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SURVEY ON CR- MAC PROTOCOLS FOR SPECTRUM ACCESS AND ENERGY EFFICIENCY

Tushar Pandey[1],Sashank Phatkare[2],Aniket Sawant[3],Ashish Pandey[4],Trupti Harhare[5]
[1,2,3,4] Students of Electronics Department, [5]Faculty
Department of Electronics Engineering, LTCOE, Mumbai University, India
[1]pandeytushar30@gmail.com,[2]sashankp94@gmail.com,[3]aniketsawant714@gmail.com,[4]pashish017@gmail.com
[5]mtruptis@gmail.com

Abstract— **Cognitive radio (CR) is a promising technology developed to solve the spectrum scarcity problem by opportunistically identifying the vacant portions of the spectrum and transmitting in them, while ensuring that the licensed or primary users (PUs) of the spectrum are not affected. Cognitive radio technology enables the secondary (cognitive) users to use the unused licensed spectrum of the primary users. It is been noted that there is a lot of unused spectrum known as 'white spaces' even in commercial broadband and mobile network frequency bands. Cognitive radios can sense and adapt to their environment, utilize the white spaces and improve the spectrum utilization. Medium Access Control (MAC) protocol plays a vital role in spectrum utilization, primary user's (PU) interference management and secondary user's coordination in cognitive radio (CR) networks. In this paper we present an overview of current medium access control protocols.**

Index terms- **Common Control Channel, Medium Access Control, Spectrum Sensing, Spectrum Access.**

I. INTRODUCTION

The radio frequency spectrum is a limited natural resource to enable wireless communication between transmitters and receivers. Licenses are usually required for operation on certain frequency bands. The use of radio frequency spectrum is globally governed by the International Telecommunication Union (ITU). Recent measurements reveal that many portions of the licensed spectrum are not used during significant time periods. Since the number of users and their data rates steadily increase, the traditional fixed spectrum policy is inefficient and is no longer a feasible approach. Unlicensed bands are over occupied and the licensed bands are not fully utilized. Much greater spectral efficiency can be achieved with unlicensed spectrum usage in the bands that are not heavily used**.** Thus, there is an opportunity for systems that can exploit the available bands with suitable power without interfering the present users who have higher priority (primary users). One drawback is that guaranteed QoS is not available in unlicensed spectrum. The underutilization of some frequency bands opens up the opportunity to identify and exploit spectrum holes. A spectrum hole is defined as a band of frequencies assigned to a primary user, but, at a particular time and specific geographic location, the band is not being utilized by that user. If a secondary user can access a spectrum hole, the spectrum utilization is improved significantly. A promising mechanism to improve the spectrum utilization by exploiting the spectrum holes is based on the cognitive radio concept. However an important consideration is the control and coordination of communication over wireless channel and prevention of performance degradation to the licensed users of the band used for CR transmission associated with CR MAC protocol. This motivates the research in CR MAC protocols by designing an efficient MAC protocol for successful deployment of any CR

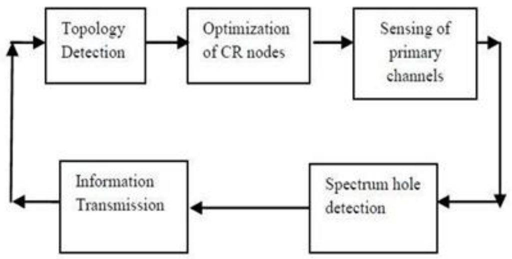

Fig.1. Block diagram of cognitive radio flow [3]

In cognitive radio terminology primary users can be defined as the users having higher priority. They have legacy rights on the usage of a specific part of the spectrum. On the other hand, secondary users, which have lower priority, exploit this spectrum in such a way that they do not cause interference to primary users. Therefore, secondary users need to have cognitive radio capabilities, such as sensing the spectrum reliably to check whether it is being used by a primary user and to change the radio parameters to exploit the unused part of the spectrum.

Spectrum sensing, an essential component of CR technology involves

1) Identify spectrum holes (white space)
2) When the spectrum hole is used by the secondary users, detect the onset primary transmission.

