Opportunistic Cognitive MAC (OC-MAC) Protocol for Dynamic Spectrum Access in WLAN Environment

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Abstract

In the last decades, mobile communication services have progressed very rapidly, which demands wider spectrum band. Studies by Federal Communications Commission (FCC) show that much of fixed assigned spectra are not used efficiently. Such kind of spectrum scarcity can be overcome by a use of the cognitive radio (CR). It has the capability that allows the Secondary Users (SUs) to use the wireless licensed spectrum when it is not used by the Primary Users (PUs). In this paper, an Opportunistic Cognitive Medium Access Control (OC-MAC) protocol is proposed that helps the CR to use the spectrum efficiently whenever it is vacant. The proposed OC-MAC protocol increases the spectrum efficiency. Moreover, it also removes the traditional hidden terminal problem commonly faced by the CR. Interference between the PUs and SUs is removed by the use of Request to Send (RTS) and Clear to Send (CTS) packets.

Keywords: *Cognitive Radio, Radio Spectrum Management, Spectrum Analysis, Medium Access Control.*

1. Introduction

There is a rapid improvement in the field of telecommunications resulting in the scarcity of available spectrum. According to the studies carried out by Federal Communications Commission (FCC), the main cause of the spectrum scarcity is the poor utilization of the spectrum. Much worse is that, 90 percent of the time, certain portion of the spectrum remains unoccupied. [1] One way to improve the poor utilization is cognitive radio (CR) [4,7] technology. CR aims to improve spectrum utilization in which primary (licensed) and secondary (un-licensed) users co-exist simultaneously. The owner of the channel is referred as Primary User (PU) and all other users are termed as Secondary Users (SUs) [5]. SUs are allowed to opportunistically access the spectrum not used by primary users (PUs). SUs leave the occupied spectrum when PU requires it. SU get some other vacant spectrum which is not occupied by PU. Following this procedure allows both PUs and SUs to communicate seamlessly and simultaneously. Moreover CR has many smart features like quickly sensing the presence of PUs and utilizing unused bands efficiently [6].

In this paper, we consider a Wireless Local Area Network (WLAN) environment consisting of both primary users (PUs) and secondary users (SUs). Cognitive radio users or SUs need an Opportunistic Cognitive Medium Access Control (OC-MAC) protocol to borrow data channels when they are not used by PUs.

We have proposed a cross layer designed OC-MAC protocol which integrates spectrum sensing at physical layer and packet scheduling at MAC layer. The proposed MAC protocol gives information about available data channels to SUs. Based on this information OC-MAC protocol is able to remove the conventional hidden terminal problem and improves the overall utilization of available data channels.

2. Survey of Related Works

The MAC protocols such as frequency hopping of Bluetooth and channel allocation of cellular network does not consider the PUs while it is necessary for CR. These protocols can cause serious damage to PUs [1]. A CR node should take into account primary users, the interference between primary and secondary users, data channel selection and collision avoidance. Hence a new MAC protocol is required for realizing the concept of Cognitive Radio. The cognitive borrowing algorithm in [2] raises the utilization of channel with only rare damage to PUs. Meanwhile the drawback of this algorithm is that it uses only one data channel which can get saturated in the case of congestion. Each of the SU in [3] uses two transceivers. One of the transceiver is tuned to the dedicated control channel while the other keeps sensing available data channels and dynamically uses them.

3. Problem Statement and Main Contribution

When the PU or a SU is using the data channel, due to shadowing or fading effects, it might not be familiar to other SUs that a specific data channel is under use. A SU might claim that inuse channel resulting into collision with the SU or PU using that channel. This will result in hidden terminal problem and will cause the inefficiency in spectrum utilization.

Our research question is how the MAC protocol can cope with the issue of data channel selection and hidden terminal problem, and help to improve data channel utilization.

We hypothesized that an OC-MAC protocol can solve the hidden terminal problem and improve channel utilization with the help of handshaking mechanism at control channel. By using this technique, appropriate data channels can be selected for both PUs and SUs. The collision rate between SUs and PUs is maintained below threshold level which is assumed to be provided by the primary network.

