioning properly. CRN can adopt in distributed, centralized, mesh and ad hoc type of architectures and be able to solve the spectrum utilization problems. The main component in this architecture are base station, mobile station, and backbone network. The two main types of Architectures are shown below.

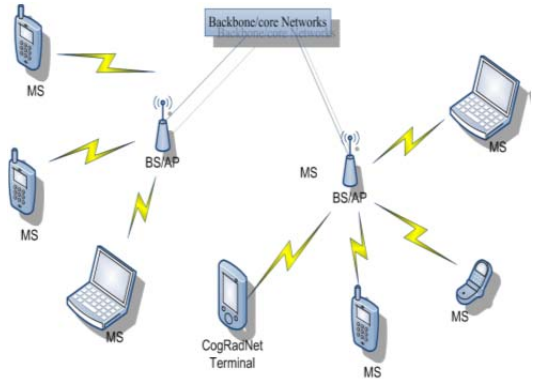

Fig 2: Infrastructure Architecture

1. Infrastructure Architecture:

In this type of architecture mobile station could be able to access the base station if it is in a distance of one hop. The mobile station and base station can communicate only when they are in the same transmission range. Backbone network helps to establish communication among the different cells. In order to satisfy demand from the mobile stations, the base stations can execute one or more routing protocols at the same time. Various kinds of communication systems are accessed by terminals of the cognitive radio through its access points. This type of architecture works under a centralized mechanisms and maintains entity called base station to process the request in the network. The functionalities of the CR node are predefined in this type of architecture so that it can be able to link with other node which is at distance of one hop. So the information received by each and every cognitive node is transformed to the central base station, this base station avoids the interference with other networks. So based on this each CR node redefines or updates its communication parameters in accordance with the central statio**n.**

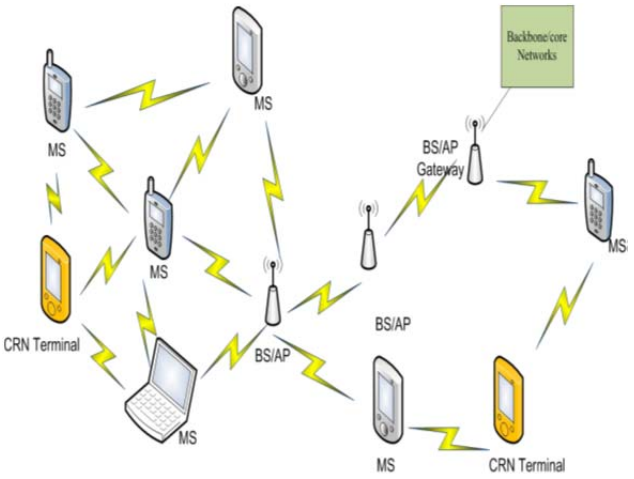

Fig 3: Mesh Architecture

2. Mesh Architecture:

This architecture can be regarded as combo of ad hoc and infrastructure type of architecture which maintains connections between the access points. In this type of architecture access points acts as backbone and behave as and function like wireless routers. In order to access the base station mobile stations use direct access or use multi hop relay nodes. Some of the base stations which area attached to the wired backbone act as gateways. They behave flexible even without being connected to wire backbone. This architecture offers less cost in establishing the locations of these access points. The combination of cognitive radio capabilities with the base points mainly use holes of the spectrum for the communication purpose. Because of the large availability of the spectrum holes we can be able to serve link between cognitive radio base stations as wireless bones. It comprises both the advantages and disadvantages of the both infrastructure and ad hoc architecture.

B. Cognitive radio Functionalities

1. Spectrum Sensing

Spectrum sensing means to detect the unused spectrum bands, so this detection of spectrum poles is one of the key function of cognitive radio. This uses two types of techniques:

In Transmitter Detection mechanism CR detects the primary transmitter signal. It identifies the frequency in which the primary user is present and primary user contains some kind of known frequency and that known frequency says that primary user is available at that moment. So this frequency can be known by the techniques like

cyclostationary feature detection, energy detection and matched filter detection In Cooperative Detection method the information is shared form the secondary users. SU will inform if there is any free space available to the network so all the nearby SU`s will share the information of presence of primary user. Hence it is cooperative.

2. Spectrum Management

It is the process of allocation of allocating in the available spectrum by considering user and performance requirements. The spectrum hole must be best enough to get occupied. It is an important function of cognitive radio as it deals with the occupation in best spectrum hole available, it can be further classified into spectrum analysis and spectrum detection

3. Spectrum Mobility:

It refers to movement of the licensed or unlicensed user from one bandwidth to another. This transition is because of arrival of the primary user at that point. According to FCC whenever the primary user comes to the position secondary user must leave it and should occupy other best spectrum hole available. As cognitive radio depends on the dynamic spectrum access these transitions are necessary.

