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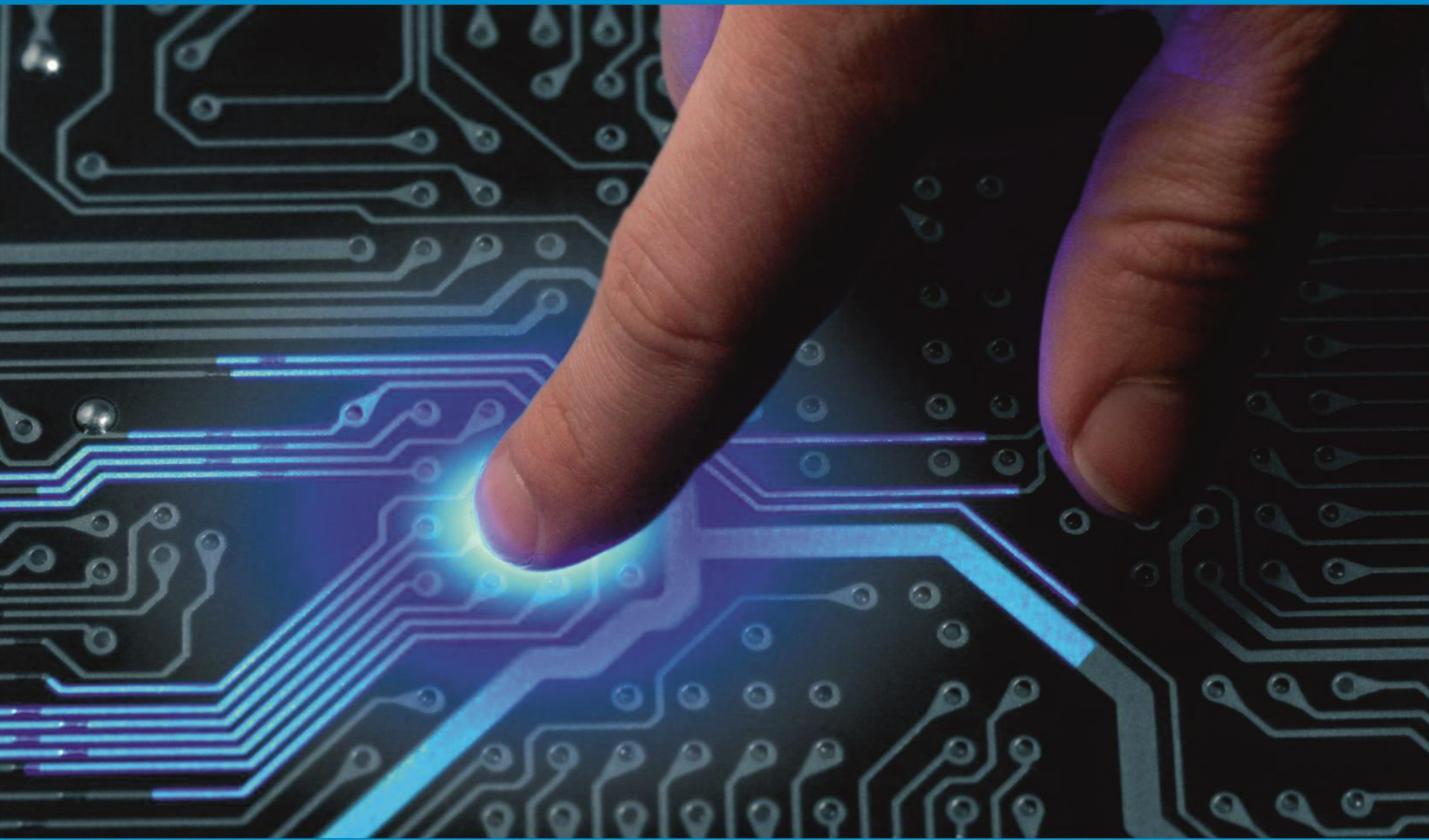