The main contribution of this paper is to design and simulate OC-MAC protocol which improves spectrum utilization while keeping acceptable level of collisions. The solution is validated using simulation results from OPNET version 14.5.

4. Problem Solution

4.1 Method Modeling

The OC-MAC protocol implies a cross layer design and uses *N* data channels and *M* control channels. The PUs have the higher priority to use the spectrum and on the dedicated control channel, only the CR nodes compete for the reservation of the data channel. Each CR device has basic knowledge about the channels, such as data rate and tolerable damage percentage. The cognitive nodes sense for the availability of data channel and keep updating their channel state table in a regular way. The content of channel state table consists of:

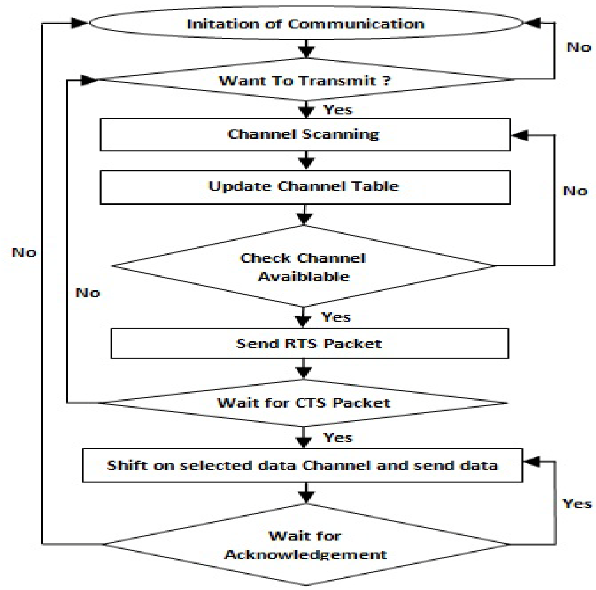


Fig. 1. Flow Chart of OC-MAC Protocol

- *avail_timer(x)* which gives information, how much time the data channel is available for [1].
- *utilize(x)* which categorizes channels depending on the previous utilization. The channel with the lowest utilization is given the higher priority.

Handshaking is done on the control channel for the reservation of data channel. The sender sends the Request to Send (RTS) packet to the receiver containing the information about the set of available channels and possible transmission duration. Receiver compares the RTS packet's content with its available set of data channels. After this it responds with Clear to Send (CTS) packet to transmitter. CTS packet contains the information about maximum transmission duration and the available data channels, that are free to use on both transmitter and receiver end. The CTS packet is also sent to all neighbours. In [1] the CTS packet is sent to the transmitter first and then transmitter broadcasts it to all the neighbours but here the receiver sends the CTS packet to transmitter as well as to all the neighbours simultaneously. This reduces the delay in communication. From the received CTS packet, the neighbors get informed that specific data

channel is used by the pair of cognitive user and other users should not claim for that. In this way hidden terminal problem is resolved. The data channel that is available on both transmitter and receiver side is selected for data transmission. After sending the CTS packet, CR node switches from control channel to data channel and then starts transmission. Receiver will send acknowledgements to sender after receiving the data successfully [1].
The flow chart describing the whole process for the data channel reservation is shown in Fig. 1. When the available time for the connection is gone and the node still has the data to transmit, it again scans to reserve the data channel [1].

