



International Journal of Emerging Technologies in Computational and Applied Sciences (IJETCAS)

www.iasir.net

Routing Solutions in Cognitive Radio Network Using Local Network State Information

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Abstract: Cognitive Radio (CR) technology is introduced to solve the problem of spectrum usage inefficiency of wireless networks. CR technology allows sharing of licensed spectrum band in opportunistic and non interfering manner. However it should be aware of spectrum availability and Primary User (PU) activities. Routing and spectrum management are the main challenges in Cognitive Radio Network. Here routing challenges and solutions are explained in detail. Spectrum occupancy information maintained at each cognitive user is used for routing decision. With this local information methodologies are explained for different routing metrics. Finally open research issues of routing in CRN are outlined.

Keywords: Cognitive radio; Primary user; White space; Spectrum management; Local spectrum information;

I. Introduction

Today's wireless networks are using fixed spectrum band assigned by different governmental agencies. Now a day's spectrum demand increases. In current wireless network most of the portion of spectrum band is used irregularly in specific geographical areas where most amount of spectrum remains unutilized. The use licensed spectrum is quite uneven and depends on specific wireless technologies, their commercial success in market. According to recent studies by Federal Communications Commission (FCC) utilization of assigned spectrum varies in the range from 15% to 85%. Dynamic Spectrum Access (DSA) is introduced to solve spectrum usage inefficiency problem. DSA introduced policy based intelligent radios known as Cognitive Radios (CR). Cognitive radios are software-agile devices that can be programmed to change their parameters (like operating parameters, modulation, transmission power and communication technology) based on spectrum environment. Cognitive radio technology is wireless network technology, which allows sharing of wireless channel with licensed users in an opportunistic manner. Cognitive radio networks provide high bandwidth to mobile users through heterogeneous wireless architectures and dynamic spectrum access techniques. Thus CR technology enables cognitive users to use existing spectrum efficiently without disturbing primary user activities.

Cognitive Radio technology allows users to sense available portion of spectrum as well as primary user's presence, to select best channel, to share the channel with other users and to free the channel whenever primary user is detected. Cognitive radio has 2 main characteristics.

1) Cognitive Capability: It is ability of radio technology to sense the radio environment. It captures the temporal and spatial variations in radio environment and avoids interference to primary user. This capability identifies unused portion of the spectrum, which is known as "spectrum hole" or "white space". Cognitive capability task is represented as the cognitive cycle. Three main steps of cognitive cycle are: spectrum sensing, spectrum analysis and spectrum decision.

i) Spectrum Sensing: Cognitive radio detects available spectrum bands by capturing their information.

ii) Spectrum Analysis: Characteristics of spectrum holes such as data rate, transmission mode, and bandwidth are estimated.

iii) Spectrum Decision: According to spectrum characteristics and user requirements appropriate spectrum band is selected.

Cognitive radio should keep track of radio environment since it changes over time and space.

2) Reconfigurability: Once radio environment gets captured, reconfigurability helps cognitive radio to program dynamically according to radio environment. It is programmed to operate on different frequencies and to use different transmission technologies. It is the capability of adjusting the operating parameters for the transmission. Parameters that can be adjust are, operating frequency, modulation, transmission power, communication technology. The main objective of cognitive radio is to detect best available spectrum via cognitive capability and reconfigurability.

Functions of Cognitive Radio are as follows,

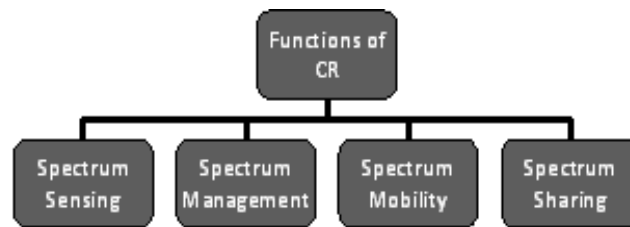


Fig. 2 CR Functions

1) **Spectrum Sensing:** Spectrum sensing allows cognitive user to detect spectrum holes by detecting primary users that are receiving data within its communication range. Spectrum sensing techniques are classified as follows, transmitter detection, cooperative detection, interference-based detection.

2) **Spectrum Management:** To meet QoS requirements of application cognitive radio should select best available spectrum band among all available spectrum bands. This is achieved through following spectrum management functions, Spectrum Analysis, Spectrum Decision.