CR will improve the spectrum utilization in wireless communication system and include various other applications as Global System for Mobile Communication networks, satellite communication, military purpose, public safety and next generation technologies. . For new wireless applications there is a scarcity of available spectrum because of static spectrum allocation. With limited spectrum, the wireless systems will be congested because of higher traffic demands. Today the condition about the spectrum allocation is congestion in wireless spectrum and in the other side statistically assigned [3].

A general framework of the spectrum functions and the inter-layer coupling is shown in Fig. 2.Based on the radio frequency (RF) stimuli from the physical layer RF environment, the sensing scheduler at the MAC layer can determine the sensing and transmission times. The availability of the spectrum, whenever a data packet needs to be sent, is coordinated by the spectrum access function. The spectrum sensing block plays a crucial role, both in terms of long term channel characterization and ensuring that the channel is available at the time of actual data transmission [1].

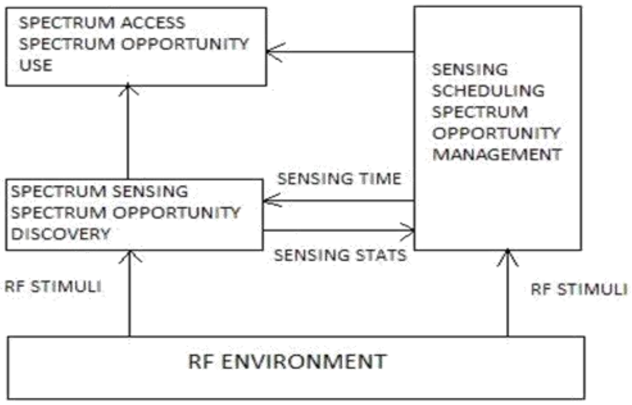

Fig.2. Architecture of CR MAC [1]

II. Cognitive Radio MAC Design: Issues and Challenges

This section deals with issues related to CR research, challenges to overcome spectrum scarcity, multichannel hidden terminal problem (MHTP), difficulties in common control channel (CCC) design, and CR MAC operation. We need to develop an efficient and robust MAC protocol to provide SUs with the maximum chance to access the unused spectrum, while respecting the PU's priority rights.

A. Spectrum Sensing and Availability

Spectrum sensing aims to find vacant spectrum options and avoids interference with the PUs. The detection technique that is used to find PUs in CR networks follows three stages: detection of primary transmitter, detection of primary receiver, and maintaining interference temperature. Local observations of CR users are necessary to detect weak signals from a primary transmitter. A primary receiver finds PUs that are receiving data from within the communication range of a CR user [6]**.** The interference temperature cannot distinguish between actual signals from a PU and noise/interference caused by cumulative radio frequencies let out/transmitted by multiple transmissions. Most of the current research focuses on transmitter detection methods. Three different schemes have been proposed to detect transmitters: matched filter detection, energy detection, and feature detection. Energy detection is the easiest scheme to implement. If the strength of a detected signal is above a certain threshold, it is considered busy. But energy detection needs coordinated quiet periods to avoid false alarms. As the availability of radio resources is uncertain and depends on a PU network, sensing PU channels becomes necessary. In order to do so, an efficient sensing mechanism should be implemented. Accurate sensing is impossible in practice, but efforts should be made to keep sensing errors to a minimum. An inaccurate result increases the uncertainty of finding available resources. It is important to note that high sensing performance creates more opportunities for SUs to use a licensed spectrum, while longer data transmission time guarantees the efficient use of PU resources by SUs.

B. Optimization of Spectrum Sensing Duration and Level of Interference

The primary objectives of the MAC design are minimizing interference on PU and optimizing the duration of channel sensing. Due to the hardware limitations of SU nodes, delays and errors cannot be completely avoided. Implementation of a cooperative sensing scheme may improve sensing performance. In a CR network, the spectrum sensing phase is followed by the data transmission phase. So, careful consideration should be taken when specifying the duration and frequency of the sensing phase in MAC. There are two existing approaches: fine sensing and fast sensing. Fine sensing ensures proper detection of the spectrum, but
provides a short duration for data transmission. On the contrary, fast sensing ensures optimal detection of the spectrum, but provides a short time for sensing. There are two important metrics used in spectrum sensing: false alarm probability and detection probability.