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Wireless Multimedia Cognitive Radio Networks: A Comprehensive Survey

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ABSTRACT: Cognitive Radio (CR) technology is developed to overcome the spectrum scarcity due to rapid development in wireless networks. Both licensed and unlicensed users can utilize the spectrum using this technology. Spectrum is allocated dynamically in cognitive radio networks thus it increases the spectrum utilization. The unlicensed users can transmit in the vacant spectrum already assigned to licensed users with minimum level of interference. It senses the spectrum to find the vacant spectrum and choose the best spectrum which meets the required QoS of the unlicensed users. To make radios and wireless networks truly cognitive, however, is by no means a simple task, and it requires collaborative effort from various research communities, including communications theory, networking engineering, signal processing, game theory, software– hardware joint design, and reconfigurable antenna and radiofrequency design. We provide a systematic overview on CR networking and communications by looking at the key functions of the physical (PHY), medium access control (MAC), and network layers involved in a CR design and how these layers are crossly related. In particular, for the PHY layer, we will address signal processing techniques for spectrum sensing, cooperative spectrum sensing, and transceiver design for cognitive spectrum access. The MAC layer, we review sensing scheduling schemes, sensing-access tradeoff design, spectrum-aware access MAC, and CR MAC protocols. In the network layer, cognitive radio network (CRN) tomography, spectrum-aware routing, and quality-of service (QoS) control will be addressed.

KEYWORDS: Cognitive radio (CR), Cognitive Radio Networks (CRNs), Dynamic Resource Management, Dynamic Spectrum Access (DSA), Spectrum Sensing, Spectrum Sharing.

I. INTRODUCTION

The rapid development in communication applications the spectrum becomes more congested and also the need for data rate increased. Radio spectrum is a limited resource and the service is allocated by fixed spectrum assignment. So some frequencies are heavily used and other bands are weakly used. The number of devices utilizing the unlicensed spectrum is growing, which indicates the increase in spectrum demand. So spectrum scarcity is a major issue faced by wireless networks. In order to overcome this issue Dynamic spectrum access (DSA) is introduced, which improves the spectrum efficiency. In DSA the unlicensed systems are allowed to use the licensed bands without interfering the existing user. So the weakly used spectrum can be used by other users.

Cognitive Radio (CR) uses dynamics spectrum allocation which provides higher bandwidth and efficient spectrum usage. CR enables to reuse the licensed spectrum in unlicensed manner i.e., it open the licensed bands to unlicensed users to use them without causing any interference to the licensed user. Radio sensing, self adaptation and dynamic spectrum sharing are the abilities of CR. Spectrum underutilization and spectrum scarcity can be mitigated by an efficient spectrum usage of CR. CR network contains two types of users: primary user (PU) and secondary user (SU). Licensed users are PU. They have the higher priority to access the channel. SU are unlicensed user. They can access the spectrum only in the absence of the PU. The SU can use the channel without causing any interference to the PU. SU wants to leave the channel when the PU reappears. SU is also called as Cognitive Radio (CR) user. CR users choose the vacant portion of the spectrum which can meet its QoS.

To support various wireless applications and services in a no interfering basis, the ***fixed spectrum access*** **(FSA)** policy has traditionally been adopted by spectrum regulators, which assign each piece of spectrum with certain

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bandwidth to one or more dedicated users. By doing so, only the assigned (licensed) users have the right to exploit the allocated spectrum, and other users are not allowed to use it, regardless of whether the licensed users are using it. With the proliferation of wireless services in the last couple of decades, in several countries, most of the available spectrum has fully been allocated, which results in the spectrum scarcity problem. On the other hand, recent studies on the actual spectrum utilization measurements have revealed that a large portion of the licensed spectrum experiences low utilization. These studies also indicate that it is the inefficient and inflexible spectrum allocation policy that strongly contributes to spectrum scarcity and, perhaps, even more than the physical shortage of the spectrum. To maintain sustainable development of the wireless communication industry, novel solutions should be developed to enhance the utilization efficiency of the radio spectrum.