3) **Spectrum Mobility:** Spectrum mobility occurs when primary user requires its licensed band. Such type of handoff is referred as spectrum handoff. Spectrum mobility ensures that transition of network protocol from one mode of operation to another is made smoothly and without degrading network performance.

4) **Spectrum Sharing:** Provides spectrum scheduling among all existing users. Spectrum sharing process is divided into following 5 steps, spectrum sensing, spectrum allocation, spectrum access, transmitter-receiver handshake and spectrum mobility.

This paper presents current challenges of routing in Cognitive Radio Network (CRN) and different solutions with different routing metrics. We first explain difference between classical routing in wireless network and routing in cognitive radio network. Then we provide brief overview of spectrum management for cognitive radio network. We explain existing work and challenges in cognitive radio network. And finally different methodologies for different routing metrics are explained as solutions for different challenges of CRN.

II. Classical Routing vs. Routing in CRN

Routing is the process of moving packets across a network from one host to another host. Traditional wireless network routing is different from cognitive network routing. In traditional wireless network, routing nodes uses same frequency for communication. Only the node mobility and transmission power affects the routing. In cognitive radio network, routing is combination of traditional routing and spectrum management since spectrum availability varies from node to node with respect to time and location. Spectrum availability is also affected by the primary user activities.

For routing and spectrum management two approaches are considered-cross-layer and decoupled. In decoupled approach, route selection is performed independent of spectrum management using various shortest path algorithms. In this approach each source code finds candidate path by using DSR and by scheduling time and channel for each hop. In cross-layer approach considers route selection and spectrum management jointly. As spectrum availability affects the network performance more thus, cross-layer approach is more beneficial for cognitive radio network.

The major challenges of routing in cognitive radio network are as given below.

1) **Lack of CCC (Common Control Channel):** In traditional routing protocols, specific functionalities such as neighbor discovery, route discovery and route establishment are done through local or global broadcast messages. In cognitive radio network, due to lack of CCC broadcasting becomes a major problem.

2) **Intermittent Connectivity:** In cognitive radio network, due to spectrum availability and primary user activities reachable nodes may change frequently. Thus, network connectivity in cognitive radio network depends on spectrum availability. This challenge can be solved by using time and space based solutions with respect to channels.

3) **Spectrum availability:** Routing module must be aware of spectrum availability which is achieved by monitoring spectral environment.

4) **Primary User Activity Awareness:** Topology of cognitive radio network is affected by primary user activities as well as by route quality measurements such as bandwidth, throughput, delay, energy efficiency which should be considered with spectrum availability.

5) **Route Maintenance:** Primary user activities may results in frequent route rerouting which in turn will degrade the network performance. Thus effective signaling procedures are required for convenient routing in cognitive radio network.

III. Routing Solutions

For spectrum awareness challenge, one of the approaches is use of local network state information to take local spectrum management decisions. Local spectrum occupancy information is retrieved in a distributed way similar to classical wireless network routing. However it is quite difficult since local network state is highly

affected by variable in time and space. Here solutions are categorized according to different routing metrics to achieve quality routes.

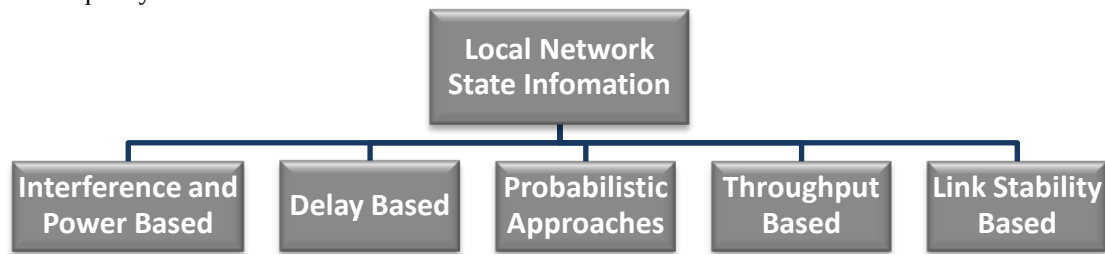


Fig. 3 Routing Schemes

A. Interference and Power based solutions

Routing metrics used are transmission power and interference generated between two secondary users during transmission.