4.2 Implementation and Validation

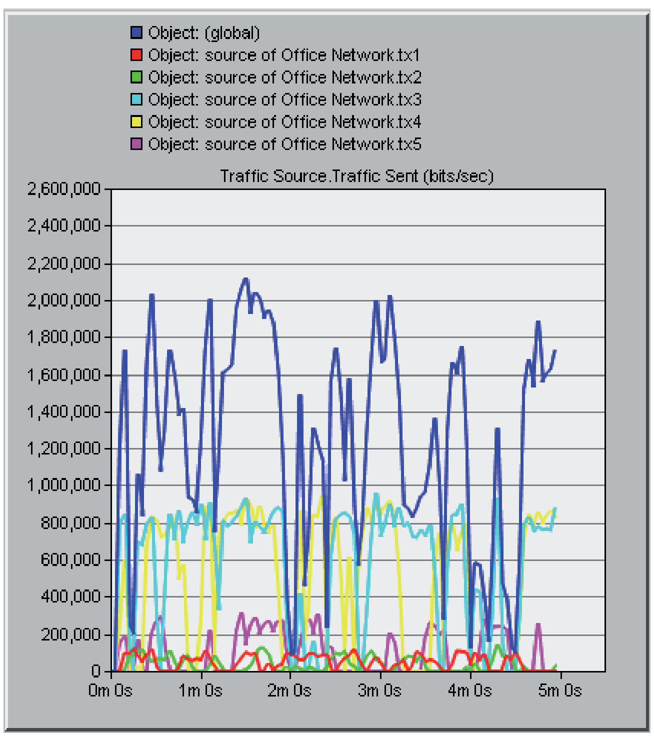
All simulations are done in OPNET version 14.5. IEEE 802.11b is used as a primary network. In the project we consider 5 pairs of primary nodes communicating with each other while 2 pairs of CR nodes utilizing the spectrum opportunistically during communication. The project scenario size is an office (100x100) meters. PUs are operating at the data rate of 11 Mbps by using the modulation scheme of Differential Phase Shift Keying (DPSK). The tolerable collision rate is assumed to be 1% provided by the primary network. [8]

5. Performance Evaluations

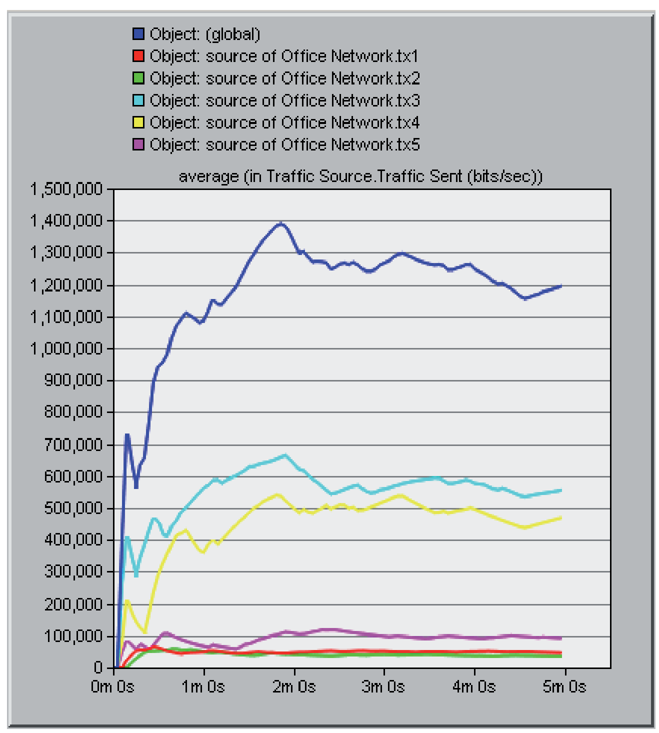
This section gives a detailed analysis of simulation and results for different scenarios to evaluate the performance. The performance of OC-MAC is evaluated with respect to average data sent over the network and number of collisions. Simulation duration is five minutes and results are collected for three different scenarios. In the first scenario, the performance of network is observed when only primary users are allowed to use the network. In second case, secondary users are permitted to use the network and in third scenario, both primary and secondary users are allowed to use the network simultaneously.

5.1 First Scenario

In the first scenario, network is analyzed with random seeds of 128. Figure 2(a) and Figure 2(b) show the performance of network when only primary users are using the network. The peak traffic sent over the network is 2.1 Mbps approximately as sown in Figure 2(a) and Figure 2(b) shows the average traffic sent by 5 PU nodes. Here again, the blue curve represents the total average traffic sent over the network which is about 0.898 Mbps and the rest 5 curves represent individual average traffic of PU nodes.

