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AN EMPIRICAL ANALYSIS OF ROUTING IN COGNITIVE RADIOS

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Abstract: *In wireless communication, users requirement continuously increase therefore wireless technologies should evolve with the same pace as the user`s needs. This helps to facilitate the integration of the innovative services and their implementation in daily communication. Therefore, a technical approach for all the management problems is introduced. This technical approach is based on the use of cognitive radio. Cognitive Radio Network (CRNs) is the key technology for future mobile computing and wireless network. Enabling several key capabilities in CRNs require localization of primary user.*

Keywords: *Cognitive radio, Primary User, Secondary User, Spectrum sensing, Routing,*

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INTRODUCTION

An ever-increasing demand for more radio spectrum is created by the rapid proliferation of wireless technology and explosion of wireless devices and mobile data. Due to the limited spectrum resources, the spectrum scarcity issue is expected to occur. A key technology for future wireless communication and mobile computing is introduced which is cognitive radio network. It is believed to be consistent as defined by Haykin`s.[1]

Cognitive radio network is an intelligent wireless communication system that is aware of its surrounding environment and which uses the environment to learn the methodology of understanding-by building. This network keeps two objectives in mind i.e. highly reliable communication wherever and whenever needed and an efficient utilization of the radio spectrum. To achieve these two primary objectives, the network adapts its internal states to statistical variance in the incoming RF stimuli by making corresponding changes in certain operating parameters such as carrier-frequency, transmit-power, and modulation strategy in real time.

For a good network and application performance, a cognitive radio network that can sense their environment and adapt their transmission waveform, channel access method, spectrum use, and network protocols accordingly are needed. To acquire knowledge about spectrum occupancy properties through spectrum sensing are the most important and technically most challenging in Cognitive radio networks. When the spectrum is not used by the primary users the secondary users can sense the spectrum and can utilize the licensed bands. The same process is show in the following figure,

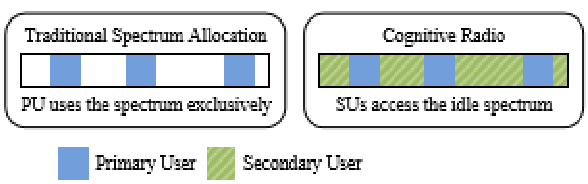

Figure 1. Cognitive Radio

1.1 Cognitive radio networks

A Paradigm shift from static spectrum allocation to dynamic spectrum is seen in which a non-license holder can borrow idle spectrum form those who hold the license. This makes cognitive radio the most promising technology because it utilizes the spectrums effectively. Cognitive radio is a software defined radio technology which avails the license to the unlicensed users without any inference.

1.2 Cognitive Radio Architecture

The following figure shows a typical cognitive radio which consists of a sensor, a radio, a learning engine, a knowledge database and a reasoning engine. It consists of 4 components: physical layer, network layer, linked layer and transport layer. Functions performed by each layer are given below.

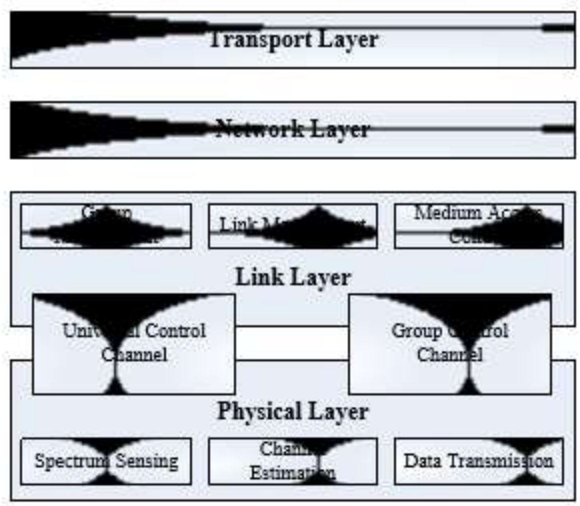

Figure 2. Architecture of Cognitive Radio

1.2.1 Physical layer

Sensing available free media for an effective transmission is called as spectrum sensing and it also helps the primary users to avoid any interference in their vicinity. Channel Estimation is used to check the quality of the sub channels base on their transmission parameters. This is done before setting up the link. After these two steps the data transmission occurs. IT can operate at different channel coding schemes, at variable symbol rates, power levels and are capable of using multiple antennas to nullify the interference.