II. LITERATURE REVIEW

It is an intelligent wireless technology capable of learning and adapting changes in surrounding environment parameters. However, the security of Cognitive radio restricts its widespread application. In addition to traditional wireless network security threats, cognitive radios are vulnerable to new threats posed by flexible spectrum allocation policy. Various attacks are targeting the physical, MAC, network, transport and application layers of a protocol stack. There is a need to have an excellent knowledge of the attacker's characteristics for secure and robust Cognitive Radio deployment. This paper meticulously recaps the security hazards posed to the cognitive radio network at various layers. Also, we have summarized attacks according to protocol layer and security requirements in a tabular format.

To the best of our knowledge, this study involves multimedia capability in CRNs. Various QoE models and their supportive multi-media architecture have been discussed in this study. QoE has been analyzed in-depth with respect to the video streaming in CRNs. However, this survey is very brief and the network centric approach regarding QoS for WMCRNs is not discussed. Also, various CR-based networks that support the various multimedia applications are not highlighted. An in-depth discussion of the various communications protocols, especially the MAC protocols, is also missing. Authors in have presented a survey on QoS provisioning in CRNs.

This survey, QoS objectives merely listed. The rest of the paper is about the spectrum sensing approaches used in CRNs, and does not provide any detail about QoS provisioning and QoS objectives. This survey also lacks discussion of different MAC supporting multimedia applications, routing, and other communications protocols. Except for naming different QoS objectives, this survey does not cover any topic related to multimedia communications in CRNs.

The existing surveys on the energy-efficient multimedia communications in the wireless networks are, while QoS in the various wireless networks is discussed. QoE is presented. Different cross-layer designs related to multimedia communications are presented. Multimedia communications in the wireless sensor networks (WSNs) are examined. Authors explore the various compression techniques related to multimedia applications, and in discuss different wireless architectures supporting multimedia communications.

Multimedia communications in the satellite networks are outlined, and video bandwidth forecasting and standardization regarding multimedia content are surveyed. Different dimensions regarding multicast video streaming is presented, while the voice over Internet, H.264 video codec's, and different video traffic models are surveyed, respectively.

All these surveys, however do not address multimedia communications in CRNs. The existing studies on CRNs related to the routing protocols are discussed in the, while the link layer protocols of CRNs are surveyed. Authors present the various approaches for spectrum sensing, sharing, and occupancy in CRNs. The concept of white space is widely. Different standards related to CRNs and the TVWS are discussed, while the authors have studied various security approaches related to CRNs. The resource allocation schemes including the radio resource allocation are surveyed.

The concept of artificial intelligence has been explored in detail, while the machine-to-machine communications employing CRNs is explored. The green energy-powered using the DSA approach is covered. However, the primary topics of all these surveys do not include multimedia communications in CRNs from any perspective.

III. METHODOLOGIES

Cognitive radio is a radio which alters its transmission parameters according to the environment in which it operates. Cognitive radio is dynamic in nature. The main objective of CR is to choose the best spectrum. The CR user senses the spectrum in order to find the vacant one. The vacant spectrum is called as the spectrum holes or white space.

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CR user continues its transmission until the PU reappears otherwise it leaves the spectrum as illustrated. The CR user should be aware about the interference level with the PU. For seamless transmission it moves to new vacant spectrum.
Dynamic spectrum access (**DSA**) has been proposed as an alternative policy to allow the radio spectrum to more efficiently be used. In DSA, a piece of spectrum can be allocated to one or more users, which are called primary users (PUs); however, the use of that spectrum is not exclusively granted to these users, although they have higher priority in using it. Other users, which are referred to as secondary users (SUs), can also access the allocated spectrum as long as the PUs are not temporally using it or can share the spectrum with the PUs as long as the PUs' can properly be protected. By doing so, the radio spectrum can be reused in an opportunistic manner or shared all the time; thus, the spectrum utilization efficiency can significantly be improved.

