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Cognitive Relay Networks: A Comprehensive Survey

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Abstract

Cognitive radio is an emerging technology to deal with the scarcity and requirement of radio spectrum by dynamically assigning spectrum to unlicensed user. This revolutionary technology shifts the paradigm in the wireless system design by allowing unlicensed user the ability to sense, adapt and share the dynamic spectrum. Cognitive radio technology applied to different networks and applications ranging from wireless to public safety, smart grid, medical, relay and cellular applications to increase the throughput and spectrum efficiency of network. Among these applications, cognitive relay networks is one of the famous application where cognitive radio technology is applied. Cognitive relay network increases the throughput of network by reducing the complete path loss and also by ensuring cooperation among secondary users and cooperation among primary and secondary users. In this paper, our aim is to provide a survey on cognitive relay network. We also provide a detailed review on existing schemes in cognitive relay networks on the basis of relaying protocol, relay cooperation and channel model.

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1. Introduction

There is an increasing demand of spectrum resources in the past recent years due to emerging wireless technologies. Within the current framework of spectrum management, all the spectrum bands are allocated to some specific areas or services. This issue led the Federal Communications Commission (FCC) to move trend from static to dynamic spectrum allocation because large portion of licensed spectrum is underutilized in geographic and vast temporal regions. Spectrum utilization can be improved by allowing secondary user to use the licensed band opportunistically while causing no interference to primary users [1].

A novel technology proposed for effective spectrum utilization is Cognitive radio (CR) technology. In CR technology, secondary user senses the spectrum holes for effective utilization and then adapt the environment causing no interference to primary users. In order to detect the reappearance of primary user, cognitive user must continuously sense the available spectrum for effective communication and spectrum utilization [3].

Cognitive radio can be applied to different networks and applications in order to increase the network throughput and to ensure the effective spectrum utilization. Cognitive radio network plays a significant role in different applications like public safety, smart grid, medical, relay and cellular applications.

In cognitive radio network, secondary users dynamically senses to the local environment for available spectrum. Secondary devices in cognitive radio network experience diverse spectrum conditions due to dispersed geographical locations of other secondary users. Cognitive radio network can dynamically exploit the spectrum in order to support continuous transmission. In order to ensure spectrum opportunity and effective data transmission, a new concept is introduced that is Cognitive Relay Network.

Cognitive relay networks have been proposed to increase the throughput of network. In a cognitive relay network, a relay node is used to reduce the complete path loss. Cognitive relay network increases the throughput by cooperating among secondary users or cooperation among primary and secondary

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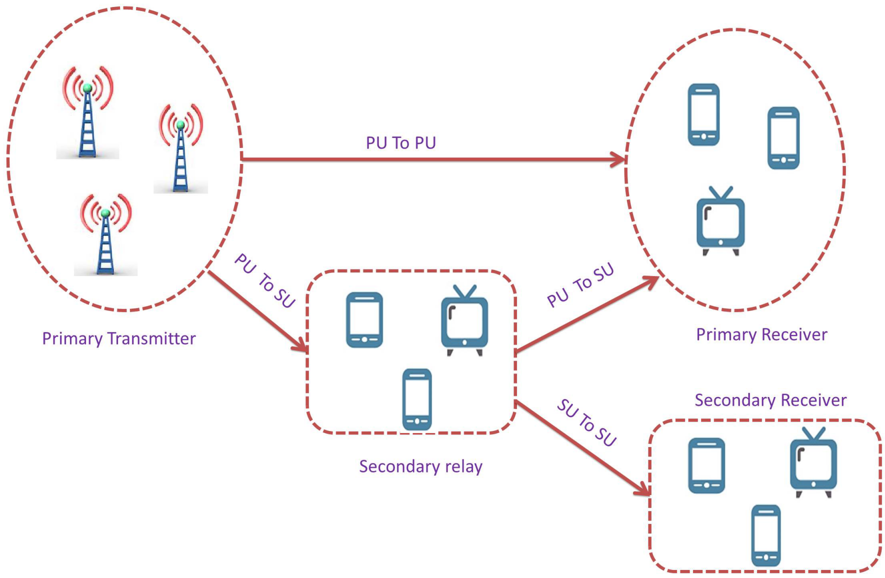

Figure 1. Basic architecture of relaying in cognitive relay networks [2]

users. Seamless data transmission can be realized and monitored in cognitive relay network because without cognitive relay, there is a direct link between source node and destination node. If primary user returns to that channel that is utilizing by primary user, then secondary nodes stop their transmission causing no interference to primary user. There are two phases in cognitive relay network. In the first phase, source node will broadcast all the information or data to all the intermediate nodes. In the second phase, depending on the protocol used, the message delivered to destination node via a relay node [4].

