CUCB-MAC: Channel Usage and Collision Based Medium Access Control Protocol for Cognitive Radio Networks

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ABSTRACT

Cognitive Radio Networks (CRNs) allow their unlicensed users named Secondary Users (SUs) to share and access licensed wireless spectrum band without any kind of interference with its original users named Primary Users (PUs); and under condition that the PUs' Quality of Service (QoS) won't degrade. Due to the large number of SUs and as all of them will have the right to access the available spectrum band; a spectrum sharing protocol must be added in order to divide the available spectrum band fairly among these SUs. Spectrum sharing is similar to Medium Access Control protocol MAC in the current systems. This paper proposes a scheduling protocol named Channel Usage and Collision Based MAC protocol (CUCB-MAC); this protocol is a slotted one that depends on 1) counting the number of collisions for each SU, 2) predicting the ideality of the entire available channels then 3) excluding some of the available channels at each time slot before allocating channels to SUs. It has been proved that the performance of the proposed CUCB-MAC protocol overcome the performance of the Collision Based MAC protocol (CB-MAC).

KEYWORDS


1 INTRODUCTION

Cognitive Radio Networks (CRNs) build a policy to be allowed to share and access licensed wireless spectrum band with its original users named Primary Users (PUs), without any kind of interference with them and with the guarantee that their QoS won't degraded. This is done based on the intelligence of cognitive radio that consider both the limited available spectrum and the unutilized wireless spectrum band [1,4]. In other words, CRNs don't have a specific licensed wireless spectrum band to operate on, but it shares and access other licensed wireless spectrum bands in a dynamic manner without any interference with its PUs. The CRNs users; named Secondary Users (SUs); access the licensed spectrum band opportunistically by detecting if PUs are transmitting or not.

With the large number of SUs and as all of them have the right to access this available spectrum band, a spectrum sharing technique is responsible for coordinating spectrum access by the SUs. This is done by providing a scheduling technique to be able to divide the available spectrum band among the SUs. Spectrum sharing is similar to MAC protocols in the current systems, but with different challenges in the CRNs due to the dynamic nature of the spectrum and the existence of two different sets of users (PUs, SUs). Many spectrum sharing techniques were proposed in [5-13].

It has been noticed that even with the most perfect spectrum sharing techniques, collision between PUs and SUs won't be avoidable. Due to the frequent collision occurrence, collision statistics - counted by the average number of collisions- must be taken into consideration in the scheduling technique. A spectrum sharing technique using this concept is used to make a fair scheduling schema in [11].

This paper proposes a time slotted scheduling protocol that depends on 1) counting the number of collisions for each SU, 2) predicting the ideality of the entire available channels then 3) excluding some of the available channels based on the probability of channel usage by each SU’s nearby PUs at each time slot, before allocating channels...
to SUs. By this exclusion; it is expected to
decrease the chance of collision occurrence taking
in consideration that if a channel has a high
probability to be used by a PU, its nearby SUs are
prohibited from using this channel.

The rest of this paper is organized as follows;
related work is explained in section 2. Section 3
overviews the fair scheduling collision based
MAC protocol (CB-MAC) [11]. In section 4, the
proposed MAC protocol (CUCB-MAC) will be
explained in details. Evaluation of the proposed
protocol will be given in section 5. Finally
summarized conclusion and future works will be
illustrated in section 6.

2 RELATED WORK

MAC protocols in CRNs can be categorized into
to three main categories: random access protocols,
time slotted protocols and hybrid protocols [5-7].

Random access protocols don’t have to be
synchronized with the network. It is mainly based
on Collision Sense Multiple Access with Collision
Avoidance (CSMA/CA). Time slotted protocols
have to be widely synchronized with the network;
this is done by dividing the time into slots for both
data and control channels. Hybrid protocols are
partially time slotted such that the controlling
signals transmission appears at synchronized time
slots, while the data transmission is done at a
random access schema. But in some other
techniques the data and controlling transmission
might be done in a predefined period of time, this
done by a superframe which is known to all the
users in the network. During the control and data
duration the channel access might be random.
Many protocols occur under these categories [5-
12].