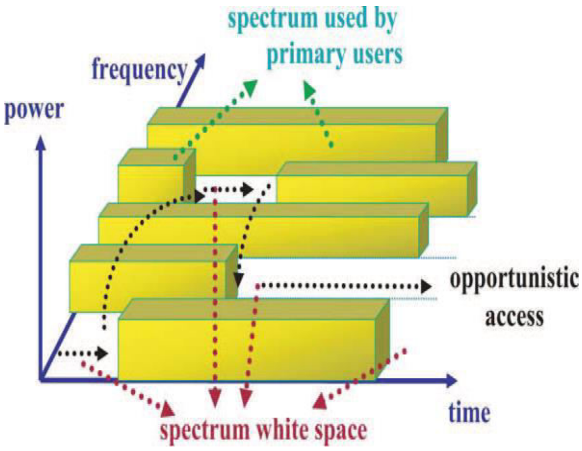

Fig.1. Spectrum hole concept

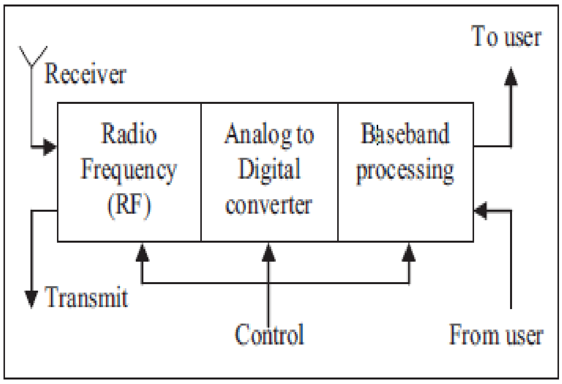

Fig.2. Cognitive radio transceiver

The CR transceiver contains a Radio Frequency (RF) unit, analog to digital converter and baseband processing unit. RF and analog to digital converter together called as the RF front end. General CR transceiver. The RF front end amplifies the received signal and it converted to digital signal. Then the signal is modulated/demodulated and encoded /decoded at the base processing unit.

Spectrum-Sensing Techniques

As aforementioned, a spectrum hole is a frequency band that is assigned to the PUs but is not utilized at a certain time and location [6], [8], [14]. In some portions of the spectrum such as the TV band, the TV program may be predetermined in some regions; thus, such spectrum hole information can be broadcast to the SUs using relocation database solutions. When such information is not available to the SUs, spectrum sensing enables CR users to identify the spectrum holes, thus protecting the PUs. Therefore, spectrum sensing is considered one of the critical elements in CRN design. As shown in the figure, a primary Tx sends data to its intended Rx in a certain licensed spectrum band. A pair of CR users (CR Tx and CR Rx) intends to access the spectrum holes for secondary communication. To guarantee the protection of PUs, the CR Tx needs to perform spectrum sensing to find spectrum holes. In particular, the CR Tx is required to detect whether there is an active primary Rx inside the coverage of the CR Tx. If not, the CR Tx can safely transmit to the CR Rx using the identified spectrum hole. Otherwise, the CR users are not allowed to use the band. Therefore, detecting the nearby primary Rx's can directly identify the spectrum hole, which is called *direct spectrum sensing*. It is well known that detecting a Rx is a challenging task, because the Rx does usually not transmit signals when it works.