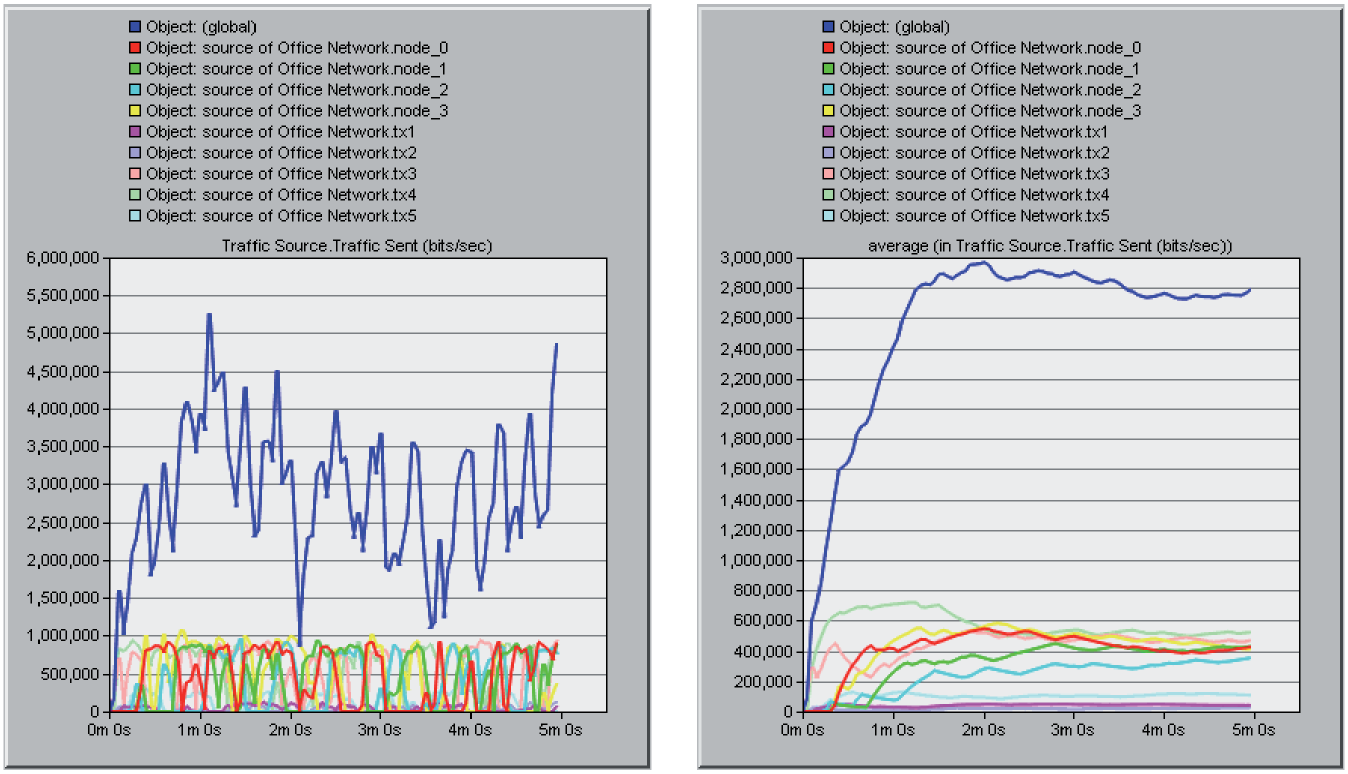


a). Total Instantaneous Traffic (PU)



b). Total Average Traffic (PU)

Fig. 2. Total Instantaneous and Average Traffic by PUs only



a). Total Instantaneous Traffic (PU+SU)

b). Total Average Traffic (PU+SU)