As an example for random access MAC protocols
in [5]; the primary network follows the ordinary
Collision Sense Multiple Access (CSMA). The
PUs and the SUs have different base stations. This
protocol permits the SUs’ simultaneous
transmission even when the PUs are detected but
providing a predefined interference threshold. It
allows the SUs sensing time to be greater than the
PUs sensing time, so the priority is for the PU.

Based on both the distance between the SU and its
base station and also the detected noise power, the
base station determines the SU’s transmitting
power and data rate. Any SU is only allowed to
send one packet on negotiation rounds to
minimize the PU interference.

Recent studies show that many protocols have
been developed to achieve better fairness among
all the SUs in the network. In [11]; the average
number of collisions is used to make a fair
scheduling schema; this is done by periodically
counting the number of collisions for each SU,
based on that counting; the scheduler dynamically
changes the SUs' priorities. Then a prediction
technique is used to predict the idle probability of
the available channels in the next time slot. The
fair scheduling technique is done by sorting both
the SUs list based on the their priorities and the
channel list based on their idle probabilities, then
providing the SU with the higher priority the
channel with the higher idle probability.

Using the SUs’ mobility information and the PUs’
activity profile, [12] tries to assign the most
suitable channel for each SU in each time period
by constructing a complete two column bipartite
graph; where the left column vertices corresponds
to all SUs in the network, the right column vertices
corresponds to all the used channels, and the edge
connecting between a SU and a channel is the
probability that this SU will be able to use this
channel. Optimally this complete bipartite graph
can be solved by any maximum weight matching
algorithm, such that the throughput of the network
is maximized. The previous two protocols act as
an example for time slotted MAC protocols.

Predicting channel availability is used in many
medium access control protocol, some of these
protocols estimate the channel availability for the
next time slot by taking samples of the channel
status at each period of time, then predict the next
channel status. One of the used prediction method
uses the renewal theory [13,14].

A game theoretic hybrid MAC protocol is given in
[5]; where the data transmissions is done in a time
slotted manner while the controlling signals is
done on a random access manner. This protocol
consists of four components; dynamic spectrum
access algorithm, clustering algorithm, negotiation
mechanism and collision avoidance mechanism. The dynamic spectrum access algorithm is a game theory algorithm that models the SUs’ behavior as a repeated game model with players, strategies, local utility function and decision timing for the game. The clustering algorithm divides the area into hexagonal clusters so that the virtual header carries a token that is used for the playlist update. The negotiation mechanism is responsible for the exchange of the control messages and SUs actions coordination. The collision avoidance mechanism is responsible for avoiding collision in different cluster within the time of the negotiation.

3 COLLISION BASED MAC (CB-MAC) PROTOCOL

The main idea of the CB-MAC protocol [11] is to make a fair scheduling among SUs, this is done by not allowing some SUs to meet more collision than others. To guarantee such fairness; collision statistics such as the average number of collisions must be taken into consideration. Figure 1 illustrates the CB-MAC protocol briefly. Incoming SUs packets are retained into the central spectrum scheduler buffer; so some of them will be served in the next time slots based on their priorities.

![Central Spectrum Manager Diagram](image)

**Figure 1. Fair Scheduling System Model Based On Collision Statistics**

The central spectrum manger includes three modules; the allocation procedure is done at the beginning of each time slot. First for each SU the number of collisions is calculated by the collision statistics module. Also for each of the available channels the channel state prediction module predicts their idle probability. This is done at the channel state prediction module. Based on both the collision statistics and the idle probabilities the central control module instructs the scheduler to allocate the channel with the higher idle probability to the SU that has the higher collision statistics. This protocol improved the fairness among SUs.

The waiting packets are stored in the buffer. If the packets number exceeded the buffer length some packets will be dropped.

At the rest of this section the three modules of CB-MAC protocol included in the Central Spectrum Manager will be explained.

3.1 Collision Statistics Module

In CRNs; SUs use the licensed spectrum that is mainly allocated for the PUs in an opportunistic manner without any interference with the PUs. But if a SU supposes a channel to be idle and began sending on it, and suddenly a PU appears, collision will happen. Collision can’t be avoided due to the lack of an idle spectrum sensing technique done by SUs, and also due to the random arrival of PUs. So the QoS of both PUs and SUs will degrade due to the frequent occurrences of collision.