C. Negotiation Mechanism & Time Synchronization

There must be an efficient mechanism for a transmitter and its intended receiver to select a common available channel for transmission. In distributed CR networks, there is no central authority, which makes it necessary for SUs to go through a channel negotiation process. Many CR MAC protocols use CCC in an initial control message exchange, which is shared by many or all SUs. Some MAC protocols incorporate time synchronization among SUs. Selection of CCC is not easy and may also cause a loss of resources. Therefore, the channel negotiation mechanism should be designed properly. If not, it may be troublesome to manage the proper utilization of resources and overhead time. Without time synchronization, it is difficult to implement channel negotiation. It leads to improper coordination between network establishment and SUs. Therefore, network-wide time synchronization is a major research challenge at present, because of the uncertainty of spectrum availability.

D. Problems in Common Control Channels

Two SUs in a CR network can be connected if they have a common control channel for communication. For example, if Node A wants to transmit to Node B, A and B should negotiate their channel sets and exchange a control message to reserve a channel for communication in a manner outlined in IEEE 802.11 DCF. But a dedicated CCC has several drawbacks. First, a channel dedicated to control signals is a wasteful use of channel resources. Second, a control channel will become saturated as the number of users increase. And finally, an adversary node can cripple the dedicated control channel by intentionally flooding the control channel. This leads to a decrease in the number of channels available to all users. Available channels may vary in the frequency of operation, bandwidth, and transmission range. Due to heterogeneity in the transmission range, a channel with a shorter transmission range may not cover all areas, but a channel with a longer transmission range may cover all the areas.

E. Problems in Multichannel Hidden Terminal

Multichannel hidden terminal problem have been recognized in various multi-channel networks [7]. A SU equipped with single radio can listen to only one channel at any time, and therefore can miss control messages when its radio is busy transmitting or receiving data. This SU might initiate communication with another SU node in an already allocated channel, resulting in a collision. This is called the MHTP. It can be better addressed in a multi-transceiver MAC protocol. But multiple radios at each SU node make the system more complex and expensive. However, single radio MAC protocols are much cheaper and less complex to implement.

III. CLASSIFICATION OF MAC PROTOCOLS

Based on the base station CR MAC can be divided into centralized and adhoc networks.

A. MAC Protocols for Centralized CR Networks

These protocols need a central entity, such as a base station, that manages network activities, synchronizes and coordinates operations among nodes

B. Random Access Protocol:

Random access protocol is based on CSMA/CA mechanism. A CSMA-based protocol [8] uses a single transceiver, and PUs coexists with CR users. CR users require a longer sensing/detection period than PUs. Therefore, the priority for spectrum access is given to the PUs. CR base stations and users cannot find out if the PUs experiences multiple failed transmission attempts. Also, coding schemes for transmission power and transmission rate of the users are not assigned properly in this protocol.

C. Time slotted protocol:

A time slotted protocol like IEEE 802.22 as mentioned in [12] needs network wide time synchronization, where time is divided into slots for control channels and data transmission. A super frame is defined, which is further divided into a super frame header and a MAC frame. A MAC frame is comprised of an upstream and downstream sub frame. The main disadvantages of this protocol are the exchange of a high volume of control messages and lower data throughput. It is difficult to maintain time synchronization as well. Back up channels are used to restore communication after PU interference

D. Hybrid protocol

Hybrid protocols are basically implemented as a game theoretic dynamic spectrum access [5]. These protocols use control signals over synchronized time slots, and data transmission may have schemes for random channel access. Mechanisms for dynamic spectrum access with clustering, negotiation, and collision avoidance are used in the game theoretic approach. One of the major drawbacks is that negotiation delay increases with the number of players. Difficulty in synchronization and possible collisions among game information packets makes the game theoretic hybrid approach more challenging.