In this paper, we provide a survey on cognitive relay networks. Following are the contributions of this paper:

1. We provide the detail of relaying in cognitive radio network, its advantages and types of relaying in cognitive radio network

2. We discuss about existing schemes of relaying in cognitive radio network on the basis of relaying protocol, relay cooperation and channel model.

The organization of paper is as follow: In section 2, we discuss about relaying in cognitive radio network, advantages of relaying in cognitive radio network and types of relaying in cognitive radio network. Section 3 is about existing schemes of relaying in cognitive radio network. Last section 4 contains conclusion of paper.

2. Relaying in Cognitive Radio Networks

2.1. Advantages of Relaying in CRNs

One of the challenges faced by the cognitive radio networks is exploitation of transmission opportunity. Secondary users try to maximize their own spectrum utilization without interfering primary user resources. In order to maximize their transmission opportunity and efficient resource sharing, they might be cooperating or competing for the available resources. There are several advantages of relaying in cognitive radio network [5].In this section, we discuss the basics of relaying in cognitive relay networks. Figure 1 shows the basic architecture of relaying in cognitive relay networks. We classify the existing schemes of relaying in cognitive relay networks into three main classes, which we mention in Figure 2.

Cooperative transmission. In a wireless network by enabling different cooperative relay, spatial diversity can be improved. There are two types of cooperative transmission to increase the secondary throughput and also to increase the probability of transmission opportunity. One is transmission between secondary users in which secondary user act as a relay node for other secondary users transmission. The second one is transmission between primary and secondary users in which secondary user act as a relay for the primary user transmission [6] as shown in Figure 1.

Cooperative relay. Within a secondary network, handling of unbalanced spectrum is a great challenge. In order to resolve this challenge, cooperative relay concept is introduced. In this scheme, secondary users having low traffic demand act as relay nodes for other secondary users having high traffic demand, in order to improve the system or spectrum efficiency and performance[6].

Throughput maximization. In order to increase the throughput of whole network, there should be the best

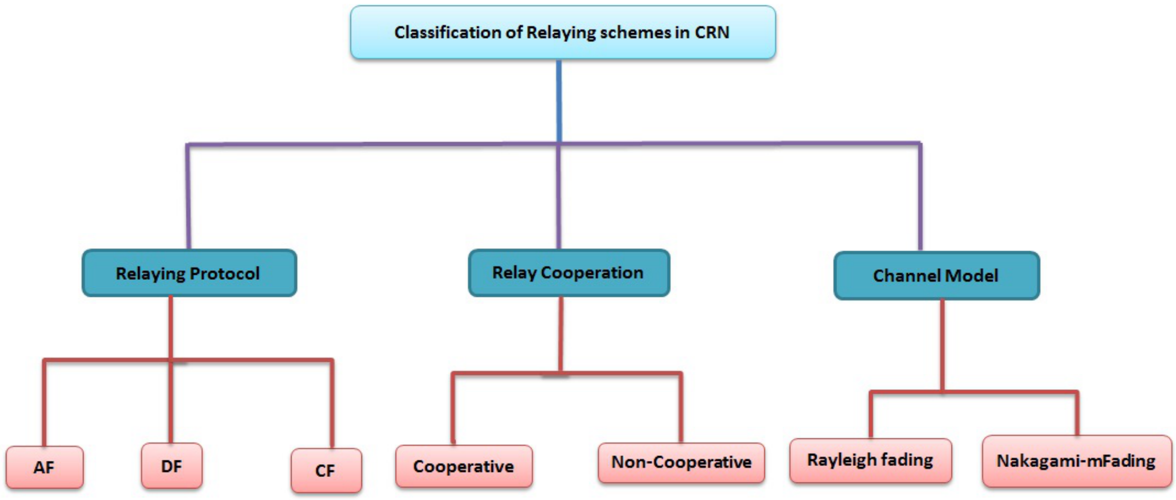

Figure 2. Classification of relaying in cognitive radio networks

selection of relay and destination node. Node having high traffic demand may not act as a relay node, as it may not exploit the throughput of whole network. In order to increase the throughput of network, there should be synchronization between nodes, so that they can negotiate the resource allocation and exchange information between both relays and channels control messages [7], [6].

Primary user detection and protection. In order to ensure the synchronization, there are MAC frames which consist of downlink and uplink transmission and control information. By making the fixed length of MAC frames, primary user protection ensures for dynamic spectrum sensing and also helps to reduce high transmission delays. Primary user detection becomes easy and efficient by ensuring frame synchronization [8].