Therefore collision statistics; must be taken into consideration in the scheduling technique. In fact it is a very important performance metric to fairly share the available spectrum among SUs by identifying their priorities. These priorities are based on counting the number of collisions for each SU. At the beginning of each time slot this module updates the number of collision of each SU based on the collision information collected by spectrum sensing module from each SU. In CB-MAC protocol the collision statistics module can be performed in two modes, the difference between the two modes is the duration among which the number of collisions for each SU is considered. In mode 1 the collision statistics module considers the number of collisions among each SU during its whole data transmission time, while in mode 2 the collision statistics module considers the number of collisions among each SU.
during a certain period of its data transmission time, not its whole transmission time. The choice between these 2 modes is done based on traffic type and user’s experience.

3.2 Channel State Prediction Module

CB-MAC protocol supposes that the characteristics of the spectrum occupation is measured and already known by the CRN. The channel state prediction module uses the primary network measurements to predict the idle probability of all the available channels. Any prediction technique can be used to calculate the idle or occupancy probability for any channel using the characteristics of the spectrum occupation of the primary network can be used.

3.3 Central Control Module

This module uses the collision information from the collision statistics module to prioritize the SUs’ packet. All the available channels will be sorted based on their idle probabilities obtained by the channel state prediction module. Then the available channels will be reallocated, where channels with higher idle probability will be given to the SU’s packet with higher number of collision. If all the available channels are busy by the SUs and the buffer is still not empty, the packets will either wait till the next time slot or it will be dropped if the buffer reaches its maximum limit. Eventually, the central control module sends the channel reallocation information to the scheduler to be able to control the packets transmission in this time slot.

Based on the CB-MAC protocol; for the SU to be able to have a better channel it has first to collide frequently with PUs, which will enhance the SUs QoS. Fairness will be fulfilled by dividing collision among SUs.

4 CHANNEL USAGE AND COLLISION BASED MAC (CUCB-MAC) PROTOCOL

The proposed CUCB-MAC protocol is based on 1) counting the number of collisions for each SU, 2) predicting the ideality of the entire available channels then 3) excluding some of the available channels based on the probability of channel usage by each SU’s nearby PUs at each time slot, before allocating channels to SUs.

Channel exclusion is done by the following; first at each time sample the scheduler records the channels that are used by each PU, then the probability of each channel usage for each PU is calculated. Each SU needs to send a packet must sense the surrounding media for any nearby PUs and sends the list of this PUs to the scheduler; which excludes the channels with high probability to be used by each of the nearby PUs. Hence the protocol is named; Channel Usage and Collision Based Medium Access Control (CUCB-MAC).

The (CUCB-MAC) protocol is depicted in Figure 2. As shown in the figure the proposed protocol involves three main parties; SUs, channels and central spectrum manger.

- **SUs**: are the users that have packets to be sent. Whenever any of them needs to send a packet, it provides the scheduler with the packet id, the number of collisions this packet encounters and also with its nearby PUs. Each SU has a buffer to store the packets waiting till the central spectrum manger sends it a channel ID to send the packet on.

- **Channels**: are the frequencies used to send the SUs’ data packets. At each sample time; the central spectrum manger provides the scheduler with each channel status either idle or busy, and if busy which user is using it either PU or SU.

- **Central Spectrum Manger**: It contains both the packets requests buffer and the scheduler. The buffer is used as storage for the collected information of both SUs and the channels. The scheduler uses the information stored in the buffer to assign the appropriate available channels for the SUs’ packets.

