Study of Performance Evaluation of Time Slotted Cognitive Radio MAC Protocols on a Common Framework

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***Abstract*— Cognitive Radio Ad Hoc Network (CRAHN) has introduced a lot of new challenges in the field of wireless networks. In this paper, study of performance evaluation of two existing time slotted CRAHN MAC (CR MAC) protocols has been done. Namely, Simple Sequential CR MAC, this is a simple time slotted CR MAC protocol. Another one is Decentralized Cooperative Sensing CR MAC with decentralized scheduling using pseudo random selector, in this protocol cooperative sensing policy is used within each cluster of CRAHNs and pseudo random generator is used as a scheduler to solve multi-user access problem within the secondary network by using decentralized scheduling scheme. Observation of the performance behavior of those protocols through Monte Carlo Simulation and analysis of the same is done here.**

***Keywords*— Cognitive Radio Network, Contender Nodes, Cooperative Sensing, Decentralized Scheduling, Primary User, Pseudo Random Generator, Secondary user.**

I. INTRODUCTION

Cognitive radio (CR) [7] is a promising technology to wisely solve the spectrum scarcity problem by the identification of the vacant portions of the spectrum opportunistically and transmitting in them, while the licensed or primary users (PUs) of the spectrum are not active. This necessitates adaptation towards the dynamically changing spectrum resource, learning related to the spectrum occupancy, taking decisions on the quality of the spectrum resource available, inclusion of expected duration of its use, probability of disruption due to PUs, among others [1].

While in frequency allocation charts of traditional static spectrum allocation reveal that almost all frequency bands have already been assigned, there exist temporal and geographical holes in the spectrum of licensed bands. In recent years, development of technologies such as WiFi, Bluetooth, cordless phones, etc. have allowed in the Industrial, Scientific and Medical (ISM) unlicensed bands. On the other hand, the problem of coexistence of heterogeneous systems that might interfere with each other exists in this band. To improve the overall spectrum usage by exploiting spectrum opportunities in both licensed and unlicensed bands cognitive radio technology emerges [5].

However, the most important consideration in this CR technology is the prevention of performance degradation of the licensed users during CR transmission. This motivates the research in the area of CR MAC (Medium access control) protocols. In general, the main part of the operation of any network system is the medium access control (MAC) protocols. Coordinating access of multiple users to spectrum channels is one of the responsibilities of this MAC protocols. In conventional wireless network, MAC protocols deal with the problems regarding network start-up, node joining, channel access collision, time synchronization, hidden /exposed terminal etc. [6]. On the other hand, MAC protocols for CR network have to face more challenges than that of the conventional wireless network regarding DSA (Dynamic Spectrum Access) related functions, such as, spectrum sensing, spectrum sharing, spectrum allocation, spectrum access, spectrum mobility [6], [12] .

Cognitive radio ad hoc networks (CRAHNs) [11] operates in ad hoc mode with autonomous nodes and main aim of this CRAHNs protocols is to utilize efficiently the spectrum resources by providing means to sense the channel efficiently to determine its occupancy, and sharing of spectrum among the other CR users to attain a tolerable interference levels to the privileged PUs [1].

In time slotted CR MAC protocols [1] each CR node is assigned with a unique control channel [1] slot and data transmission slot. Therefore probability of collision and Interference [10] in channel is less here though allocation of these slots and synchronization of time between CR users create problem [6].

Here approaches like multichannel [13] communication, cooperative sensing policy [8], [9], location sensing of PUs transmitter [3], [16] with conventional channel sensing, decentralized scheduling has been studied through the study of the above mentioned protocols.

In CRAHNs, CR MAC design is classified into two major categories: centralized and ad hoc; each of these further classified into three different types: random access, time slotted and hybrid as in [3], [4], [6].

Rest of the paper follows this order of organization. In section II discussion on system models of two existing protocols- Simple sequential CR MAC, Decentralized Cooperative Sensing CR MAC has been done. In section III the result of performance evaluation of those two protocols has been discussed. In section IV a conclusion has been drawn on performance of the protocols and in section V future scopes are discussed.

II. EXISTING SYSTEM MODELS

A. *Simple Sequential CR MAC*

This section describes the development of a simple sequential CR MAC for Cognitive Radio networks which can be used as a demonstrative example in the field of CRN [2].