1.2.2 Link layer

The arriving user in Group Management can join any of the existing group or it can also form a new one through a universal control channel. Any two secondary users can communicate with each other with the help of link management. The link is maintained until the duration of the communication. Medium Access Control manages the use of sub channels, i.e. a sub channel used by a particular secondary user cannot be used by any other secondary user.

1.3 Cognitive radio capability and type

Cognitive radio possesses the ability to sense the spectrum in order to utilize their free sections in an opportunistic way. These free sections are called as spectrum holes or white spaces.

Cognitive radio consists of the following characteristics; they are cognitive capability, self-organised capability and reconfigurable capability. Further, cognitive capability has five components: Spectrum holes can be detected by spectrum sensing, these are frequency bands which are not used by the licensed users. The sharing of spectrum is done under an agreement between the licensee and the third party. The ability to determine location along with locations of other transmitters is called location identification. After selecting the location, it selects the appropriate operating parameter. The available network and service is guaranteed by service discovery accompanied with network system discovery.

There are 5 components of reconfigurable capability, they are: the ability of a radio to change its operating frequency is indicated by frequency agility. The mechanism of dynamically detecting the signals from other radio frequency systems and to avoid co-channel operation with such system is called as dynamic frequency selection. To modify transmission characteristics and waveform the provided opportunities for more intensive use for spectrum, adaptive modulation /coding is used. Transmit power control reduces transmitter power to a lower level in order to share spectrum on a larger basis when high power operation is not necessary. To make CRNs more compatible with other communication systems or networks, network access/dynamic system is used.

There are 3 important features of self-organized capability: Information about spectrum holes is organised by spectrum/radio resource management in the cognitive radio. It also provides an efficient management scheme. Mobility and connection management is used in a complex CRN to ensure better routing and networking for neighbourhood discovery, supporting vertical handoffs and detecting available internet. The safety of CRN is guaranteed by trust/security management. The following table shows three types of cognitive radios,

Table 1. Types of Cognitive Radio

Types	Description
Policy Radios	Governed by a set of rules called the radio`s policy. Do not posses learning or reasoning engine.
Procedural Cognitive Radios	Operational adaptation is based on observations by utilizing hard-coded algorithms. Do not have learning capabilities and thus vulnerable to short-term attacks.
Ontological Cognitive Radios	Flexible and intelligent with reasoning and learning engine.

1.4 Cognitive radio network architecture

Cognitive radio network can be defined as complex multiuser wireless communication system capable of emergent behaviour. It is used for the following function:

1. It helps each user`s receiver to sense the environment on a regular basis in order to perceive the radio environment.

2. To judge the statistical variations in the incoming RF stimuli, it helps the user to learn from the environment and adapt the performance of each transceiver.
3. It facilitates communication in a self-organized manner between multiple users.
4. It allocates available resources properly among the competing users in order to control the communication process.
5. It creates self-awareness.

1.5 Primary objectives of cognitive radio networks

Efficient utilization of the radio spectrum

- Reliable communication.
- A basic signal processing cycle is shown in the following figure,