The CUCB-MAC protocol can be divided into two main phases.
4.1 Phase 1: Performed at Secondary Users

Whenever any SU has a data packet to send, it performs the following tasks:

a. First, it buffers the packet till the central spectrum manager allocates a channel for it at the beginning of a time slot.

b. Second, it senses the surrounding area for any nearby PU. This is done periodically whenever the SU has a packet to send; as the PUs and SUs are in a periodic motion.

c. After that, it collects its number of collisions this packet encounters to be used as a priority measure.

d. Finally, using the parameters from all the previous three tasks, the SU sends a request for the central spectrum manager including the packet id, list of the nearby PUs and the number of collisions the packet encounters. At the start of the next slot; the central spectrum manager tries to allocate an appropriate channel for this packet. As the central spectrum manager may not have enough channels for all of the waiting packets, the SU will wait till the central spectrum manager allocates a channel for its packet at the beginning of a time slot (doesn’t have to be the next time slot), but if the waiting time exceeds a certain threshold; the packet will be dropped.

The requests sent by SUs with waiting packets to be sent are stored in the central spectrum manager.

4.2 Phase 2: Performed At Central Spectrum Manger

The central spectrum manager performs essential tasks that can be considered the fundamental tasks of the CUCB-MAC protocol. Some of these tasks
are performed either at the beginning of the sample time or at the beginning of the slot time.

a. The central spectrum manager estimates the probability of all channels’ availability at each time slot based on the channel status at each sample.

b. The central spectrum manager sorts the SUs’ packets based on their collision statistics (number of collisions) sent by the SUs.

c. The central spectrum manager calculates the probability of channel usage by each PU based on the channels statuses recorded at each time sample, and the nearby PUs lists sent by SUs with packet request.

d. Finally, using the parameters from all the previous three tasks, the central spectrum manager assign the appropriate channels for the SUs with a packet to send.

These tasks will be explained in details in the next subsections.

### 4.2.1 Estimation of Channels Availability

Many techniques exist to predict the channel availability using the past channel observation; any one of these techniques can be used in this step. In this paper the renewal theory process is used [13,14].

Any channel i can be in one of two statuses either ON or OFF, the ON duration is represented by a random variable $Y^i_t$ while the duration of the OFF period is represented by a random variable $X^i_t$. So the probability distribution function (pdf) of the ON duration can be $f_{T_{ON}}(Y^i_t)$, and $f_{T_{OFF}}(X^i_t)$ can be the pdf of the OFF duration. Note that the ON and OFF durations are supposed to be independent and identically distribute (iid) random variables. The arrival of each PU is independent, each of these transition obey Poisson arrival process.

\[
\begin{align*}
    f_{Y_t} &= \lambda_Y e^{-\lambda_Y t} \\
    f_{X_t} &= \lambda_X e^{-\lambda_X t}
\end{align*}
\]  

(1)

where $\lambda > 0$ is the parameter of the distribution

The utilization or the load of channel $i$ is calculated as follows:

\[
\mu^i_t = \frac{\lambda_Y^i}{\lambda_Y^i + \lambda_X^i} = \frac{E[T_{ON}^i]}{E[T_{ON}^i] + E[T_{OFF}^i]}
\]  

(2)

where $E[T_{ON}^i]$ and $E[T_{OFF}^i]$ are the mean of the distribution.

$E[T_{ON}^i] = 1/\lambda_Y^i$ and $E[T_{OFF}^i] = 1/\lambda_X^i$

The renewal process is used to calculate $\mu^i_t$ and $\lambda_X^i$ as follows:

Assume having a vector of $r^i$ samples results from the sensing process of channel $i$ for $T^i_p$ duration:

\[
Z^i = \{Z^i_{t1}, Z^i_{t2}, Z^i_{t2}, \ldots, Z^i_{t_k}\}
\]

(3)

where $Z^i_{tj}$ is the status of the link at time $t_j$ ($j = 1, 2, 3, \ldots, r^i$), note that status of a link is either ON (1) or OFF (0)

Four types of transition probability based on ON (1) or OFF (0); $0 \rightarrow 0, 0 \rightarrow 1, 1 \rightarrow 0, 1 \rightarrow 1$. Using the joint probability mass function, the probability of the four transitions can be calculated as follows:

\[
\begin{align*}
    P_{00}^i(t) &= (1 - \mu^i_t) + \mu^i_t e^{-(\lambda_Y^i + \lambda_X^i)t} \\
    P_{01}^i(t) &= \mu^i_t - \mu^i_t e^{-(\lambda_Y^i + \lambda_X^i)t} \\
    P_{10}^i(t) &= \mu^i_t + (1 - \mu^i_t) e^{-(\lambda_Y^i + \lambda_X^i)t} \\
    P_{11}^i(t) &= (1 - \mu^i_t) + (1 - \mu^i_t) e^{-(\lambda_Y^i + \lambda_X^i)t}
\end{align*}
\]  