Fig. 3. Total Instantaneous and Average Traffic by both PUs and SUs

The main objective of CR technology is to increase the utilization of the available spectrum in such a way that it will not affect the primary usage above an acceptable level. Now to evaluate the performance of the network with CR concepts, SUs are allowed to access the spectrum opportunistically by avoiding collision using the OC-MAC protocol. Figure 3(a) and Figure 3(b) shows the performance of the network with both PUs and SUs. Figure 3(a) shows the instantaneous traffic sent by 5 PU nodes and 4 SU nodes. The blue line is the total instantaneous traffic sent by all PU nodes over the network and the rest of the 9 curves represent individual traffic sent

Table 1: Collision Count on CR Nodes

Static	Average Collision (Packet)	Maximum Collision (Packets)	Minimum Collision (Packets)
0	2.0478	3	1
1	6.7942	10	1
2	2.9083	3	1
3	1	1	1

The total peak traffic sent over the network with both SU and PU nodes using the same spectrum is now about 5.2

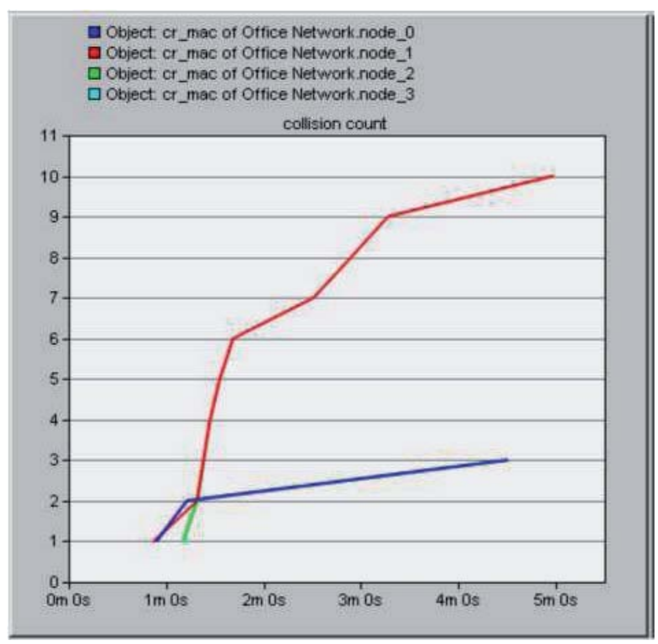


Fig. 4. Collision Count of CR Nodes

IJCSI International Journal of Computer Science Issues, Vol. 10, Issue 6, No 1, November 2013
ISSN (Print): 1694-0814 | ISSN (Online): 1694-0784
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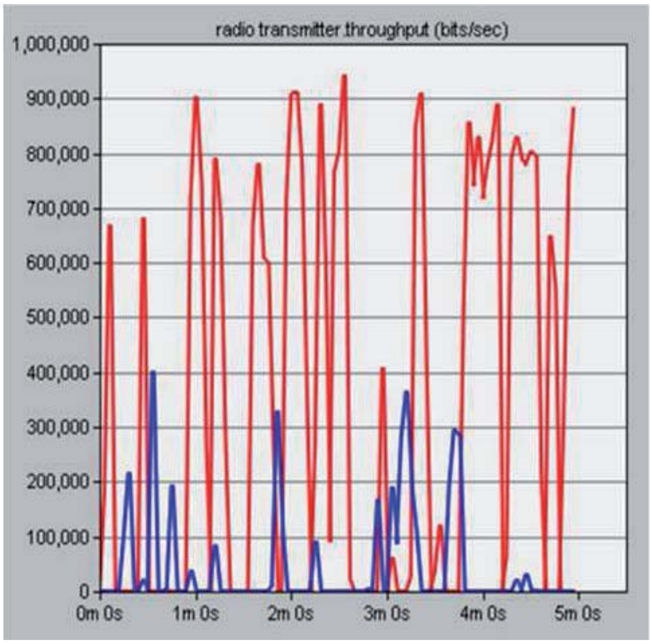
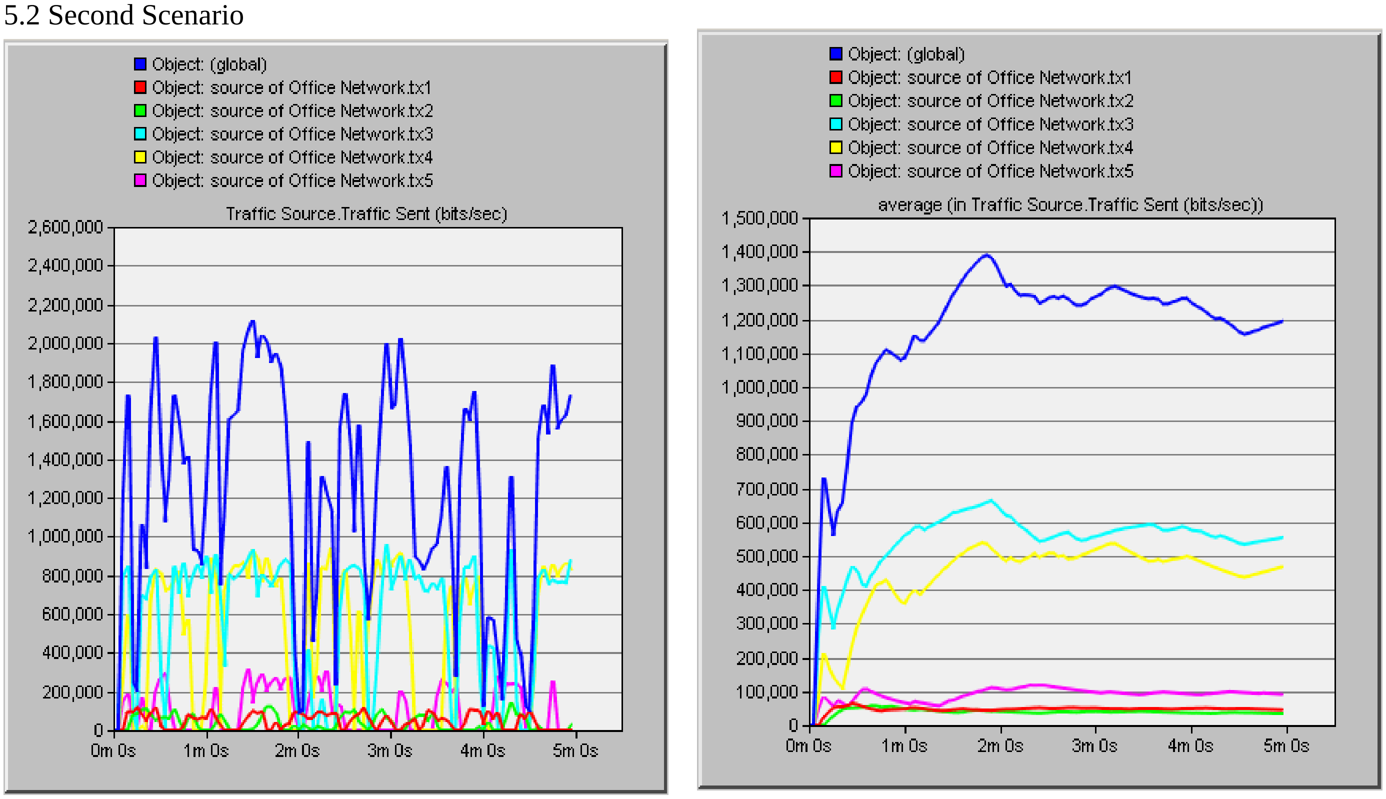


Fig. 5. Spectrum Hole Utilization (PU+SU)

Mbps approximately as compare to 2.1Mbps with only PU nodes as shown in Figure 2(a) and Figure 3(a) respectively.