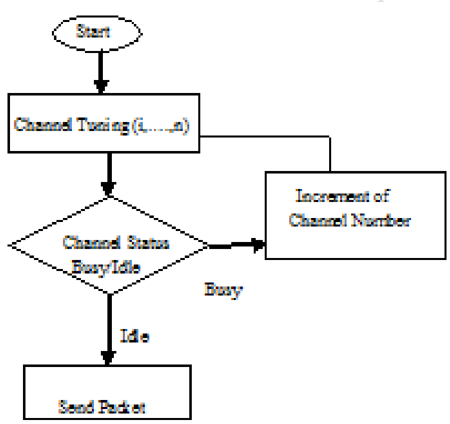

Fig. 1 Flow Chart of Simple Sequential CR MAC.

At the starting, tuning to the channel is done and then the decision on the status of that channel (Busy/Idle) is taken by the detection of the presence of primary user or not in that channel .If it is not a primary user then in that channel secondary users can send packets otherwise index value of the tuned channel is incremented and the new channel is tuned again to detect the presence of primary user and the steps will be going on.

This MAC protocol can serve the following purposes in [2]:-

- Primary Focus is always on DSA (Dynamic spectrum access).
- Both primary and secondary users have Same MAC.
- A vivid distinction of Primary and Secondary users should have existed.
- One assigned channel should remain for Primary user.
- Searching of the available channels should be done by only Secondary user during run time.
- Every node should know the number of total channels.
- In MAC layer channels should be visible as numbers and not as a range of frequencies and Physical layer should handle that.
- Primary user detection is done on reception of the packet from primary user.
- After detection of primary user, the channel is vacated by secondary user and they tune to next channel, after last channel, it should jump to first channel.
- On reception of packet from the secondary user, Primary user ignores the secondary user by just dropping the packet.

B. *Decentralized Cooperative Sensing CR MAC*

This section describes the development of a decentralized cooperative sensing CR MAC for Cognitive Radio networks which can be depicted through the following two flow charts [3].

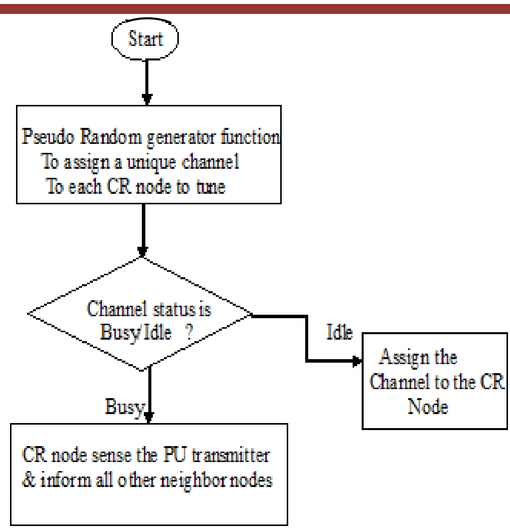

Fig. 2 Flow Chart of Decentralized Cooperative Sensing Algorithm.

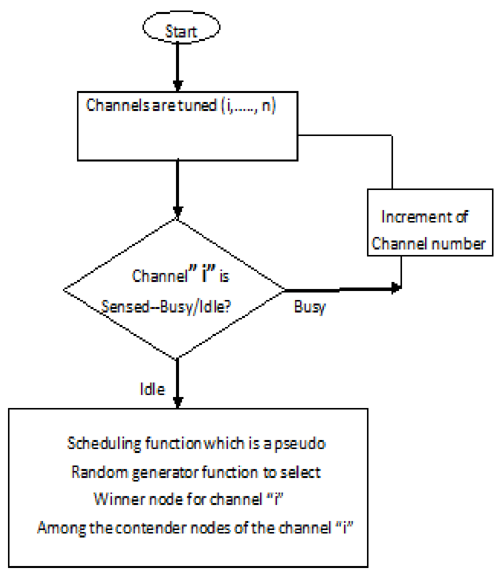

Fig. 3 Flow Chart of Pseudo Random Selector in Decentralized Scheduling Algorithm.

In the decentralized cooperative sensing strategy, a pseudo random generator function assigns a unique channel to each CR nodes which randomly chooses one channel out of the **N** number of primary network channels and checks whether the channel status is busy or idle. If the channel is busy, primary transmitter location is sensed by secondary nodes equipped with antenna array [14], [15] and using DoA (Direction of Arrival) technique and RSSI (Received Signal Strength Indication) [18] for the determination of the primary transmitter location. This approach needs no cooperation between CR network and primary network. In addition, CR nodes inform all other nodes of a cluster about the current status of the sensed channel within a time slot.