Coordination. In a centralized CRN, nodes collect the information about spectrum availability and data demand in a frame format. This information is then broadcasted on a common control channel to ensure coordination among nodes and to ensure best decision about relay and destination node [9].

2.2. Types of Relaying in CRNs

Relaying protocols. After detecting the effective spectral holes in cognitive relay network, source node broadcast the signals and then these signals forward towards the destination node through relays. There are generally three different relaying protocols used in cognitive radio networks as shown in Figure 2, to determine what an individual relay should do after receiving a signal. These relaying protocols are Amplify-and-Forward (AF), Decode-and-Forward (DF), and Compress-and-Forward (CF).

Amplify-and-Forward Relaying protocol (AF). In an AF protocol, signals received at relay station is first amplified and then retransmitted to different available bands simultaneously. Communication will be in two-hops if relay node shifted from primary and secondary users. Cognitive relay networks apply AF protocol as shown in Table 1 to achieve maximal throughput by exploiting the idle channels [10] [11] [12] [13] [14] [15]. The major advantage of implementing AF protocol is that it requires low cost implementation and is more flexible.

Decode-and-Forward Relaying Protocol (DF). In a decode-and-forward protocol, node acting as a relay node will decode the information or message, encode it again and then retransmit it towards the destination by selecting appropriate channel from spectrum pool. Different cognitive relay networks apply DF protocol for relaying scheme to enhance the network capacity and to ensure security [24] [23] [25] [26] [22] [19] [20]. DF relaying scheme takes large amount of time to decode and then to retransmit the message or information.

Compress-and-Forward Relaying protocol (CF). Received signal estimation is carried out by Compress-and-Forward protocol. In CF protocol, received signal is compressed first by the relay node, encoded and then retransmit towards the destination. This relaying protocol increases the signal redundancy received from the source node.

2.3. Relay Cooperation

Cooperative relaying in CRN. For traditional wireless technology, cooperative relay technique has been