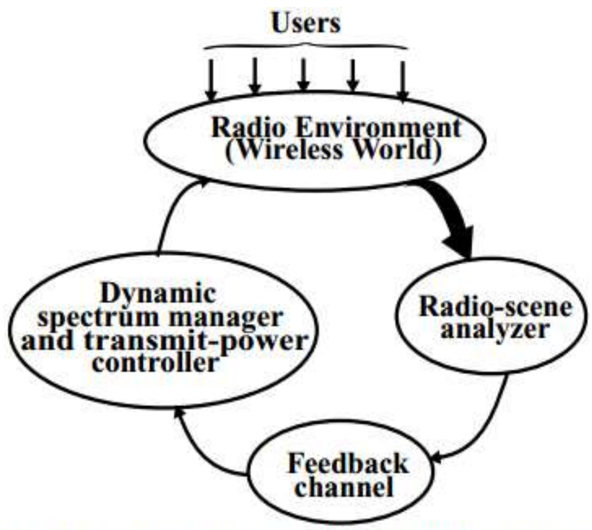

Figure 2. Basic signal-processing cycle, as seen by a single user (transceiver).

The CRN is divided into three categories:

1. Ad-hoc based.
2. Infrastructure based.
3. Mesh based architecture.

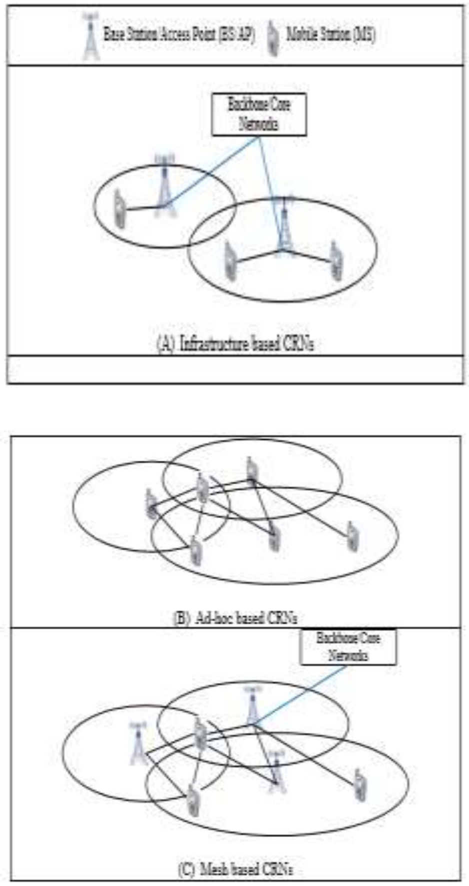

Figure 3. Architecture of Cognitive Radio Networks

The Ms in infrastructure based architecture can access only a BS/AP in the one-hop manner. Backbone core network is used as a route for communication between the different cells. The MSs communicate only under their transmission range of their BS/AP. The MS in ad-hoc based architecture can recognize nearby MS and form a link with them to form an ad-hoc network. The combination of the other two architecture makes mesh based architecture. MSs can directly access the BS/AP or can use other MS as multi-hop relay node.

1.6 Types of channel sensing techniques for cognitive radios

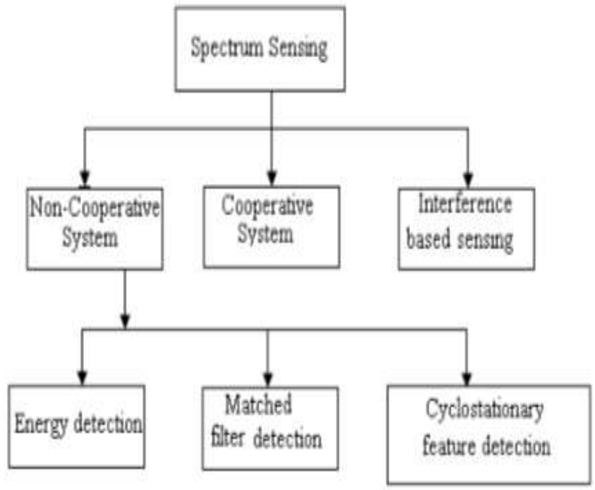

Figure 4: Classification of spectrum sensing techniques

Figure four shows the careful classification of spectrum Sensing techniques. They're loosely classified into 3 main varieties, transmitter detection or non-cooperative sensing, cooperative sensing and interference primarily based sensing. Transmitter detection technique is any classified into energy detection, matched filter detection and cyclostationary feature detection.