4. Spectrum Sharing:

It refers to allocation of different spectrum space to the unlicensed users, so it refers to scheduling of the empty space to the users. It must be able to satisfy all secondary users by allocating the available required necessary and sufficient amount of spectrum to the unlicensed users. This task must be done effectively and efficiently. This function is also one of the major challenge of open spectrum access.

III. Cognitive Radio Networks: Routing Protocols

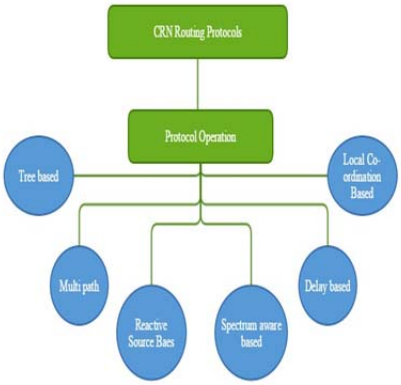

Fig 4: Diagram showing all routing protocols

A. Tree Based Routing:

An example of centralized type of routing is Tree based routing. Now we can understand that this routing protocol works under the single source of entity called base station, there will be only one entity in which all can work under supervision of it. Thus this network can be built among these stations by making base station as root and the rest of the section can be built from the help of base station. Now we see how this protocol works.

Cognitive Tree based Routing:

For the wireless mesh networks we have a routing called Cognitive tree based routing protocol which works under the principle of tree based routing protocol. In order to know the route directions this protocol mainly uses local and global decision schemes. Local decision scheme uses the least load with best interface whereas Global decision scheme decides the route by using best available end-to-end metric in global. But we can have same end-to-end metrics for the same destination, so in this case we mainly use local decision scheme for the path selection in which less load is measured and applied.

As we have seen earlier that this protocol (CTBR) works according to TBR, so the root mainly sends the messages in the form of announcement (RANN) for the formulation of the tree. Any node receiving this message (RANN) which make a copy of the node from which it had received and assumes it as its parent and again broadcast this (RANN) message by updating its cumulative metric. The selection of the parent by node depends on best hope count available from the source to destination. Now the node should register with the root so node that having route to source will send route reply message (RREP). The nodes before to it when receive this message will forward it and make a note of it by updating its routing table by mentioning the node form which it had received as its destination. Thus we can be able to construct the tree which contains information about the source and destination for each node.

Advantages:

This protocol mainly requires the calculation of end-to-end metric thus we have a new link aware cognitive metric for this purpose. The final end-to end delay achieved is 5 times better than scheme of hop count which is very best feature available. In order to reduce the local contention condition along with multiple interfaces they have used local decision rule for the selection of an interface for the CT. They have also introduced global decision rule for the route estimation between source and destination. For the decisions to be made on the route it doesn't depend on the cross layer methods. It has got the best mechanism in which link never gets failed and handling the links is also very easy in this method. As it is centralized type of topology if any failure occurs it happens only at a single point so can be recovered. Also as it maintains the tree based topology it has several more advantages in various aspects like route discovery, failure handling etc. and is used by several other networks for the purpose of route discovery.

Table 1: Summary of CTBR Routing Protocol

Feature		**Explanation**
Overhead of protocol	Yes	We require more control bytes for transmission
Nature of route		Periodical
Packet size in route discovery	Fixed	Each node need to update its cumulative metric

B. Multi-path Routing:

In this type of protocol the name itself indicates that multiple routes are found for destination and then the best available route is discovered based on several other factors. Now we see in detail about this protocol.

Multipath Routing and Spectrum Access (MRSA):

Currently available multi-path routing protocols in area of wireless networks cannot be implemented in cognitive radio networks because they never consider the factors like

spectrum availability nor the existence of primary and secondary users. The problems in CRN like interference and inter path contention can be reduced by using this protocol. Also the interference of primary user can be reduced by allowing the traffic to be distributed in various paths. It mainly uses Round robin fashion for the traffic distribution.in the network. The concept of spectrum wise disjointness is revised as several paths do not have any bands that are interfering between them. It assumes that there are N total channels for sake of data traffic and over these channels the signal is delivered along with traffic in the data. For the route discovery process this protocol uses dynamic source routing (DSR) in which RREQ message is broadcasted with new RREQ_ID along with the band radio usage table (BRT). The intermediate node when receives the RREQ it generally forwards the message but before that it verifies whether the RREQ_ID is new or old and it need to update the hop count and then forwards the packet. If the hop count of RREQ is less than previous RREQ it now adds it's BRT and then move it further. So with this process the destination receives same RREQ message from various paths. So it first assigns radio and band to each and every link and then checks all the candidate paths with the available bandwidth. The sudden arrival of PU can be recovered by extending the RERR message of dynamic state routing as it is part of recovery of route process.