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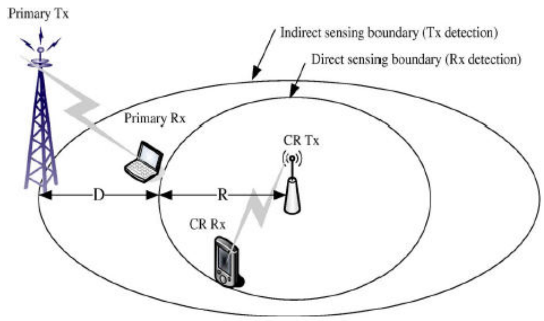

Fig. 3. Spectrum Sensing

Centralized MAC protocols

In centralized CRNs, the central unit is responsible for spectrum sensing and allocation and manages all other SUs. All the activities of PUs are also monitored by this unit. In [213], authors design MAC protocols for the centralized CRNs to support the delay sensitive traffic of voice users. In order to maintain fairness for all involved SUs, an efficient scheduling mechanism has been developed. The proposed MAC protocol has been compared with other distributed link layer protocols and shows enhanced performance in terms of required QoS for voice users and supporting the fairness among SUs.

Distributed MAC protocols

MAC protocols supporting multimedia content have also been designed with the distribution CRNs topology. As compared to the centralized CRNs, distributed CRNs do not have any central unit to control all the sensing and managing operations, instead individual SUs monitor PUs activities and perform the spectrum sensing operations. The current studies on distributed MAC protocols for WMCRNs take into consideration either the multi-channel or cross-layer approach to maintain the long sessions for the time-critical traffic.

V. ALGORITHMS

One straightforward form of cooperative spectrum sensing is to transmit and combine the samples received by all the CR users in the local spectrum-sensing phase. In [41], a combining scheme is proposed to process all the samples using tools from a random matrix theory. Consider K CR users, each taking N samples. Denote yk(n) as the sample that is received by the kth ($1 \leq k \leq K$) user at the nth ($1 \leq n \leq N$) time instant.
Then, we can construct the following matrix:
Let λi's be the eigenvalues of (1/N)YYH and α = K/N. Denote the noise variance at each CR user as σ2. If σ2 is known at the combining user and whenK →∞and N →∞, the final decision will be H0 if

$$\mathbf{Y} = \begin{bmatrix} y_1(1) & y_1(2) & \cdots & y_1(N) \\ y_2(1) & y_2(2) & \cdots & y_2(N) \\ \vdots & \vdots & \ddots & \vdots \\ y_K(1) & y_K(2) & \cdots & y_K(N) \end{bmatrix}.$$

$$\lambda_i \in \left[\sigma^2(1-\sqrt{\alpha})^2, \sigma^2(1+\sqrt{\alpha})^2\right]$$

for all i's, and H1 if there are eigenvalues outside the aforementioned range. If the noise variance is unknown, the final decision will be H0 if

$$\frac{\max_i \lambda_i}{\min_i \lambda_i} \leq \frac{(1+\sqrt{\alpha})^2}{(1-\sqrt{\alpha})^2}.$$

Otherwise, the final decision will be H1. This cooperative spectrum-sensing scheme [41] uses the same test statistics as the EBD in [35], and the decision threshold is chosen as a fixed value. Assuming that both K and N tend to infinity, the decision threshold in [41] is, indeed, not related to the system parameters, because the test statistics converge to a deterministic value [42], and the cooperative spectrum-sensing scheme can achieve a nearly optimal performance with the utilization of all the samples. For practical values of K and N, the performance of the aforementioned scheme significantly degrades, because the test statistics are no longer deterministic but are a random variable.

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VI. CONCLUSIONS

We have provided a systematic overview on CR communications and networking. Due to the explosion of research and publications in this field, this paper had difficulty in covering all the related topics. Instead, our focus has been on the key elements of the PHY, MAC, and network layers of a CR user who operates in a CRN, as well as the interrelation among these elements across different layers. We hope that this paper can help researchers and practitioners have a cross-layer view on designing CRNs. the fundamental concepts of cognitive radio, its functions and issues are presented. Spectrum is a valuable resource for wireless communication. CR sense and adapt their transmission parameters based on the environment. So, it solves the scarcity problem in wireless communication and also it increases the spectrum utilization. Sensing is the most important function of CR. Accuracy in sensing increase the performance of network.

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