1.6.1 Primary Transmitter Detection

1.6.1.1 Energy Detection

It is a non-coherentenergy detection methodology that detects the first signal based on the detected energy. Because of its simplicity and no demand on a priori data of primary user signal, energy detection (ED) is that the most well liked sensing technique in cooperative sensing.

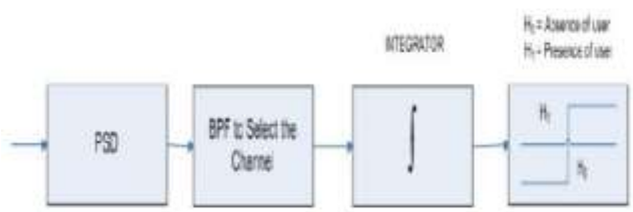

Figure 5: Energy detector diagram

The diagram for the energy detection technique is shown within the Figure five. During this methodology, signal is versed band pass filter of the bandwidth W and is integrated over amount. The output from this measuring device is compared to a predefined threshold chart.

This comparison is employed to get the existence of absence of the first user. The threshold value will set to be fixed or variable based on the channel conditions.

1.6.1.2 Matched Filter

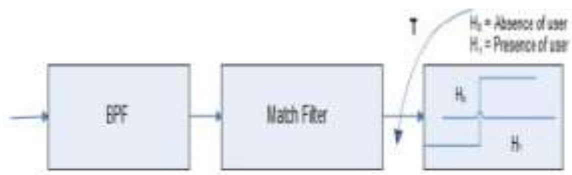

Figure 6: matched filter

A matched filter (MF) is a linear filter designed to maximise the output to noise magnitude relation for any given input signal. Once secondary user features a priori data of primary user signal, matched filter detection is applied. Matched filter operation is similarly equivalent to correlation during which the unknown signal is convolved with the filter whose impulse response is that the mirror and time shifted version of a reference signal. The operation of matched filter detection is expressed as:

$$Y[n] = \sum_{K=-\infty}^{\infty} h[n-k]x[k] \qquad (4)$$

Where 'x' is that the unknown signal vector and is convolved with the 'h', which is the impulse response of matched filter to the reference signal for maximising the SNR. Detection by using matched filter is helpful solely in cases wherever the data from the first users is understood to the cognitive users.

1.6.1.3 Cyclostationary Feature Detection

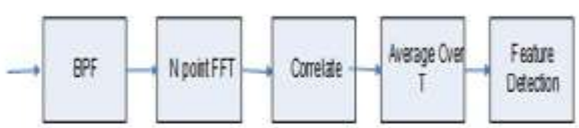

Figure 7: Cyclostationary feature detector diagram

Periodicity is exploited in the primary received signal to detect the presence of primary users (PU). The periodicity is usually embedded in curved carriers, pulse trains, hopping sequences, spreading code or cyclic prefixes of the first signals. Because of the periodicity, these cyclostationary signals exhibit the options of periodic statistics and spectral correlation, that isn't found in stationary noise interference.

Therefore, detection of cyclostationary characteristics is strong to noise uncertainties and performs higher than the energy detection in low SNR regions. Though it needs a priori data of the signal characteristics, cyclostationary feature detection is capable of identifying the CR transmissions from varied forms of chemical element signals. This eliminates the synchronization demand of energy detection in cooperative sensing. Moreover, CR users might not be needed to stay silent throughout cooperative sensing and so up the general CR output. This methodology has its own shortcomings as a result of its high machine quality and long sensing time. Because of these problems, this detection methodology is a lesser amount common than energy detection in cooperative sensing.

1.6.2 Cooperative Techniques

High sensitivity necessities on the cognitive user will be mitigated if multiple CR users collaborate in sensing the channel. Varied topologies are presently used and are loosely identifiable into three regions in step with their level of cooperation.

