CRN Survey and A Simple Sequential MAC Protocol for CRN Learning

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***Abstract*—With the idea to use the spectrum band efficiently, much of the research is being published in the field of cognitive radio network to share the licensed spectrum band with unlicensed users when licensed users are not active. Cognitive Radio Network (CRN) has introduced a lot of new challenges in the field of wireless networks. In this research paper, we had listed the cognitive radio network issues by conducting a survey of MAC protocols for CRNs. We have also developed a very simple MAC protocol for learning CRN for the entry level researcher.**

Keywords-Cognitive Radio Networks; Dynamic Spectrum Access; MAC protocol.

I. INTRODUCTION

Recently, authorities are exploring the ways to fully utilize the licensed spectrum band, as portions of spectrum in 30MHZ to 30GHZ, as shown in Figure 1, are being used only 5% [1][17] while unlicensed spectrum is overcrowded. As spectrum is rarely used so lot of white and grey space areas occurs in licensed spectrum. Grey space areas are the portions with medium licensed users' activity whereas in white space areas, activity of licensed users is almost none. Black space areas are the portion where spectrum is being fully utilized. By sharing the licensed band between licensed and unlicensed users with the constraint that unlicensed user will only use the band when licensed user is inactive and have to vacate on his activity, provides the opportunity that spectrum band will be fully utilized and need for searching new radio spectrum will be reduced [2]; this is the solution provided by cognitive radio networks. For this purpose, a lot of research is being conducted in this area and a large number of MAC protocols are being published. This paper will list out some of the recent protocols. A generic method for developing a simple MAC protocol for an entry level researcher in the field of CRN will also be described in this paper.

Including this section on Introduction, the paper is organized in six sections. Issues related to cognitive radio networks will be described in Section II. Section III gives a literature survey of MAC protocols. Section IV will give a brief overview of how to develop a Simple MAC protocol for CRN in NS2. Section V will present simulation scenarios and the results. The conclusion of the paper will be in Section VI.

II. ISSUES IN COGNITIVE RADIO NETWORKS

Several studies have shown the various issues in cognitive radio networks. These issues are normally categorized into three categories, namely Dynamic Spectrum Access, Dynamic Spectrum Sharing and Dynamic Spectrum Multi-channel operation.

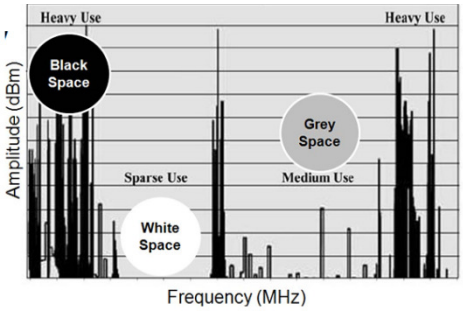

Figure 1. Licensed Spectrum Usage [17]

A. *Dynamic Spectrum Access*

Basic issues of cognitive radio networks lie in the Dynamic Spectrum Access (DSA), which separates the cognitive radio network from the other wireless networks. The main aim of DSA is the co-ordination of primary (licensed) user and a secondary (unlicensed) user for a channel. The biggest problem here is that primary user should not face or face minimum interference in his communication.

As the primary user has more priority for using the channel, secondary user must vacate the channel as soon as the primary user initiates its activity. This also creates several secondary issues such as security and integrity of primary user should not be compromised. How much interference is tolerable for the primary user? What are the effects of irregular activity of primary users on secondary user's communication and vice versa?

This category also deals with the issues of channel discovery and co-ordination of quiet period by secondary user when primary user is active.

B. *Dynamic Spectrum Sharing*

This category deals with the issues of co-ordination between different secondary users. Efficient channel sharing is the ultimate goal. Issues of neighbor nodes discovery and channel sharing comes into this category.

C. *Dynamic Spectrum Multi-channel operation*

Issues dealing with multichannel communication come under this category. Quality of service and integrity of communication are the primary goals here.

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TABLE I. MAC PROTOCOLS WITH ISSUES

Mac Protocol	Type	Access Method	Multi-Radio	Hidden Terminal Problem	Efficient Utilization of Band	Common Control Channel Problem	Primary User's Protection	Energy Consumption
CSMA-MAC	Infrastructure	Random Access	No					
IEEE 802.22	Infrastructure	Time Slotted	No					
DSA driven MAC protocol	Cluster	Hybrid	No					
(DOSS) MAC	Ad hoc	Random Access	Yes	No	No	Yes		High
(DCA) MAC	Ad hoc	Random Access	Yes		No			High
(SRAC) Mac	Ad hoc	Random Access	No		No	No		
(HC) MAC	Ad hoc	Random Access	No	Yes	No	Yes		
C-MAC	Ad hoc	Time Slotted	Yes		No	Yes		High
Full Duplex CR-MAC	Ad hoc		Yes					High
OS-MAC	Cluster	Hybrid	No	No		Yes	No	
SYN-MAC	Ad hoc	Hybrid	Yes	No	No	No	No	High

III. LITERATURE SURVEY

MAC protocol plays an important role in cognitive radio network as it allows the user to co-ordinate with other users to effectively use the broadcast domain/ channel. In normal wireless networks, all the users have equal rights and priorities whereas CRN divide the users into two groups 'Primary' (licensed) and 'Secondary' (unlicensed) users. Secondary users use the vacant frequency spectrum (frequency holes) for communication among different secondary users by creating a secondary network under a primary network.