(4)

The Maximum Likelihood (ML) estimator $\hat{\mu}_t^i$ and $\hat{\lambda}_X^i$ can be calculated as follows:

\[
\hat{\mu}_t^i = \frac{1}{r^i} \sum_{k=1}^{r^i} Z^i_{t_k}
\]

(5)

\[
\hat{\lambda}_X^i = -\hat{\mu}_t^i \ln \left[ \frac{2A}{-B + \sqrt{B^2 - 4AC}} \right]
\]

(6)

where $A = (\mu^i_t - (\mu^i_t)^2) (i - 1)$

$B = -2A + (i^2 - 1) - (1 - \mu^i_t) n_0 - \mu^i n_3$

$C = A - \mu^i n_0 - (1 - \mu^i) n_3$

$n_0, n_3$ denotes the numbers of occurrences of the $0 \rightarrow 0, 1 \rightarrow 1$ transition respectively
• At each time sample:
For each channel the value of $Z$ is changed based on the channel status got from the sensing done by the central spectrum manager. Also for each channel; the values of $n_s$ are changed based on the channel status got from the sensing done by the central spectrum manager, and on the channel’s previous status.

• At each time slot:
For each channel the central spectrum manger uses the variables calculated at the time samples to calculate the possible probabilities $P_{60}$ or $P_{10}$ (equation 4) using $\lambda_{34}$ and $\lambda_{34}$ calculated using equations 5, 6 and 2 respectively.

### 4.2.2 Calculation of Probability of Channels Usage for Primary Users

The central spectrum manager has a stack of a specific predefined length for each channel to identify the previous channel primary users for a certain period of time. In this step the same sample observation done for each channel in the previous subsection is used. But in addition the central spectrum manger while checking each channel status, also identify the user that is occupying the channel whether it is a PU or a SU, and also the user_id. Then the central spectrum manger updates each channel user stack by the current observation as follows:

$$S_i(\text{Primary User using Channel } i) = \begin{cases} \text{PU}_i & \text{if a PU is used Channel } i \\ \text{0} & \text{Otherwise} \end{cases} \quad (7)$$

Then; at each slot the probability of the channel usage is calculated for each PU as follows:

$$\text{Channel } i \text{ Usage for Primary User } j = \frac{\text{Number ofAppearances of PU}_j \text{ in stack of channel } i}{\text{Stack Length}} \quad (8)$$

### 4.2.3 Allocation of Channels for Secondary Users

The central spectrum manger uses the collected number of collisions from each SU, each SU’s nearby PU list, the estimated probability for each channel availability and the estimated probability for each channel usage for PU; to assign (or allocate) a channel for the waiting SUs. To do this, the following is performed:

• Remove the waiting packets’ requests that exceeded the allowable waiting time.
• Prioritizing the waiting SUs' packets’ requests using the number of collisions collected for each packet (collected from section 4.1).
• Based on the estimated probability of channel availability (calculated in section 4.2.1)
  - Excluding the channel with ideality probability equals to zero, so that it won’t be assigned to any SU.
  - Descendingly ordering the available channels based on the estimated probability of channel availability.
• For each packet’s request in the ordered list, the following is done:
  - Excluding the channels whose probability of its usage for the PUs in the range of the SU needing to send this packet (calculated in section 4.2.2); exceeds a certain predefined threshold. Meaning that even if the estimated probability of channel availability is high, but there exist a PU in the SU’s range with estimated usage probability of this channel higher than a certain limit, the central spectrum manger won’t assign this channel to this SU. This is due to the following; as this PU is in the range of the SU; there is a good chance that this PU will use this exact channel, and then collision will happen. This is a try to prevent collision form happening.
  - Allocating the channel with highest probability (but not form the excluded ones) to this packet’s request. Send a message by that meaning for the SU owing this packet.
  - Remove the allocated channel from the available channel list.
- Removing the packet’s request from the waiting packet list.