5.2 Second Scenario



a). Total Instantaneous Traffic (PU)

b). Total Average Traffic (PU)

Fig. 7. Total Instantaneous and Average Traffic by PUs only

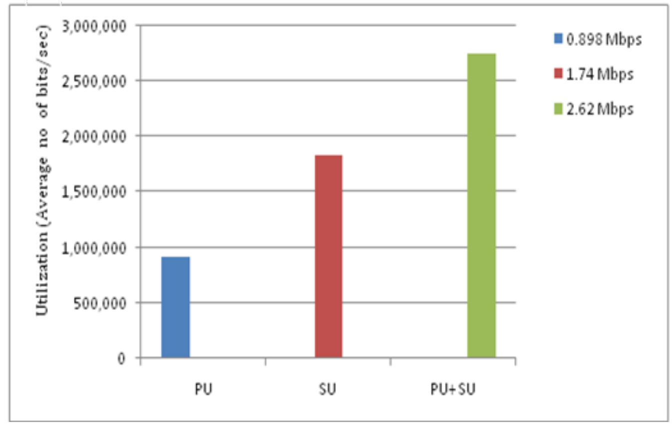
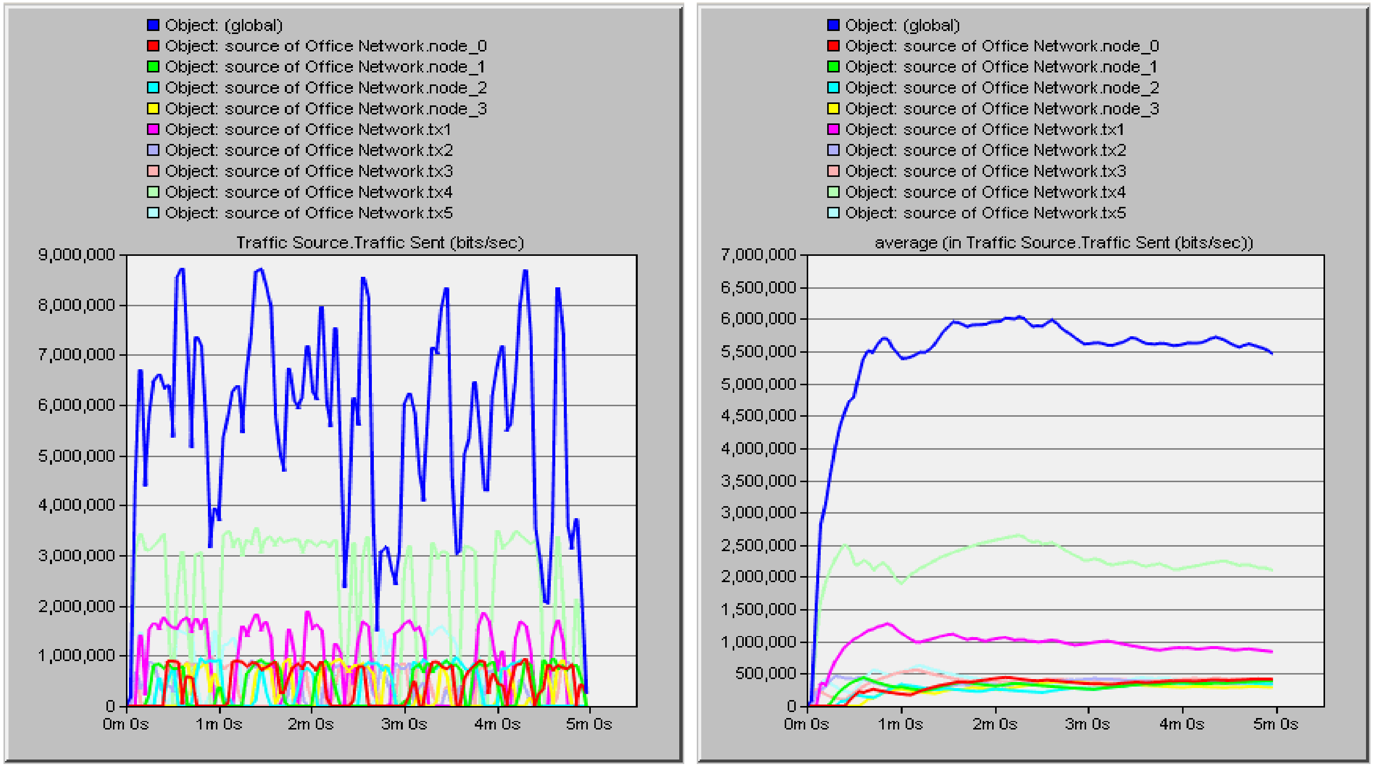