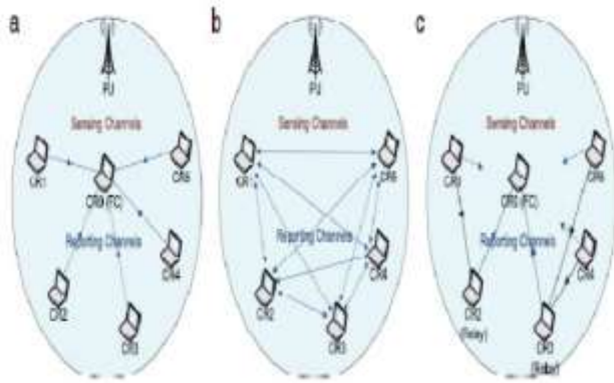

Figure 9: Cooperative sensing techniques: a-Centralised Coordinated, b- localised Coordinated, and c-Decentralised Uncoordinated.

1.6.2.1 Decentralized Uncoordinated Techniques: The cognitive users within the network don't have any quite cooperation which implies that every CR user can severally observe the channel, and if a Cr user detects the first user it might vacate the channel while not informing the opposite users. Uncoordinated techniques are fallible as compared with coordinated techniques. Therefore, CR users that have unhealthy channel realizations observe the channel incorrectly thereby causing interference at the primary receiver.

1.6.2.2 Centralized Coordinated Techniques: In such networks, an infrastructure readying is assumed for the CR users. A CR detecting the presence of a transmitter or receiver primary informs controller CR can be a stationary device or other user cable CR.The CR controller notifies all the CRusers in its vary by means of a broadcast control message. Centralized schemes will be classified in step with their level of cooperation as: partly cooperative wherever network nodes collaborate solely in sensing the channel. CR users severally observe the channel and inform the CR controller that then notifies all the Cr users; and entirely cooperative

Schemes wherever nodes collaborate in relaying every other's info additionally to hand and glove sensing the channel.

1.6.2.3 Decentralized Coordinated Techniques: This kind of coordination implies building up a network of cognitive radios while not having the requirement of a controller. Varied algorithms are planned for the decentralized techniques among that are the gossiping algorithms or clustering cooperative schemes, wherever cognitive users gather to clusters, auto coordinative themselves. The cooperative spectrum sensing raises the requirement for a bearing channel, which might be enforced as a dedicated frequency channel or as Associate in an underlay UWB channel.

1.6.3 Interference primarily based Detection

In this section, we have a tendency to present interference primarily based detection in order that the CR users would operate in spectrum underlay (UWB like) approach.

1.6.3.1 Primary Receiver Detection

In general, primary receiver emits the local oscillator (LO) escape power from its RF front whereas receiving the information from primary transmitter. it's been urged as a technique to observe primary user by mounting a coffee value detector node on the brink of a primary user's receiver so as to observe the local oscillator (LO) escape power emitted by the RF front of the first user's receiver that are at intervals the communication vary of CR system users. The native detector then reports the detected information to the CR users in order that they'll determine the spectrum occupancy standing. We have a tendency to note that this methodology can even be accustomed determine the spectrum opportunities to work CR users in spectrum overlay.

1.6.4 Alternative Signal Process Approaches

1.6.4.1 Multi -Taper Spectrum Sensing and Estimation: Multi Taper spectrum estimation (MTSE) has planned by Thomson (1982) before the CR construct was introduced. During this methodology, the last N received samples are collected in a very vector kind and are painted as a collection of slepian base vectors. The main plan of this methodology is that the Fourier transforms of Slepian vectors have the top energy concentration within the information measure fc-W to fc +W underneath finite sample size constraints. By exploiting this feature, CR user will simply determine the spectrum opportunities in given band. As MTSE uses multiple model filters and is best for little sample areas since the machine quality will increase with sizable amount of samples.