Reference	Relay schemes	Relay Type	Channel Model	Cooperation	Simulator used	parameters evaluated
[11]	Efficient Multiple Relay	AF	-	Cooperative Relay	-	Average SNR
[16]	Efficient Multiple Relay	DF	Nakagami-m fading	Cooperative Relay	Monte Carlo	Selection diversity order
[10]	Power Allocation	AF	-	Cooperative Relay	-	Interference Power, System throughput
[17]	Cooperative Transmission	DF	-	Cooperative Relay	Monte Carlo	Transmission of PU and SU
[18]	Power Allocation	DF	Rayleigh fading	Cooperative Relay	Monte Carlo	Ergodic achievable rate
[19]	Outage Performance	DF	Rayleigh fading	Cooperative Relay	-	Outage probability
[20]	Outage Performance	DF	Rayleigh fading	Cooperative Relay	-	Outage probability
[21]	Outage Performance	DF	Rayleigh fading	Cooperative Relay	-	Outage probability
[14]	Outage Probability	AF	Rayleigh fading	Cooperative Relay	Monte Carlo	SER, outage probabilit
[22]	Outage Analysis	DF	Rayleigh fading	Cooperative Relay	Monte Carlo	Outage probability
[23]	Capacity Analysis	DF	Rayleigh fading	Cooperative Relay	-	Capacity loss
[24]	Capacity Analysis	DF	Rayleigh fading	Cooperative Relay	-	Capacity loss
[13]	Cognitive AF	AF	Nakagami-mFading	Cooperative Relay	-	Outage probability
[12]	Cognitive AF	AF	Rayleigh fading	Cooperative Relay	-	Outage probability
[25]	Cognitive Relay Networks	DF	Rayleigh fading	Cooperative Relay	Monte Carlo	Outage probability
[26]	Cognitive Relay Networks	DF	Rayleigh fading	Cooperative Relay	Monte Carlo	Outage probability
[27]	Power Allocation	AF	Rayleigh fading	Non-Cooperative Relay	Monte Carlo	Cumulative distribution
[28]	Geometric Approach	-	Rayleigh fading	Cooperative Relay	Monte Carlo	NNR and FNR
[2]	Distributed spectrum access	-	-	Cooperative Relay	-	Average total rate of PU
[29]	Cognitive Transmission	-	Rayleigh fading	Cooperative Relay	-	Spectrum hole utilization
[30]	Cellular cognitive relay network	AF	Rayleigh fading	Cooperative Relay	-	Outage capacity
[5]	Cognitive Transmission	-	-	Cooperative Relay	USRP-based testbed	Throughput Gain
[9]	Cognitive Transmission	DF	combat wireless fading	Cooperative Relay	-	Spectrum hole utilization
[6]	MAC protocol	-	combat wireless fading	Cooperative Relay	USRP-based testbed	Throughput gain
[31]	Network Utility Maximization	-	-	Cooperative Relay	-	Average throughput
[32]	underlay-based cognitive	-	Rayleigh fading	Cooperative Relay	-	Feasibility probability
[33]	CR Cellular Relay Networks	-	-	-	-	The normalized capacity , Path loss exponent
[34]	Interference and Delay Constrained	AF	Rayleigh fading	Cooperative Relay	Monte-Carlo	Normalized Effective Capacity
[35]	Power Allocation Strategy	AF	Rayleigh fading	Cooperative Relay	Monte Carlo	Power of cognitive transmitter
[36]	Outage probability	-	Rayleigh fading	-	-	Outage probability, maximum transmit power
[37]	Full Duplex	AF	-	Cooperative Relay	-	Resource scheduling
[38]	Full Duplex	AF	-	Non-Cooperative Relay	-	Self-interference, secondary downlink
[39]	Distributed Beamforming	-	Rayleigh fading	Cooperative Relay	-	Feasibility Probability
[40]	power loading strategy	AF	Rayleigh fading	Cooperative Relay	-	Channel capacity
[41]	Power allocation (PA) and multiple relay selection (MRS)	-	Rayleigh fading	-	-	Secondary system capacity
[42]	Multiuser CRN	DF	Rayleigh flat fading	Cooperative Relay	-	Outage probability
[43]	Spectrum access	-	-	Cooperative Relay	-	Network capacity
[44]	Optimal power allocation	AF	-	Cooperative Relay	-	Transmit rate
[45]	Multiple relay selection	-	Rayleigh fading	Cooperative Relay	-	Average SNR
[46]	Two relay selection schemes	-	Rayleigh fading	Cooperative Relay	-	Outage probability
[47]	Imperfect CSI	AF	Rayleigh fading	-	-	Interference probability
[48]	Spectrum access	-	-	Cooperative Relay	-	Average capacity
[49]	Spectrum sensing	-	Rayleigh fading	Cooperative relay	-	Sensing time
[21]	outage probability (OP)	DF	Rayleigh fading	Cooperative relay	-	Outage probability
[4]	Interference Constraints	-	-	-	-	Outage Probability of Secondary User
[50]	Power and Channel Allocation	-	Rayleigh fading	Cooperative relay	-	N spectrum bands
[51]	Half-Duplex Buffered CRN	DF	Rayleigh fading	Cooperative relay	Monte Carlo	Buffer gain
[52]	Resource Allocation Techniques	AF,DF,CF	Rayleigh fading	Cooperative relay	-	Spectrum management
[53]	Cognitive Relay Beamforming	-	Nakagami-m fading	Cooperative relay	-	Cumulative distribution of PU
[54]	Simplified Power Allocation	-	-	-	-	Average capacity
[8]	Interference of Primary User	-	Rayleigh fading	Cooperative relay	Monte Carlo	Outage probability

Table 1. Existing schemes of relaying in cognitive radio networks

* "-" =Not mentioned
AF= Amplify-and-forward
DF= Decode-and-forward
CF=Compress-and-forward

studied widely but cooperative relaying face some additional challenges in cognitive radio network. One of challenges faced in cognitive radio network is mutual interference between the secondary and primary users. Due to the generation of some false alarms in sensing phase, this may led towards the mutual interference between primary and secondary users. This mutual interference causes the outage probability for secondary users data transmission [9] [6].

Cooperative spectrum sensing may removes wireless fading and consists of two phases: First phase is, within the certain time period, detection of primary user existence. In the second phase, there is a fusion centre on which detection results are forwarded in the remaining time slot. Cooperative relay improves the secondary data transmission by having primary destination (PD) relays and cognitive destination (CD) relays. Primary and secondary users apply some relaying protocols (AF or DF or CF) and then send data or message to PD and CD.

Non-cooperative relaying in CRN. Non-cooperative relaying technique proposed to carry out spectrum occupancy analysis and measurement for individual users or radios to act autonomously and locally.

Spectrum sensing in non-cooperative technique consist of these categories: blind sensing and signal specific category. In blind sensing approach for cognitive radio network, there is a central entity known as fusion centre which collects all the sensing information and then decide which frequency can be used for data transmission. In signal specific approach, there is a requirement of primary user signal knowledge to send data over appropriate channel.