As some nodes might not be eligible to transmit through some channels, a need for identification of the contenders for specified channel arises to make decision on the winner for a specified time-slot.

If the channel is idle then the pseudo random generator function which is acted as a scheduling function select a winner node for the channel among the contender nodes of that channel to send the packet through the channel [3].

III. Performance Evaluation

After analysis of the output (end-to-end delay/time elapsed) using Monte Carlo Simulation the time slotted MAC protocols for Cognitive Radio Networks, mainly Simple Sequential CR MAC protocol, Decentralized Cooperative Sensing CR MAC protocols' results have discussed below.

To maintain a common framework for comparative analysis on the performance of the two protocols, the assumptions like, common infrastructure setup (Same number of nodes, channels, packets are taken for the protocols), same sensing protocol (CSMA-Carrier Sense Multiple Access) [17], constant channel sensing time, same source and target node of delivery for both the protocols are maintained here.

During the comparative analysis among the above protocols we come across following scenarios:-

1) *Real life scenario:* With random generation of primary user activity using Monte Carlo simulation.

2) *Worst scenario:* All channels are occupied by primary user.

TABLE-I

TABLE REPRESENTING RESULT OF REAL LIFE SCENARIO

Constant Channel Sensing Time (For CSMA)=10 milisecond (ms)										
Name of Algorithms	Inputs			Outputs (End-to-End Delay/Time Elapsed) From Experiment Results					Averages	
	No. of Nodes	No. of Channels	No. of Packets	Exp No.-1 (ms)	Exp No.-2 (ms)	Exp No.-3 (ms)	Exp No.-4 (ms)	Exp No.-5 (ms)	Average of the experiments for each packet (ms)	Final Average (ms)
Simple Sequential CR MAC	4	8	1	117	118	118	118	118	117.8	**280.3**
			2	278	279	279	278	294	281.6	
			3	438	439	439	438	454	441.6	
Decentralized Cooperative Sensing CR MAC	4	8	1	93	91	91	91	91	91.4	**214.7**
			2	224	211	211	211	211	213.6	
			3	345	333	332	355	331	339.2	

For comparative analysis we have taken five experimental results of two protocols on common framework and final analysis has been done on the average result (end-to-end delay/time elapsed) of those experiments.

In this table we consider channel sensing time by CSMA protocol is 10 milisecond which is constant. We take same number of nodes (4), channels (8) and packets (3) as input for the protocol. As output we have taken five experimental results of the protocols in consideration. For comparative analysis of the result we have taken the average of the five experimental results.

As output of the experimental results we got simulation graphs for each of the protocols. Here after the table representation of the experimental results we provide the simulation graphs for each of the protocols.

At first, simulation graphs of Simple Sequential CR MAC and then simulation graphs of Decentralized Cooperative Sensing CR MAC regarding their end-to-end delay have given here which depict the real life scenario.

Here all three packets are delivered from its source to destination successfully with very less PUs interruption.