Fig. 6. Improved Utilization

Figure 3(b) shows the average traffic sent by 5 PU nodes and 4 SU nodes. Here again, the blue curve represents the total average traffic sent over the network and the rest 9 curves represent individual average traffic of PU nodes. The average traffic now increases to 2.62 Mbps from 1.2 Mbps.

The collision rate is less than tolerable damage of 1% which is supposed to be provided by the primary network. The collision count of each CR node is given in Table 1.



a). Total Instantaneous Traffic (PU+SU)

b). Total Average Traffic (PU+SU)

Fig. 8. Total Instantaneous and Average Traffic by both PUs and SUs

To validate our model we have compared our work with this of Hung et al [2]. As they do not involve channel selection mechanism, there is only one data channel and one control channel for MAC protocol. In one data channel situation, there is no choice but try to transmit over the same channel. But in multi-data channels cases, our MAC protocol can select other low-utilized channels for transmission. Therefore the collision probability can be reduced by using more than one data channels. The MAC protocol detects spectrum holes and utilizes them for secondary usage. An example of spectrum hole utilization is shown in Figure 5. In Figure 5, the red curve represents traffic sent by the PU node and the blue curve represents traffic sent by the CR node over the same channel. The CR node utilizes the portion of the spectrum not used by PU node, thus increasing the overall utilization of the available channel. When only PU nodes are using the network the overall throughput is 0.898 Mbps. When CR nodes are allowed to use the network the overall throughput increases to 2.62 Mbps from 0.898 Mbps as shown in Figure 6. Thus, the total utilization of available channels increases by introducing SUs and the collision rate is less than the specified threshold.
The designed MAC protocol also allows custom settings for each user. This means the maximum allowed traffic for each user can be set individually. To check the reliability of OC-MAC protocol, its performance is now tested with another scenario under heavy traffic.
In this scenario traffic sending capability of all SUs is increased to the maximum possible limit and traffic of PUs is also increased and finally new simulation results are observed. The ad hoc wireless network can handle up to 11 Mbps of traffic at any instant and at above 11 Mbps traffic, packet loss occurs. Figure 7(a) shows total instantaneous traffic and Figure 7(b) shows total average traffic sent when only primary users are allowed to use the network.
Now, Figure 8(a) shows total instantaneous traffic and Figure 8(b) shows total average traffic sent when both primary and secondary users are allowed to use the network.

6. Conclusions

By using OC-MAC protocol, spectrum efficiency is improved a lot. Traditional hidden terminal problem is removed by handshaking at the control channel. Furthermore by the use of RTS and CTS packets, we minimize the interference between SUs and PUs when channel is allocated for SUs usage and vice versa.

We analyzed that there is one control channel that can get saturated in condition whenever there is an increased demand for the reservation of data channels. Hence, we propose an efficient Cognitive Radio-Enabled Multi-Channel MAC Protocol for future research.

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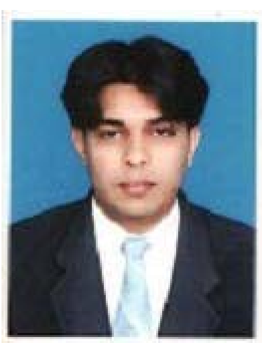

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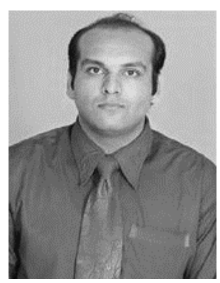

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