1.6.4.2 Filter Bank Based Spectrum Sensing: Filter bank based spectrum estimation (FBSE) is thought to be the simplified version of MTSE that uses just one model filter for every band and has been planned for multi-carrier modulation based CR systems by employing a pair of matched root Nyquist filter. FBSE uses a similar construct of top energy concentration within the information measure fc -W to fc +W. By exploiting this information, CR user identifies the spectrum occupancy and thus the spectrum opportunities. MTSE is best for little samples whereas FBSE is best for giant variety of samples.

2 Types of anonymous routing techniques

2.1 Dynamic Spectrum-aware Routing

Dynamic spectrum-aware routing protocols enable CR technologies to effectively utilize unallocated wireless spectrum. In such routing protocols route discovery is incorporated with spectrum sensing. The most important goal of such protocols is to determine and maintain route across region of various on market spectrum. The rest of the sub section summarizes these protocols and highlight their merits and their routing techniques.

2.1.1 Spectrum-Aware Routing (SPEAR) [2]

A routing protocol that supports high-throughput packet transmission within the spectrum heterogeneousness is being investigated. It achieves persistent presence of end-to-end performance by integrating flow-based approaches with link-based approaches. It assigns totally different channels to links on a similar flow for minimizing interference and integrates spectrum discovery with route discovery for best usage of accessible channels. For this, every node maintains a listing of unoccupied regionally on the market channels. These channels are neither occupied by primary user nor reserved by near neighbours. In SPEAR route discovery is completed by broadcasting a Route Request (RREQ) message on common management channel and being identified by sender and receiver IP addresses. As an intermediate node receives this message, it checks if it's a standard channel with the previous node then it appends its own id and on the market channel set with the received message so broadcasts it. The destination node selects the most effective path on the idea of most output, minimizes end-to-end latency (minimum hop count) and link quality. Throughout the transmission node sporadically broadcasts channel reservation message with every message containing timeout and time-to-live field. At the top of communication nodes on the trail are notified to prevent causing messages.

2.1.2 Spectrum Aware mesh Routing (SAMER) [3]

A routing protocol for mesh CRNs handles the variety in channel accessibility and balance between long term and short term route stability. SAMER uses the on the market white areas by transmission of the information over the route with higher spectrum accessibility. So spectrum accessibility is employed for computing routing metric for long term routes. It achieves the balance between long- and short routes by constructing a runtime forwarding route mesh. This mesh is sporadically updated and provides a group of candidate routes to the destination. So packets are routed towards the destination across this mesh. The routing selection solving the collaboration of PHY and Macintosh layer. SAMER builds dynamic candidate, candidate forwarding mesh and opportunistically forwarding.

2.1.3 Spectrum-aware On-Demand routing protocol (SORP) [4]

SORP is an on demand routing protocol that's neither based on centralized spectrum allocation nor multi-channel. The character of this protocol is thanks to lack of shared information. The routing technique planned by Cheng et.al is to pick best appropriate RF bands for every node on the route. The RF band choice is predicated on minimum additive delay. The change and back-off delay caused by each the trail itself and therefore the across flow are the decision making parameters for scheming additive delay of the trail. They planned a spectrum aware on demand framework for routing and multi-flow multi-frequency programing for RF band choice. They slightly changed modified Ad hoc on demand distance vector routing (AODV) to include the inconsistency of spectrum chance. They created some assumptions for routing technique, as follow:

To form a standard management channel every node contains a standard wireless interface additionally to the CR transceiver. Every node is in a position to produce spectrum sensing information to routing protocol through cross layer style.

For route discovery SORP inherits the fundamental procedures of AODV with changed Route Request (RREQ).In SORP Spectrum chance (SOP) information is piggybacked by RREQ messages. SOP information is piggybacked only the node finds intersection between the RREQ and its own. So destination node receives the SOP distribution of all the nodes on the path and it assigns RF band to its CR transceiver consequently. This RF band info is distributed back to the supply node likewise intermediate nodes through Route Reply (RREP) message. All the nodes on the trail assign the RF band in step with the received RREP.