A. *MAC protocols in CR Environment*

There are two basic approaches for designing MAC protocol in a CRN environment, namely, Infrastructure-based and Ad hoc-based.

1) MAC protocols for Infrastructure-based networks

In an Infrastructure-based CRN environment, base station collects the information of the spectrum in its coverage area from all the CR users. Based on its information, it determines the scheme for the CR users to share the vacant spectrum. MAC protocols for the Infrastructure-based networks have been categorized into three major categories, random access, time slotted and hybrid protocols.

Contention-based CSMA-MAC [3] protocol is a random access protocol based on classical CSMA with longer sensing time for cognitive users. It has been designed for both the primary and secondary users. Based on the distance of CR user from its base station and noise power, base station allows it to send data.

IEEE 802.22 [3] is a time slotted MAC protocol for infrastructure-based CRNs. In this standard, base station uses a hierarchy of frames to sense the vacant spectrum, inform CR users of it and knowledge of active primary users in the area to the CR users. The key features of the 802.22 are extensive sensing, channel recovery and co-existence of different users.

A game theoretic dynamic spectrum access DSA driven MAC protocol [4] is a hybrid protocol as it random access scheme for control signals where as time slots for data transmission. This MAC is cluster based and game policy or access rights for channel utilization are controlled by the cluster head. There are four main parts of this MAC protocol, namely, DSA algorithm, clustering algorithm, negotiation mechanism and collision avoidance mechanism.

2) MAC protocols for ad hoc-based networks

These protocols are also divided into three main categories, i.e., random access, time slotted and hybrid protocols.

Dynamic open spectrum sharing (DOSS) MAC [6] is a random access MAC protocol. Multiple radio transceivers are used for data, control and busy tone transmission. This protocol solves the hidden node and exposed node problem. The drawback of this protocol is that most of the band is utilized for control and busy tone information.

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Distributed channel Assignment (DCA) MAC [7] protocol is an extension of 802.11 CSMA/CA protocol. It is a random access MAC protocol. The main drawback with this protocol is the dedicated common control channel which results in the wastage of spectrum.

The single radio adaptive channel (SRAC) Mac [8] protocol can use and combine the spectrum band depending upon the need of the user. This is a random access MAC protocol and in this protocol, a single radio is used for sending and receiving data but using cross channel communication, data is send on one spectrum band and received on the other. The drawback is the unnecessary overhead.

Time slotted Cognitive MAC (C-MAC) [10] uses multiple radios to achieve high throughput. This protocol aims at two channels one is rendezvous channel RC, which is the freest channel on the network and is used for nodes co-ordination and primary users' detection and other is the backup channel. The problem with this protocol is also the RC itself. Availability of a channel for a longer period is quite difficult.

A full duplex Multichannel MAC protocol for Multi Hop CRN [14] is also a multi radio MAC protocol. It uses two radios, one for transmitting and second for receiving packets. This protocol reduces the communication delays by allowing node transmit and receive packet simultaneously at different radios.

Synchronized MAC (SYN-MAC) [12] is a multi radio hybrid protocol. This protocol allocates each channel a time slot. In the beginning of a time slot, nodes tune to a particular channel and the node who wish to communicate, can exchange control packets. On negotiation, one of the free channels among both nodes is selected for data transmission. Problem with this protocol is that primary user protection and efficient channel utilization is not taken into account in this protocol.

IV. SIMPLE SEQUENTIAL MAC FOR CRN LEARNING

This section describes the development of a simple sequential MAC for Cognitive Radio networks which can serve as a demonstrative example for an entry level researcher in the field of CRN. Although they are number of example available in CRN extension of NS2 like MACng and MACngenhanced [13], but they create lot of confusion for the starter. They do not provide clear distinction of primary and secondary users and random assignment of channels to the primary user during runtime (simulation time) creates lot of confusion in reading of the results from the trace file. Apart from this, they send strategy packets (Control packet) to let the receiver know that on which channel they will send the packets at the start of simulation that violates the basic rule that cognitive user should search the channel during runtime. All other MAC protocols, as described in section III contains too much complexity for a new researcher to understand. So a new MAC protocol was developed which can serve the following purposes

- Primary Focus on DSA
- Same MAC for Both primary and secondary users
- Should have clear distinction of Primary and Secondary Users
- Primary User should remain on One assigned channel
- Only Secondary User should search the available channels during run time
- Number of Total channels should be known to every node
- Channel should be visible to MAC as numbers and not as a range of frequencies, that should be handled by Physical layer
- Primary user can be detected on reception of the packet from primary user
- On detection of primary user, secondary user should vacate the channel and shift to next channel, after last channel, it should jump to first channel.
- Primary user on reception of packet from the secondary user, just drop the packet and ignore the secondary user.