The previous steps are done for all the waiting packets, as long as there exist available channels. But as the waiting packets may be more than the available channels, the central spectrum manager will assign channels for the packets’ with higher number of collisions till there are no more available channels. Then the rest of the waited packets’ requests either will wait for the next slot to be served or dropped for exceeding their waiting time.

5 EVALUATION OF THE PROPOSED CUCB-MAC PROTOCOL

Using “Java” a simulation program was built to develop, evaluate, test and compare the performance measurements of the proposed CUCB-MAC protocol with the original CB-MAC protocol. The built simulation program is divided into four parts; Packets’ creation, CB-MAC protocol, CUCB-MAC protocol and the calculation of the performance metrics for both protocols.

To achieve correct results that are comparable to reality, the packet creation process are done randomly. The same created packets have to serve as an input for both protocols to be able to obtain an accurate comparison between both protocols’ performance. Because of that the packet creation process is a separated function from the two compared protocols, the output of this creation process serve as an input for the two MAC protocols. As for the packet arrival function a negative exponential distribution [15] is used for the generation of the packets random arrival time, associated with random users’ number.

The used simulation parameters are listed in Table 1 [11,16]. These parameters are changed either up or down in various scenarios. This is done to test the proposed protocol upon several constrains and then prove its efficiency.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>PU Data Rate</td>
<td>20 packets/sec</td>
</tr>
<tr>
<td>Number of PUs</td>
<td>20</td>
</tr>
<tr>
<td>SU Data Rate</td>
<td>30 packets/sec</td>
</tr>
<tr>
<td>Number of SU</td>
<td>20</td>
</tr>
<tr>
<td>Packet Transmission Time</td>
<td>70 msec</td>
</tr>
<tr>
<td>Number of Channels</td>
<td>4</td>
</tr>
<tr>
<td>Sample Time</td>
<td>5 msec</td>
</tr>
<tr>
<td>Slot Time</td>
<td>0.6 * Packet Transmission Time</td>
</tr>
<tr>
<td>Dropping Time</td>
<td>3 * Packet Transmission Time</td>
</tr>
<tr>
<td>Channel Usage Threshold for each PU</td>
<td>0.3</td>
</tr>
<tr>
<td>Simulation Time</td>
<td>10 sec</td>
</tr>
</tbody>
</table>

5.1 Performance Metrics

In this section the performance metrics used to evaluate and test the proposed CUCB-MAC protocol are illustrated. Five performance metrics are used; average throughput, average delay, average number of PUs’ packets collided, percentage of channel utilization and finally percentage of dropped packets.

5.1.1 Average Throughput

Average throughput is defined as the average rate of packets delivered successfully per one second.

\[
\text{Average Throughput} = \frac{\text{Number of packets reached their Destinations}}{\text{Simulation End Time} - \text{Simulation Start Time}}
\] (9)

It’s preferable to retain it as extreme as possible.

5.1.2 Average Delay

Average Delay is defined as the average time taken for a packet to be transferred from the source to the destination.

\[
\text{Average Delay} = \frac{\sum_{\text{packets}} (\text{Arrival Time} - \text{Sent Time})}{\text{Number of Packets}}
\] (10)

It’s preferable to retain it as minimum as possible.
5.1.3 Average Number of Primary Users’ Packets Collided

Collision occurs when a PU and a SU aim to use the same channel.

\[
\text{Average Number of Collisions} = \frac{\sum \text{Number of Collision it encounters for each PU}}{\text{Number of PU’s Packets}}
\]

(11)

It’s preferable to retain it as minimum as possible.

5.1.4 Percentage of Channel Utilization

Percentage Channel Utilization is defined as the percentage of how efficient the channels are being used. Or it can be defined as how much time the channel is being used from the beginning of the simulation till its end.

\[
\frac{\sum \text{Time the channel is used}}{\text{Simulation End Time} - \text{Simulation Start Time}} \times 100
\]

(12)

In reality the aim is to retain the percentage of channel utilization as extreme as possible, as long as the packets are transferred safely from the first attempt. But when using a simulation program; where the same random packets’ arrival act as an input for both the original and the proposed protocols, the protocol having less percentage of channel utilization is more efficient. As the protocol with lower percentage of channel utilization can send more packets than the other one. So It’s preferable to retain it as minimum as possible.