2.1.4 Multi-hop Single-transceiver psychological feature Radio Networks Routing Protocol (MSCRP) [5]

MSCRP is not based on management channel. Therefore, routing protocol messages are being changed while not common management channel. MSCRP is an on demand protocol supported modified Ad hoc on demand distance vector (AODV).

Ma et.al modifies AODV to handle the on the market channel set drawback that every node within the network doesn't understand the on the market channel set of alternative nodes within the network. The initial time introduced the new drawback known as "deafness", that's thanks to channel change of the nodes. To avoid the hearing loss drawback, they planned that 2 consecutive nodes in an exceedingly flow cannot be within the change state at the same time. Communication with a change node is difficult, so MSCRP change node uses LEAVE/JOIN messages to tell its neighbours regarding its operating channel. MSCRP assumes that CR transceiver will tune up a large vary of RF spectrum however it solely operates on restricted and smaller vary of RF and CR transceiver will solely treat single channel at any time. MSCRP may be a cross layer protocol therefore it identifies six system functions that implement the core practicality of spectrum aware routing. These functions are as follow:

The physical layer includes three of them that are spectrum sensing, detection active primary user and estimating the standard of accessible channels.

The network layer includes two of them that are routing and programming within the multi-flow and multi-channel environment.

2.2 Reactive Source-Based Routing

In reactive supply primarily based routing technique supply specifies however the information travels across the network path to destination node is computed by the supply node. Within the remainder of the sub section we tend to summarize a reactive source-based routing protocol and highlight its routing technique and its advantages.

2.2.1 Routing in Opportunistic Cognitive Radio Networks [6]

Reactive source-based routing protocol for CRNs is planned by Khalife et.al and it uses a unique routing metric that's supported a probabilistic definition of the on the market capability over a channel. This routing metric determines the most probable path (MPP) to satisfy a given information measure demand though it doesn't guarantee to satisfy the demand. Therefore during this case an augmentation part is employed within which bottleneck links are increased with further channels therefore the ensuing path meets the information measure demand with a given likelihood.

The available capability is measured because the likelihood distribution of the PR to a user interference at any node over a channel.

When an application requests a route of capability demand the supply can initiate it and management channel is employed for node coordination. Based on the demand all links possibilities are calculated. Once all link weights are calculated, the supply runs Dijkstra-like rule to search out a route to the destination. The obtained path is named MPP because it has the very best likelihood of satisfying the demand and stability to destination. The Dijkstra-like rule stops computing once it reaches to the one in all the subsequent 2 states.

1. On every link of MPP, the whole capability are bigger than the demand.
2. When augmentation if the whole calculable capability on all the channels of 2 nodes won't fulfil the demand. During this case no path is appropriate to the destination so it's declared out of reach.

2.3 Local Coordination-Based Routing

The local coordination may be a type of enhancement theme that's applied on across nodes on a path. The local coordination is started once nodes appraise the work of each accommodating the flow and redirecting it. Nodes select the flow accommodation or flow redirection supported the analysis results and neighbourhood interaction.

In the remainder of the sub section we tend to summarize an area coordination-based routing protocol and highlight its routing technique and its advantages.

2.3.1 Local Coordination based Routing and Spectrum Assignment in Multi-hop cognitive Radio Networks [7]

An on demand routing and spectrum assignment protocol to exchange the local spectrum information and act with multi-frequency programming in every node is proposed by Yang et.al. AODV is changed to create a mechanism on common management channel for exchanging spectrum chance (SOP) among the nodes to beat the inconsistency of SOP. It conjointly identifies traversing flows at each node and calculates RF band utilized by any node and this can be used for multi-flow multi-frequency programing. Path delay and node delay show the change and backtrack delays on the trail and wont to calculate the additive delay of the trail. An area coordination theme is employed for load reconciliation on across nodes for multi-frequency traffic. Every network node is provided with ancient wireless interface additionally to

CR transceiver to make sure the thriving delivery of routing messages at every node despite of the inconsistency of the frequency bands likewise each node provides the SOP info to its network layer. The native coordination is applied on each network node of multi-hop CRNs.