Advantages:

The main advantage with this protocol is mainly improved bandwidth, failure handling and reduction of interference of primary and secondary user. The throughput is higher in this protocol when compared to other which maximum utilizes the network resources. It has best resilience from the primary user interruptions.

Table 2: Summary of MRSA Routing Protocol

Feature		Explanation
End-to-end throughput	Yes	Using multiple paths and radios.
Nature of Route		Periodical
Size of packet	Variable	Each node adds it BRT and its ID
Striping of data	Yes	Round robin method
Topology of network		Mesh

For the purpose of route discovery it uses RREQ messages which is safe and efficient way of using or knowing the channel. It has also got the advantage of not depending on the cross layers. It has got the ability to handle the failures as it uses RRER messages. It has also got the ability to select the best path available with the help of hop count method.

C. Reactive Source-Based Routing:

In Reactive source based routing protocol the name itself indicates that the source itself tells how the data moves across the network. That means the route to destination is computed by source node. Now we see in detail about this protocol.

Routing in Opportunistic Cognitive Radio Networks:

In CRN's this kind of protocol is proposed by Khalife et.al. It mainly uses a metric which is based on a definition of probability on the capacity available over the current channel. To satisfy the demand of bandwidth we need to find the most probable path (MPP), which can be found by using this protocol. So for this we require augmentation phase in which all bottleneck links are mounted with some more channels so that the path obtained will be able to satisfy the demand of bandwidth with the probability given. The capacity available can be calculated with the help of probability distribution of the PR to CR user interference over the channel for a given node.

When a request of bandwidth with some capacity is arrived now the source will accept the request and initiate the process and the node is coordinated using control channel mechanism. Link probabilities are measured based on the number of requests. This protocol uses Dijkstra-like algorithm after all the link weights are measured to find the route for destination. The resultant path is MPP as it contains highest and best probability of satisfying the stability and need to reach the destination. The Dijkstra-like algorithm when reaches one of the below two states it stops its computing.

1. On and every link of MPP the final total capacity will be greater than the requested one.
2. After the enhancement of links if the total calculated capacity on each and every channel of two nodes will not satisfy the stability and demand to destination. In this scenario, there is no suitable path to the destination and thus declared as unavailable.

Advantages:

As this protocol directly deals with the multiple channel transmissions and PR to CR interference it has got some several advantages. As it uses most advanced algorithm, Dijkstra-like algorithm to calculate the route we have less chance of failure in between route. It also doesn't depend on cross layers. The data structure used in this is Graph and has several associates and applications with it and adds as an added advantage. It also protects the network from failure handling.

Table 3: Summary of MRSA Routing Protocol

Feature		Explanation
End-to-end Throughput	Yes	As MPP is determined to satisfy the demand over the channel.
Nature of route		On demand
Assignment of Link weight	Yes	Done on capacity of link available
Packet size in route discovery	Fixed	Hop-to-hop

D. Dynamic Spectrum-aware Routing:

Dynamic Spectrum aware routing protocol allows to maximum utilize the wireless spectrum which is unallocated and unshared in this type of network. Spectrum sensing is also integrated in route discovery process in these type of protocols. The main aim of this is to create a route

in a region where the spectrum is available free. We see in detail about these protocol below section.

1. Spectrum-Aware Routing (SPEAR):

This type of routing protocol allows to obtain high throughput for the packet transmission. By combining link based and flow based approaches we can achieve high persistence performance in packet transmission. In order to minimize the interference between two types of users we maintain various channels on the same direction to links. Integration of route discovery with spectrum discovery process makes use of channel very optimal. To achieve optimality each node preserve the list of unshared channels which are present locally. Primary users nor the nearby neighbors may not utilize those free channels. In order to discover the route we use or broadcast RREQ message on the same control channel which can be identified by receiver and sender IP addresses. Now the intermediate node checks whether it has a common channel with the above node if then it adds its own Id along with the message received and it again broadcasts it. Keeping the factor of maximum throughput into account the destination selects the best route available and try to minimize the latency delays and improves the link quality. During this transmission process each node periodically sends channel reservation message. Those message contains time-to-live and timeout field. Nodes are notified with stop message along the path whenever the communication ends.

Advantages:

This routing protocol mainly helps to maximum utilize the free spectrum usage in various channels. This protocol mainly takes less computational and low communication complexity. It really gets maximum throughput for end-to-end transmission and also improves the performance even when extra nodes gets added. In order to protect from the link failure there is a field named Timeout field which simplifies the task of management of links. We have Time-to-live field in order to reduce an overhead of broadcast and contention. Narrow band control channel is used in this type of protocol.