5.1.5 Percentage of Dropped Packets

Packets waiting in the SUs’ buffer for a long time without being served due to the lack of channels are useless, so dropped.

\[
\text{Percentage of Dropped Packets} = \frac{\text{Number of Dropped Packets}}{\text{Total Number of Packets}} \times 100
\]

(13)

It’s preferable to retain it as minimum as possible.

5.2 Simulation Results

Three scenarios are used to prove the efficiency of the proposed CUCB-MAC protocol compared to the original CB-MAC protocol. In each scenario one simulation parameter takes different values to be able to see the effect of this change on both MAC protocols. The first two parameters used in the first and second scenarios are; data rate and time used to drop a packet respectively. The third scenario depends on changing the values of channel usage threshold to examine its impact on the proposed CUCB-MAC protocol; of course this parameter won’t have any effect on the original CB-MAC protocol.

It is anticipated that the performance of the proposed CUCB-MAC protocol will be better than the original CB-MAC protocol, as the proposed protocol prevent the SUs from using a channel if this channel is expected to be used by any PU, this will lead to preventing more collisions i.e. 1less number of collisions for the proposed CUCB-MAC protocol. Decreasing the number of collisions will lead to decreasing the resent process for the packets involved in the collision process i.e. 2better spectrum utilization. By using the proposed protocol the packets that was going to be sent on an expected non-free channel will have to wait, these seem to be a drawback, but those packets will most probably collide with the PU that was expected to use the channel. If this collision happened the SU will have to wait and resend the collided packets again, which will lead to more delay. So by using the proposed protocol it is expected to acquire 3less delay. And based on that the proposed protocol is expected to transmit and deliver larger number of packets in smaller period of time, i.e. 4greater throughput.

Finally as mentioned before using the original CB-MAC protocol will lead to an increase in the waiting and resending of the SUs’ packets, this will lead to an increase in the waiting time, which will increase the probability of packet dropping. Consequently when using the proposed CUCB-MAC protocol it is expected to decrease the number of dropped packets i.e. 5lower number of dropped packets.
5.2.1 First Scenario: Changing Data Rate

In this scenario the effect of changing the SUs’ data rate is shown in Figures 3 to 7. The SUs’ data rate values vary from 10 packets to 50 packets per second.

It is obvious from Figure 3 that the average throughput of the proposed CUCB-MAC protocol is higher than that of the original CB-MAC protocol. As for the average delay of the proposed CUCB-MAC protocol, it is a bit lower than that of the original CB-MAC protocol as shown in Figure 4. Figure 5 shows that the average number of collided packets is lower using the proposed CUCB-MAC protocol than using the original CB-MAC protocol. The channel utilization and the average number of dropped packets were both lowered using the proposed CUCB-MAC protocol as it is clear from Figures 6 and 7.

It can be concluded that varying the data rate while using the proposed CUCB-MAC protocol enhances the results of the performance metrics than when using the original CB-MAC protocol.

It is observed that almost all the difference between the values of the performance metrics increase with the data rate increase for both protocols, this is true for all the performance metrics except for the delay. The reason for this is that when increasing the data rate it will lead to
increasing the number of packets needed to be sent i.e. there will be more packets to pass across the channels. So it is preferable to prohibit the SU from using expected non-free channels than to permit using these channels when knowing that it will most probably lead to collision.

5.2.2 Second Scenario: Changing Packet Dropping Time

Some packets may be worthless to the destination, due to the long time these packets have been waiting in their SUs’ buffer. Also some of these packets may have collided before even more than one time. So the best decision is to drop these packets instead of trying to use the spectrum to send a useless data. In this scenario the effect of changing the maximum time that any packet is allowed to wait in their SUs’ buffer -on the performance metrics on both protocols- is shown in Figures 8 to 12. The packet dropping time values varies from 1 * packet transmission time to 5 * packet transmission time.