a) Minimum Power Routing

In [2], to get minimum weight paths communication system is divided into operating system and communication system. Operating system is responsible for selecting wireless communication interface which is used to access various wireless systems like cellular or WLAN. A dedicated interface Common Link Control Radio (CLCR) is used for communication between cognitive radio terminals to maintain cognitive network functions. Two main functions using CLCR interface are neighbor discovery and path discovery. For neighbor discovery CLCR uses transmission power required to reach to all neighbors. The link weight is defined as a function of transmission power used by wireless systems. For increasing transmission power $WS[i]$ with distance the paper uses space propagation model as follows,

$$PTXWS[i] = PRXWS[i] \cdot (4\pi d / \lambda WS[i])^2$$

Where, $i=1, 2 \dots W$ are W wireless systems

$PTXWS[i]$ = Transmission power of $WS[i]$

$PRXWS[i]$ = Received signal power of receiver $\lambda WS[i]$ = Wavelength of $WS[i]$ and d = distance between transmitter and receiver

Routing protocol is proposed to find path with minimized routing weight between source and destination. Route discovery is similar to state routing algorithms where the newly introduced weight is used. Analyze and understand all the provided review comments thoroughly. Now make the required amendments in your paper. If you are not confident about any review comment, then don't forget to get clarity about that comment. And in some cases there could be chances where your paper receives number of critical remarks. In that cases don't get disheartened and try to improve the maximum.

b) Bandwidth Footprint Minimization

In [3], authors introduced routing module that is based on the idea of Bandwidth Footprint Product (BFP). Footprint represents interference area of a node for given transmission power. As each node has a specific footprint corresponding to its transmission power then objective of this paper is to minimize network-wide BFP i.e. sum of BFPs of all nodes in the network. For route selection, link scheduling, and power allocation, Conservative Iterative Procedure (CIP) and Aggressive Iterative Procedure (AIP) is used. CIP increases rate of session with smallest scaling factor whereas AIP increases session rate by maintaining limited decrease in other session's rate. Routing module is based on Incremental Link Cost (ILC) to increase data rate through captured local information. This algorithm is useful for performance predictions rather than distributed resource allocation.

B. Delay based solutions

Routing quality can also be measured in terms of delay required for information transmission. In wireless network, delay components are considered related to spectrum mobility. Delay-aware routing metrics consider following delay components,

Switching Delay: Delay required by a node for path switching from one frequency band to another.

Medium Access Delay: Based on MAC access schemes used in given frequency band.

Queuing Delay: based on transmission capacity of a node on given frequency band.

a) Solutions with Switching and Access delay

In [4], delay metrics considers both switching delay between frequency bands ($D_{switching}$) and Medium Access i.e. Backoff between given frequency bands ($D_{backoff}$). At node i , cumulative delay metric along a candidate path is computed as,

$$D_{route, i} = DP_i + DN_i$$

Where, $DP_i = D_{switching} + D_{backoff, i}$

If path is composed of H hops, switching delay can be,

$$D_{switching, i} = \sum_{j=i}^H k[Band_j - Band_{j+1}]$$

Where, k = constant

$Band_j$ = frequency band from node's active bands

b) Solutions with Queuing delay

In [5], Dswitching and Dbackoff are integrated with queuing delay occurred at intersecting nodes which processes n incoming flows. Thus the generalized cost function becomes as,

$$C_{generated} = D_{route} + D_{queuing}$$

Thus the assigned new frequency band to flow results in increases Dswitching

This queuing delay estimation provides more accurate solution for cognitive network routing. This paper also provides local coordination among neighbor nodes from intersecting node. Intersecting node decides whether to use incoming flow or to redirect it to its neighbors to avoid workload. Local coordination includes both exchange of cost evaluation information and redirection of a flow to neighbor nodes. For path set-up local state information are piggybacked into route request packets and delivered to destination node.

C. Throughput based solutions

a) Path spectrum availability routing

In [6], authors proposed Spectrum Aware Mesh Routing (SAMER) protocol which considers short term and long term spectral availability. This protocol selects routes with highest spectrum availability as candidate paths. It keeps track of long-term routing metric based on spectrum availability and "least-used spectrum first" routing protocol. It balances between long-term route stability and short-term route performance via runtime forwarding route mesh network. Authors defined metric for estimation of Path Spectrum Availability that captures,

i) Spectrum availability at node i , its bandwidth and contention from secondary users.

ii) Depending on bandwidth and loss rate quality of spectrum blocks.

In SAMER optimal routing is defined in terms of, hop-count, end-to-end throughput, spectrum utilization.