2.4. Channel model

Rayleigh Fading. In order to model multi path fading, Rayleigh fading is used widely having no line-of-sight path. Rayleigh fading is closely related to square distribution technique. For channel modelling in cognitive radio network, Rayleigh techniques is applied [45] [55] [47] [46] [49] [22] [19]. Rayleigh model is widely used for the propagation of refracted and reflected paths through on the radio link.

Nakagami-M Fading. In order to characterize the signal transmission from multipath fading channel, distribution that uses widely is Nakagami-M fading distribution. Cognitive relay networks use Nakagami-M fading distribution for in-door and land-mobile multipath radio link propagation [56] [13] [57] [16].

3. Existing Schemes in Cognitive Relay Network

Different cognitive relaying schemes proposed in order to ensure effectiveness of spectrum utilization and to increase the throughput of whole network. These cognitive relaying schemes are shown in Table 1.

3.1. Cooperative Relaying Schemes in CRN

In cognitive radio network, cooperative relay technology is introduced in order to increase the network capacity of data transmission and to increase the throughput of network. Different cooperative relaying schemes proposed to allow communication or data transmission through relay nodes.

In [19], cooperative relay technique used to gain diversity in data transmission and also improves the secondary user spectrum sensing performance. In [20], cooperative relaying technique applied for reliable and effective communication among primary and secondary users to ensure the better communication range of secondary users. Author in [21] proposed a scheme that increases performance gain by applying cooperative relaying. Relaying technique in [14], ensures the coverage, reliability and throughput of whole cognitive radio network.

Spectrum utilization is the major concern for cognitive radio network. Author proposed combination of cooperative spectrum sensing and cognitive radio to increase the effective spectrum utilization [44] [10]. In order to maximize the achievable rate of cognitive user, cooperative relaying proves to be an effective approach [18]. To increase the capacity and the throughput of channel, cooperative communication used in cognitive relay network by making the intermediate node as a relay node [23], [24].

Cooperative relaying techniques used in cognitive radio networks can be used to improve spectrum sharing [23] [24] [13] [12] [34] [36], spectrum sensing [29] [30] [9], spectrum usage [38] [39] [33], spectrum efficiency [40] [44] and spectrum availability [42].

3.2. Amplify-and-Forward Relaying Schemes in CRN

AF relaying scheme applied in CRN for achieving maximum throughput. In [13], author deployed AF relaying scheme to gain maximal outage performance. In order to maximize the total power allocation rate in cognitive radio relay network, AF technique is used [10] [44]. In [27], total power constraint can be increased using AF relaying protocol, as secondary users communicate via a relay node. In order to enhance the spectrum usage in full-duplex cognitive relay network, AF relaying protocol are used to ensure spectrum efficiency [37] [38].

3.3. Decode-and-Forward Relaying Schemes in CRN

DF relaying techniques are proposed to ensure the confidentiality and integrity of data transmitted from source to destination via a relay node. In [24], DF relaying protocol is used to increase the cooperative diversity over the cognitive radio network. Two approaches of DF relaying scheme discussed in this paper: one is proactive DF approach and the other one is reactive DF approach. Scheme proposed in [58] analyse the primary user interference for the DF scheme applied in secondary relay network, resulting an effective outage performance.

3.4. Relaying Schemes on the basis of Channel Model

Rayleigh fading Relaying Schemes. In a cognitive relay network different channel modelling techniques used, one is Rayleigh fading. In [34] author applied Rayleigh fading to maximize point-to-point channel capacity and thus data transmission become efficient. For the effective throughput in a single and in a multiple relay, fading technique used in [35] is Rayleigh fading. Secondary users outage probability can be increased by using Rayleigh fading [36] [23].

Nakagami-mFading Relaying Schemes. Cognitive relay networks applied Nakagami-mFading for the outage analysis to maximize the transmit power over versatile fading channels [13]. Spectrum efficiency and spectrum sharing becomes more effective using Nakagami-mFading [56]. In [57], author investigates the outage probability and capacity analysis for multiple primary users.

4. Conclusion

In order to increase the throughput, to increase cooperation and to decrease the complete path loss, a novel technology is introduced which is cognitive relay networks. Cognitive relay network, increases the spectrum efficiency by cooperating among secondary and primary users and also among secondary users themselves. There are two phases in cognitive relay network. One phase is the broadcasting of all information from source to all intermediate nodes. Second phase is the transfer of information towards destination through relay node. This paper, provides classification of cognitive relay networks on the basis of relay type, cooperation in relay networks, and channel model used for relaying in cognitive radio network.This paper also provides detailed analysis of different relaying schemes applied in cognitive relay network.

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