A. *Modifications in NS2 to Support Simple Sequential MAC for CRN*

Numbers of changes were carried out in NS2 to support this MAC protocol. Decision that node is primary user or not and if it is primary then which channel it will be going to use, was done in TCL simulation file.

```
$node_(5) set isprimaryuser 1
$node_(4) set isprimaryuser 1
$node_(5) set chanis 2
$node_(4) set chanis 2
```

In the above example, node 5 and node 4 were made primary users and channel 2 was assigned to both of them to be used as sender and receiver.

Values coming from TCL file were bind in common/mobilenode.cc with two variables which were declared in common/mobilenode.h isprimaryuser and chanis, in constructor function

```
bind("isprimaryuser",&isprimaryuser);
bind("chanis",&chanis);
```

To access these variables in MAC, two more functions were developed in common/mobilenode.h

```
int IsPrimaryUser() { return isprimaryuser;}
int ChanIs() { return chanis;}
```

First function will let the MAC of node know that it is primary user or not and second will describe the channel being used by that node. In order to detect that packet has come from primary user or cognitive user; new fields were added in the common/packet.h file in header field, fromprimaryuser and fromCRuser. Purpose of both the fields are self explanatory that the sender of primary will set the fromprimaryuser field and cognitive user will set the fromCRuser field in the packet header and receiver will identify the sender by these fields in the received packet.

Another field that is very important added by CRN extention is channelindex_; it was used to send the channel number with the packet and also helps to tune the physical layer (MAC/phy.cc) with the corresponding channel.

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```
nchannel= hdr->channelindex_;
```

As the primary channels had one fixed channel so they were tuned statically

```
 if(node()->nodeid()==5  || node()->nodeid()== 4)
{
        nchannel=2;
}
```

B. MAC Modification

Flow of our MAC protocol is shown in Figure 2. In order to implement this, we had chosen the Simple MAC protocol for wireless networks, already available in NS2, to be modified. This is a very simple protocol without control frames and send packet whenever it finds the channel free.

As all the working depends upon the detection of primary user on reception of the packet so firstly 'send' function was modified that if the node is primary or secondary, it should send its information in packet header.

```
if(((MobileNode*)(netif_->node())) ->
IsPrimaryUser()==0)
{
        ch->fromCRuser=1;
        ch->fromprimaryuser=-1;
        ch->channelindex_=recvchan;
}
else
{
        ch-> channelindex_=((MobileNode*)(netif_->
        node()))->ChanIs();
        ch->fromCRuser=0;
        ch->fromprimaryuser= ch-> channelindex_;
}
```

A variable named recvchan was added in the mac-simple.h file to be used as a channel number in the MAC Cognitive user sends channel number in channelindex_ whereas primary user sends its fixed channel number in fromprimaryuser header field.

At the start of the 'receive' function, all the primary nodes are tuned to their corresponding channel where as cognitive users are tuned on the basis of recvchan.

```
if (index_==4 || index_==5)
{
        chan=2;
        recvchan=chan;
}
```

In the above example, node 4 and node 5 are tuned to channel 2 and its recvchan is also modified

In 'receive' function, modifications were made to detect if the current node is primary and packet is coming from secondary user, if this is so, packet should be dropped in the receive function.

```
int isprimaryuser = ((MobileNode*)(netif_->
node()))-> IsPrimaryUser;
if(isprimaryuser==1 && hdr->fromCRuser==1)
{
        Packet::free(p);
        return;
}
```

In case if the current node is secondary and above condition does not execute, then packet is either coming from primary user or any other cognitive user. If packet is from primary user, then recvchan that is carrying the current channel number of the node is incremented. After increment, if channel number goes beyond the total number of channels then it is tuned to first channel again.