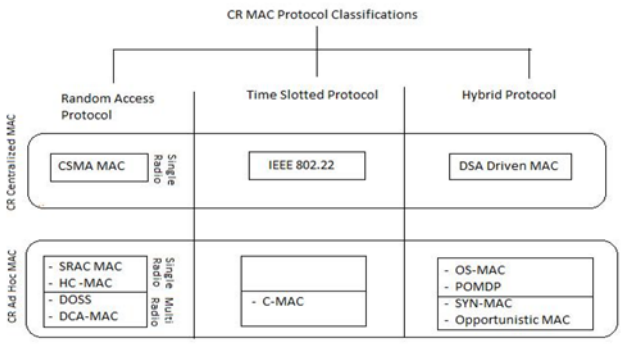

Fig.3. Classifications of CR MAC protocols [1]

1) . MAC Protocols for AD HOC CR Networks

ADHOC MAC protocols do not have a central entity such as a base station (BS). Usually most of the ADHOC MAC protocols are more scalable, efficient, and dynamic in nature than a centralized approach. That is why many researchers now focus on ADHOC protocols.

a) SRAC Protocol:

The single radio adaptive channel (SRAC) algorithm is proposed in [9] that adaptively combines spectrum bands based on the CR user requirement, called as dynamic channelization. In addition, it uses a frequency division multiplexing (FDM)-like scheme, called as cross-channel communication, in which a CR user may transmit packets on one spectrum band but receive messages on another.

b) Distributed channel assignment (DCA) based MAC:

A simple extension of the IEEE 802.11 CSMA/CA protocol using distributed channel assignment (DCA).It uses multiple transceivers, with a dedicated out-of-band CCC for signaling. In addition, the proposed protocol also utilizes spectrum pooling which helps to enhance spectral efficiency by reliably detecting the primary network activity, thus serving as physical layer signaling.

c) Cognitive MAC (C-MAC):

The synchronized and time slotted Cognitive MAC(C-MAC) [11] protocol is aimed at higher aggregate link throughput and robustness to spectrum change using multiple transceivers. C-MAC includes two key concepts: the rendezvous channel (RC), and the backup channel (BC).The RC is selected as the channel that can be used for the longest time throughout the network, without interruption among all other available choices. It is used for node coordination, PU detection, as well as multi-channel resource reservation. The BC, determined by out-of-band measurements, is used to immediately provide a choice of alternate spectrum bands in case of the appearance of a PU.

d) OS-MAC:

Hybrid protocols like OS MAC [10] use predetermined window periods. It uses a single radio that switches between the data band and CCC. The OS MAC protocol has several drawbacks: there is no consideration of protection of PUs either by adapting transmission or by power control. Here a hybrid single radio MAC protocol based on the theory of a partially-observable Markov decision process (POMDP) is proposed. The POMDP is a generalization of the Markov chain process. Multi-radio hybrid protocols such as SYN-MAC and Opportunistic MAC and respectively.

Protocols	Control Channel & no of radio	Spectrum Access	Energy Efficiency	MHTP	Sensing Error	Interference to PUs
SYN-MAC	No,2	Hybrid	No	Addressed	Not Addressed	Not Addressed
SRAC	Yes,1	Random	No	Not Addressed	Addressed	Not Addressed
OSA-MAC	Yes,1	Timeslotted	No	Addressed	Addressed	Addressed
C-MAC	No,Multiple	Timeslotted	Yes	Addressed	Addressed	Addressed
POMDP	No,1	Hybrid	No	Addressed	Addressed	Addressed
DCA-MAC	Yes,2	Random	No	Addressed	Not Addressed	Addressed

Fig.4. Distinguishing Features of the MAC Protocols [4]

IV. Conclusion

The survey of the paper has been successfully done by comparing various existing MAC protocols. All the design challenges under problem definition were carefully studied and observed. C-MAC provides enhanced data transmission and channel evacuation approach and hence increases the efficiency. Using Cognitive Radio technology, the problem of spectrum underutilization can be solved to a great extent. Channel assignment is especially challenging in CRN (Cognitive Radio Networks).A great deal of research still needs to be done on simulating and exploring these intelligent network ideas.

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