2. SER-Spectrum and Energy Aware Routing Protocol:

The SER protocol has one important goal: to establish a band with guaranteed route between the consenting nodes in the subnet while also ascertaining a Quality of Service (QoS) based routing connection. This entire agenda is carried out in a subnet where the topological changes are relatively low. The QoS that this protocol guarantee's is the number of transmission timeslots for a packet on its route from source to reach the destination. The protocol's inclusion of Time Division Multiple Access makes it more usable in MCRAHNs.

Discovering of a route:

An important procedure is entailed in the SER protocol while discovering a route to carry on the communication process. When a Cognitive Radio, CR, user wishes to communicate in a subnet, that user will first start the route discovery process by broadcasting a spectrum aware message known as RREQ message which is short for Route Request. This is the very reason SER is classified into a spectrum aware routing protocol. The RREQ broadcast is carried out on the Common Control Channel (CCC). The RREQ will be received by all of the source node's neighbors.

Table 4: Summary of SPEAR Routing Protocol

Feature	SPEAR	Explanation
End-to-End throughput	Yes	With the combination of link-based and flow based techniques
Decision of route		By broadcasting RREQ message, by using control channel
Handling of Mobility	Yes	With the help of Timeout field
Computing complexity	No	

E. Delay-Based Routing Protocol:

Delay is an important factor in measuring the nature of routing protocols and also helps to establish multi path routes and maintain traffic over the same routes. Also some delay components while transmission of packets in wireless networks associated with spectrum mobility must be alleged in CRNs with multiple hops. There are various delay based components like:

- Medium access delays depends on access schemes of MAC used in frequency band available.
- Switching Delay appears whenever the frequency band in one node changes to other band.
- Queuing Delay occurrence depends on the node's output transmission capacity in the given frequency band.

F. Local Coordination-Based Routing:

This kind of protocol is a type of enrichment technique which can be applied on the nodes that are intersecting on a path. This kind of coordination gets started when the task of flow maintenance gets assessed by the nodes available. Nodes selects the flow direction and accommodation based their obtained results and interaction with the neighborhood. We see in detail about this protocol.

Local Coordination Based Routing and Spectrum Assignment in Multi-hop Cognitive Radio Networks:

This spectrum assignment protocol helps to swap the local spectrum and coordinate with the multiple frequency in each node. In order to form the structure on common channel for distribution of spectrum opportunity among the nodes AODV is slightly modified and designed to overcome disparity of SOP. At each node it also calculates RF band by identifying the cross flows. RF band is used for multiple flow multi-frequency scheduling and also used by many nodes for this purpose. To get back off and switching delays we use node delay and path delay techniques on the path. It also helps to calculate the aggregate delay of the path. Whenever the nodes flow in different directions we may get the traffic overhead because of various operating frequencies. Local coordination scheme helps to maintain load balancing in this scenarios. Classic wireless interfaces

are equipped for each node in the network along with the CR transceiver to provide fruitful route for delivery of messages at each and every node. Although if there is any inconsistency in frequency band this scheme helps to overcome it.

Advantages:

Adaptability for the spectrum diversification is the main advantage of this routing protocol. It helps to achieve the maximum end-to-end throughput while delivering. It also helps to achieve maximum performance by controlling the flow direction and the accommodation in traffic in the network. It maintains and handles failures very effectively by traversing flow to other neighbor. The channel is well controlled by transferring spectrum opportunity among the nodes in the network.

Table 5: Summary of LCB Routing Protocol

Feature		**Explanation**
End-to-end delay	Low	Adaptive relay is supporting the routing protocol
Discovery of route		RREQ messages are broadcasted
Decision of route		Decisions are made by Network and MAC layer
Route discovery packet size	Shifting	SOP list is present in each intermediate node

CONCLUSION

Cognitive radio technology plays a major role in managing the spectrum resources and allocating them according to the requirements of the users. In the future it can be applied to many more type of technologies and in many wireless devices. As routing in CRN is more complicated, now the scholars are concentrating more on developing an innovative type of routing protocol to reduce complexity and other issues. In this paper we have shown how CRN functioning and how they study the spectrum environment with the help of their kinds of architecture. This helps to understand on CRN operations and their way of work. An analysis of different routing protocols shown will help to understand how CRN try to send data and various issues faced by them during their passage of data through various routes each of different kind. Though these routing protocols appear to be more promising than others, they too follow the usual metrics followed by the wireless network devices. So there is no need to introduce new routing metrics to the CRN characteristics. We hope in the coming future cognitive radio soon moves into wireless devices as programmable systems from the stages of laboratory.

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