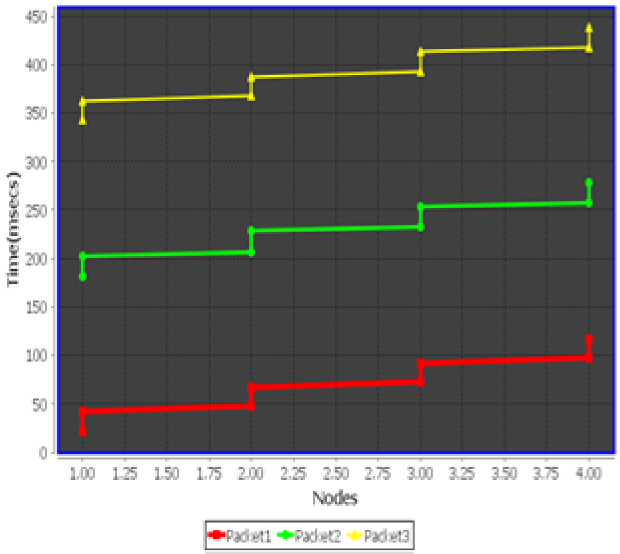

Fig 4 Simulation graph of Simple Sequential CR MAC of experiment-1

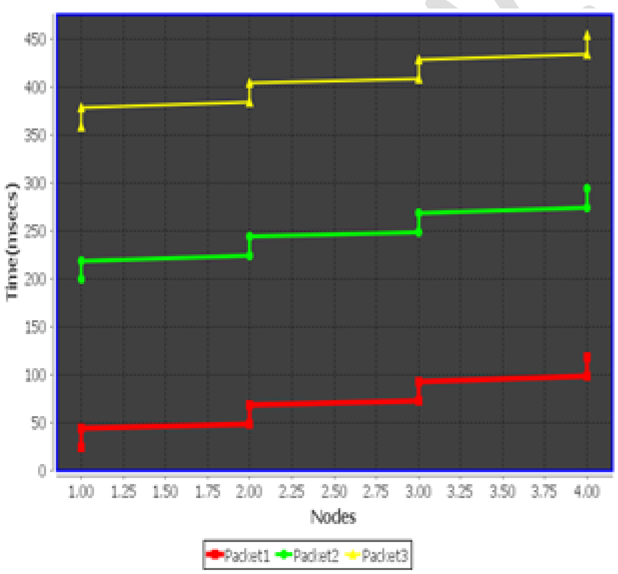

Fig. 5 Simulation graph of Simple Sequential CR MAC of experiment-5

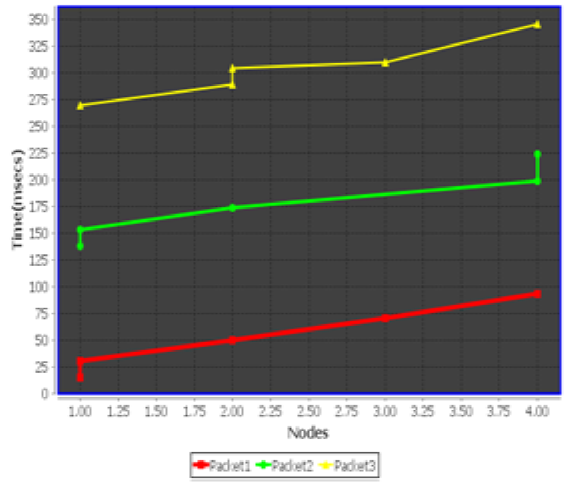

Fig. 6 Simulation graph of Decentralized Cooperative Sensing CR MAC of experiment-1

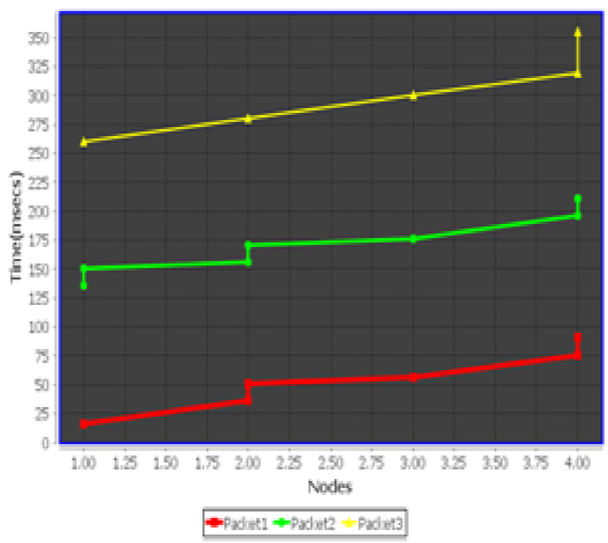

Fig. 7 Simulation graph of Decentralized Cooperative Sensing CR MAC of experiment-4

TABLE-II

TABLE REPRESENTING RESULT OF WORST SCENARIO

Constant Channel Sensing Time (For CSMA)=10 milisecond (ms)								
Name of Algorithms	Inputs			Outputs (End-to-End delay/Time Elapsed) From Experiment Results				
	No. of Nodes	No. of Channels	No. of Packets	Exp No.-1 (ms)	Exp No.-2 (ms)	Exp No.-3 (ms)	Exp No.-4 (ms)	Exp No.-5 (ms)
Simple Sequential CR MAC	4	8	1	93	73	72	71	102
			2	183	--	--	--	--
			3	--	--	--	--	--
Number of interruptions				**19**	**22**	**21**	**20**	**19**
Decentralized Cooperative Sensing CR MAC	4	8	1	15	65	81	30	15
			2	--	--	--	--	--
			3	--	--	--	--	--
Number of interruptions				**22**	**21**	**20**	**23**	**21**

Here, we provide the result of **Table-2** which we come across in worst condition when most of the channels are occupied by primary users.

In this table we consider channel sensing time by CSMA protocol is 10 milisecond which is constant. We take same number of nodes (4), channels (8) and packets (3) as input for the protocol. As output we have taken five experimental results of the protocols in consideration.