```
if(isprimaryuser==0 && hdr-> fromprimaryuser !=-1)
{
        Totalchannels = ((MobileNode*)(netif_->
        node()))-> number_of_channel;

        recvchan++;
        recvchan= recvchan % Totalchannels;
}
```

This portion of code can be modified to a better channel selection scheme, but we had chosen it to be simple sequential for understanding and learning purpose. If this portion of the code doesn't execute, it means two cognitive users are trying to use a single channel, rest of the receive function code was not modified to use the functionality of simple MAC i.e., adding jitter time in case of collision of CR users.

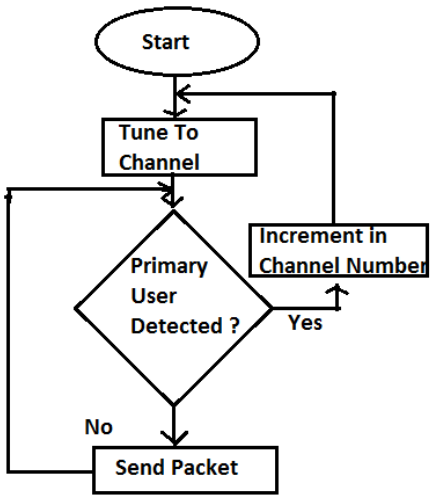

Figure 2. Flow of Simple Sequential MAC for CRN

V. SIMULATION AND RESULTS

We had taken the scenario presented in [16] and compare the average throughput result of Simple Sequential MAC with IEEE 802.11 [15] and FD-CR MAC [14] at single node. There was a total number of 30 nodes. Among them two nodes were taken as cognitive where as all of the rest were primary nodes. At least a Pair of primary nodes was on each channel among total of 12 channels. Simulation Time was taken as 100 sec with varying number of active

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(sender) nodes; initially the number was 5 including one cognitive, which increases as 10, 15, 20, 25 and 30.

TABLE II. SCENARIO 1

Parameter	Value
Data rate	11Mbps
Transport protocol	UDP (Random option ON)
Simulation time	100Sec
# of data channels	12

TABLE III. SCENARIO 2

Parameter	Value
Data rate	1,10,50,100,500, 1000 Kbps
Transport protocol	UDP (Random option ON)
# of data channels	12
Packet Size	512 bytes

Results (see Figure 3) have shown that Simple Sequential MAC has produced average result and this is due to the fact that we had compensated the efficiency for simplicity in channel selection scheme. Average throughput of Simple Sequential MAC was reasonable until the number of active nodes were 11 because MAC was able to find the free channel but afterward on each channel there was at least one primary user which had high priority then cognitive user so he had to leave the channel and as a result throughput decreases sharply. As compared to it, throughput of FD-CR had remained almost constant due to Multi-Radio usability and better channel selection scheme.

In scenario 2, we had tested the effect of primary user traffic on cognitive user throughput. We had deployed 24 primary nodes on 12 channels, one pair on each channel and one pair of cognitive nodes, i.e., total of 26 nodes. Data rate of cognitive sender node was set to 11 Mbps where as it is varied from 1, 10, 50,100, 500 and 1000 Kbps among primary nodes.

Results (see Figure 4) have shown that throughput of secondary user node decreases sharply as the primary users' activity increases. As there were no free channels, cognitive users find really hard to carry out their communication.

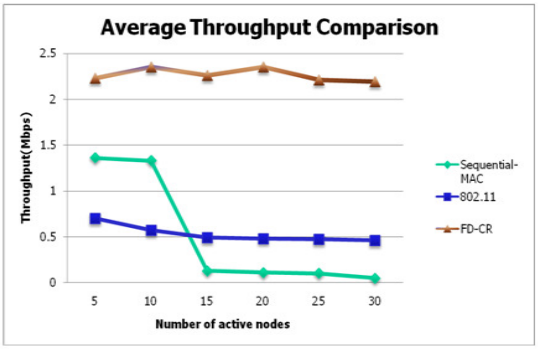

Figure 3. Average Throughput Results

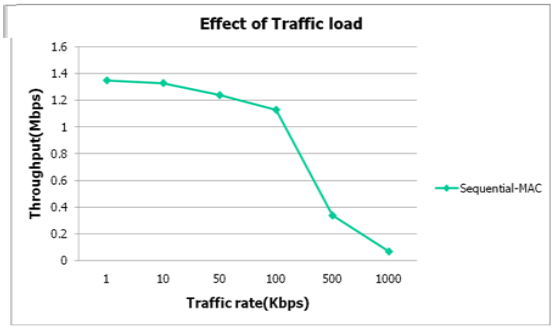

Figure 4. Effect of Primary User's Traffic load on Secondary User's Throughput

VI. CONCLUSION

Cognitive Radio networks recently have become an active topic among wireless network researcher as it promises to solve the issue of ever growing demand of new spectrum. By sharing the unused portion of the licensed band with the unlicensed users, the entire spectrum can be fully utilized. In this paper, we have surveyed the MAC protocols for CRNs and listed out the issues among them. As the idea of CRN is complex and not easily understandable for an early researcher, we had developed a Simple Sequential MAC protocol which can be taken as demonstrative example for CRN. Results of this MAC protocols were not as good in terms of efficiency as of earlier published MAC protocols and the reason is that we had compromised efficiency for simplicity.

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