Routing metric includes both route quality based and high spectrum availability based routing. To increase short-term routing performance, SAMER selects a fine time-scale and coarse time scale. SAMER avoids highly congested and unavailable links.

b) Spectrum utility based routing

In [7], main goal is to achieve high throughput. Based on spectrum utility transmit opportunities are assigned and based on that spectrum opportunities route is established. In this paper authors introduced a spectrum utility for link (i, j) i.e. maximum differential between node i and node j defined in formulas as follow,

$$U_{ij} = c_{ij} (Q_{is}^* - Q_{js}^*)$$

Where, c_{ij} = achievable capacity for link (i, j)

Q_{is}^* = Current backlog of packets at node i for session with highest differential backlog s^*

D. Link stability based solutions

Link availability in cognitive network is different from traditional wireless network. Channel availability in cognitive network varies with time and space. Thus stable links is one of the routing solution which can be achieved through following routing schemes.

a) Enhanced path recovery functionalities

In [8], authors proposed SPEctrum-Aware Routing (SPEAR) protocol to get link flexibility with spectrum heterogeneity. Spectrum availability depends on location and presence of primary user activities. SPEAR considers following concepts for link stability,

i. To deal with spectrum heterogeneity, spectrum discovery is integrated with route discovery.

ii. By minimizing inter-flow interference, channel assignments are coordinated on per-flow basis.

iii. To achieve spectrum diversity and to reduce intra-flow interference, local spectrum heterogeneity is considered.

SPEAR set-up route by broadcasting and AODV-style route discovery is used to get each node's channel quality and availability information. Each Route Request (RREQ) contains node IDs, nodes spectrum availability and link quality. All these parameters are combined at destination to select optimal route. SPEAR discovers multiple paths with redundant paths that are sent to destination for best path selection. Selected route is reserved at destination by using RREP messages.

b) Routing with mobile SUs

In [9], SEARCH routing protocol is designed on geographic forwarding principle. In cognitive radio network, route is constructed at network layer must not affect primary user's transmission and thus must be aware of spectrum availability. The frequency changing PU activity and mobility of CR user make the problem of maintaining optimal routes in Ad-Hoc cognitive radio network challenging. SEARCH mainly works on following two concepts,

PU activity awareness: In CR network, route must be constructed to avoid region affected by active PU. When PU activity affect region, SEARCH provides hybrid solution, it first uses greedy geographic routing on each channel to reach destination by identifying and circumventing PU activity region. The path information from different channels is combined at destination in series of optimization steps to decide on optimal end-to-end route in a computationally efficient way.

CR user mobility: Cognitive user mobility results into frequent route disconnections. Thus for each node, through periodic beacons, updates its one-hop neighbors about its current location.

SEARCH ensures performance as well as less interference in cognitive radio network.

E. Probabilistic Approaches

In [10], routing approach introduced is based on probabilistic estimation of available capacity of every CR link. Routing metric is probability based where metric is defined through probability distribution of PU-to-SU interference at given SU over assigned channel. This routing metric determines most probable path to satisfy given bandwidth D in network of N nodes that operates on maximum M frequency bands of respective bandwidths $W_1, W_2, \dots, W_M$. Probability that channel i can satisfy bandwidth demand D is given as,

$$\Pr[C(i) \geq D] = \Pr[PI_j(i) \leq (\Pr_j(i)/(2D/W_i - 1)) - N_0]$$

Where, $PI_j(i)$ = Total PU-to-SU interference at SU j over channel i and $i=1, 2, \dots, M$ and $j=1, 2, \dots, N$

A source-based routing protocol is used for path selection. Link state advertisement phase allows source to compute most probable path to the destination. Thus in [20], with probabilistic approach node first looks for available channels and then selects efficient channel based on the history.

IV. Conclusion

Here different routing challenges are discussed in detail. One of the approaches is explained for finding solutions of routing problems is use of local network state information for routing. Several research works is done on these approach is discussed that focuses on different routing problems. Discussion on this approach provides open view towards the routing challenges in cognitive radio network.

Different routing measurements are provided to cognitive radio network to compute and analyze performance of proposed routing solutions. It starts research on multi-hop cognitive radio network including cognitive wireless mesh network and cognitive radio Ad-Hoc networks.

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Acknowledgments

I would like to express my sincere gratitude to my Prof. Sunita Barve, MIT Academy of Engineering, India, under whose supervision this research was undertaken.