We can see in the table that some packets in all five experimental results do not transmit at all (we show it by **"--"** in the table).This is due to the occurrence of primary user in the channels which we represent as "Number of interruptions" in the table. Here comparative analysis will not be suitable as the number of interruptions is quite high and some packets don't have proper transmission over the channel. The given simulation results regarding their end-to-end delay just depict the result of the above table.

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In the graph of Simple Sequential CR MAC only two packets out of total three packets are managed to transmit through the channels due to interruptions of PUs in the channels. In which packet-2 can avail the channel at 175 ms due to interruptions of PUs in the channel.

In the graph of Decentralized Cooperative Sensing CR MAC, packet-1 tries to start its transmission at 15 ms but due to PUs interruption it can't get the channel free further to reach to its destination. Other two packets can't manage to transmit through the channels.

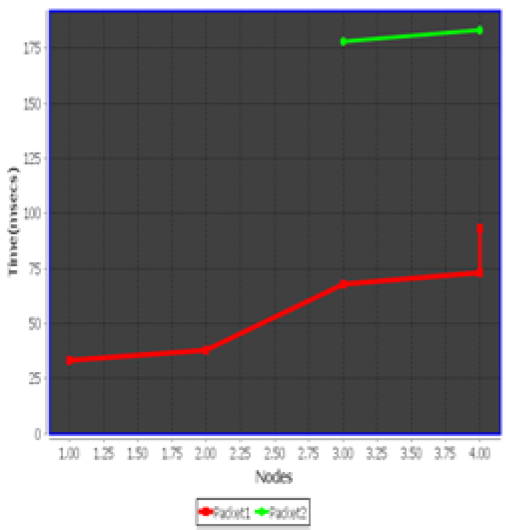

Fig. 8 Simulation graph of Simple Sequential CR MAC of experiment-1

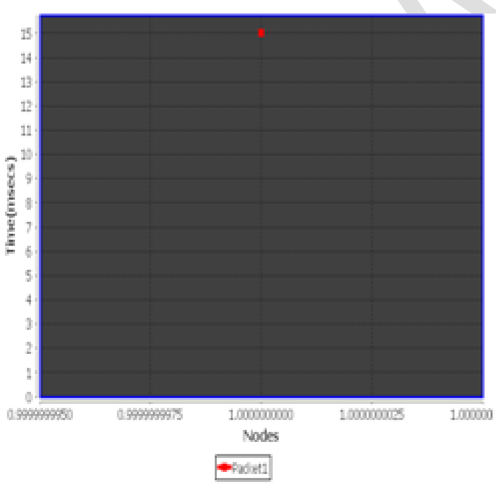

Fig. 9 Simulation graph of Decentralized Cooperative Sensing CR MAC of experiment-1

IV. 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 as well as unlicensed band with the unlicensed users, the entire spectrum can be fully utilized.

The experimental results show that the protocols are behaving as expected.

Simple Sequential CR MAC protocol for CRN doesn't provide good result in terms of efficiency than that of other one and the reason is that here efficiency is compromised for simplicity.

Decentralized Cooperative Sensing CR MAC protocol provides an efficient result as solution is provided for the cooperative channel sensing problem in a decentralized fashion without message passing among cognitive nodes. In this scheme a pseudo random number sequence generator with a same seed in all cognitive radio nodes is used which aware all other CR nodes of the cooperative sensing plan for current time-slot without any negotiation with primary networks. In addition, by this protocol Pseudo Random Selector as a scheduling function provides an efficient solution to the problem of selection of the winner node among the contender nodes of a specific channel for a specific time slot by using decentralized scheduling scheme.

By observing the output of above three protocols it can be said that in worst condition, unlike real life scenario, all packets are not delivered properly as they are unable to get the occupancy of the channel due to the privileged primary users occupied the channels.

Above all in this paper starting from the Simple Sequential MAC protocol and going through the Decentralized Cooperative Sensing CR MAC protocol end-to-end delay in CRN is decreased and performance of CRN is improved.

V. FUTURE SCOPE

From the experimental results now we can concentrate on the efficient time slotted CRAHN protocol namely, Decentralized Cooperative Sensing CR MAC protocol. In the next level of our research we may vary the common framework parameters used here to investigate the efficiency of this time slotted CRAHN protocol in varying situations. Key challenges are implementation of a common control channel for sharing sensing information. Optimization of the time for sensing and transmission also requires further investigation for network performance improvement. Above all a new improved protocol implementation may be proposed by optimizing the effects of study of existing time slotted MAC protocols in Cognitive Radio Network.

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