2.4 Tree primarily based Routing

In tree primarily based routing protocol a tree structured network is enabled by configuring a root. Tree primarily based routing is centralized routing theme that is controlled by one network entity known as base station. So constellation will be quickly made among CR station by configuring psychological feature base station as root. Within the remainder of the sub section we tend to summarize a tree primarily based routing protocol and highlight its routing technique and its blessings.

2.4.1 Cognitive Tree-based Routing (CTBR) [8]

Cognitive tree routing (CTBR) is an extension of tree based routing protocol (TBR) planned for wireless mesh network. It uses global and local call schemes for route calculation. Global decision theme selects route with the most effective global end-to-end metric whereas local decision theme selects the most effective interface with the smallest amount load. Multiple ways with a similar global end-to-end metric will exist for a similar destination. During this case the end-to-end path is chosen supported the local decision theme that uses load activity.
CTBR uses the routing procedure of TBR within which root periodically sends Root Announcement (RANN) message for tree formulation. Any node receives the RANN, caches the node whom it receives the RANN as its potential parent so beam RANN with updated cumulative metric. The node can choose a parent node from all potential parents based on the most effective metric (i.e. hope count) for the trail to root. For registering with root each node that contains acknowledged path to root sends route reply (RREP). Any intermediate node that receives RREP forwards the message to its parent node likewise updates its routing table by choosing supply node of RREP as its destination. So at the top root constructs a tree because it has learnt all network nodes. To form TBR flexible for CRNs a link quality metric has been introduced.

3. Comparative table

Metric	Energy Detector	Coherent	Matched-Filter	Cyclostationarity	Hybrid
Detection Accuracy	+ Good performance at high SNRs - Poor performance at low SNRs (EED marginally improves performance) - High noise floor could be a false detection	+ Good performance at all SNRs - Possible SNR wall due to residual frequency offsets	+ Best performance at all SNRs (if RX has sufficient knowledge of TX) - Poor performance if little is known about TX	+ Good performance at all SNRs	+ Good performance at all SNRs - Estimated pilot symbol positions could reduce performance
Complexity	+ Low computational/implementation complexity - Requires higher number of samples to converge	- Medium complexity + Requires small number of samples to converge	- High complexity (requires a dedicated RX for each primary signal class) + Requires fewest number of samples to converge	- Medium complexity + Requires small number of samples to converge	- Medium complexity - If pilot symbol positions are unknown, must estimate positions
Robustness	+ Does not require any prior information of TX signal - Does not work for spread spectrum signals	- Requires TX signal to contain a known pattern - Exact position of pattern may not be known at RX	- Requires near perfect TX information at RX	- RX must know TX signal fundamental frequency	- Requires TX signal to contain pilot symbols
Design Choices	- Difficult to choose decision threshold	+ TX pattern can be increased to improve accuracy	+ TX characteristics can be chosen to improve accuracy	+ Cyclostationarity can be intentionally induced to improve accuracy	+ Pilot symbols can be increased to improve accuracy

Table 1. Performance metric comparison summary of a variety of spectrum sensing techniques

4.Conclusion

As the usage of frequency spectrum is increasing, it is becoming more valuable. So we need to access the frequency spectrum wisely. For this purpose we are using Cognitive Radio. In our paper we discussed about the most important technique that is Spectrum sensing and the issues involved in it to establish the communication using Cognitive radio. For the past development it is observed that, approach of secure routing is a prime requirement in wireless network. To make the routing reliable a robust routing scheme is required. The network should not rely on the route developed at the route establishment stage, however should also be adaptive during communication phase. In the process of route establishment or selection intelligence logic with node characteristic should be evaluated. The nodes should be overcoming the issue of data privacy and reliable routing in concern to data forwarding, communicating and retaining of demanded quality of service in such network. The advancement of intelligent logic to the routing scheme will be an added advantage to the routing scheme.

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