It is clear from Figure 8 that using the proposed CUCB-MAC protocol leads to higher average throughput than when using the original CB-MAC protocol. As for the average delay (Figure 5.9) it is almost the same using both MAC protocols when the packet dropping time is equal to the packet transmission time, but as increasing the packet dropping time the difference between the results of using both protocols differs by small values. But still the CUCB-MAC protocol gives less delay than CU-MAC protocols.

![Figure 8. Average Throughput using Various Dropping Time](image)

![Figure 9. Average Delay using Various Dropping Time](image)

![Figure 10. Average Number of Packets Collision using Various Dropping Time](image)

Figures 10, 11 and 12 represent the effect on changing the dropping time on both protocols on the three performance metrics; the average number of collided packets, percentage of channel utilization and percentage of dropped packets respectively.
It is clear from these figures that the performance metrics values are enhanced using the proposed CUCB-MAC protocol than while using the original CB-MAC protocol. Also the difference between the values of the performance metrics using both protocols increases when increasing the packet dropping time. The reason of this is that increasing the packet dropping time; means that the packets lasts a longer time in their SUs buffer before they are dropped, i.e. larger number of packets need to use the spectrum. So it is preferable to prevent them from using expected non-free channels than to permit using these channels while knowing that it will most probably lead to collision.

But noticing from the figures that after a certain specific of the packet dropping time approximately 4*packet transmission time, the percentage of dropped packets is decreasing by a small value (Figure 12). So the other performance metrics values either change by a small value or retain a constant value.

5.2.3 Third Scenario: Changing Channel Usage Threshold

One of the parameters used in the channel allocation process protocol while using the proposed CUCB-MAC is the channel usage probability. This parameter represents the probability that a PU is expected to use a specific channel. It acts as a threshold; if the probability of channel usage exceeded this specific threshold, it means that this channel is expected to be used by a specific PU within the SU’s range that is waiting for a free channel, so this channel is not allocated to this SU.

In this scenario the effect of changing the channel usage threshold is shown in Figures 13 to 17. The channel usage threshold value varies from 0.3 to 0.7. This is done to examine the effect of this change on each performance metrics on both MAC protocols. But as this parameter is used only in the CUCB-MAC protocol, so it will have no effect on the CB-MAC protocol graphs, meaning that performance metrics values will be the same and won’t change while changing the measuring parameter. But it is still measured and drawn on the graph. So that the performance metrics values resulted from the proposed CUCB-MAC protocol can be compared to that resulted from the original CB-MAC protocol. This is to monitor when the results of the proposed CUCB-MAC protocol will approach the constant results of the original CB-MAC protocol.

It is clear from Figure 13 that the average throughput of the proposed CUCB-MAC protocol is higher than that of the original CB-MAC protocol. Also from Figure 14 it can be noticed that the average delay of the proposed CUCB-MAC protocol is lower than that of the original CB-MAC protocol. Figures 15 to 17 show that for the average number of collided packets, the percentage of channel utilization and the percentage of dropped packets are all lower when using the proposed CUCB-MAC protocol than when using the original CB-MAC protocol.

As a conclusion, we can say that when using the proposed CUCB-MAC protocol, it is obvious that all the performance metrics values get worse when increasing the channel usage threshold. The reason of this is that increasing the channel usage threshold means that the probability that the channel is expected to be used by a PU increases.

By that a channel may be used by a PU in the nearby future and still been allocated to a SU. In other words, not prohibiting that SU from using this channel as the probability that it was going to be used by the PU was lower than the high channel usage threshold. So increasing the channel usage threshold will decrease the gap difference between the proposed protocol values and the original protocol values for all the performance
metrics, till the values resulted from both the proposed and the original MAC protocols become equal when the channel usage threshold increases above 0.7.

In other words; increasing of channel usage threshold will lead to the usage of more expected non free channel; i.e. channels that most probably be used by PUs. Channel usage threshold can be increased till reaching that almost all of the channels may be allocated to SUs even if they are all will be used by PUs like in the original CB-MAC protocol. So the performance will degrade till it reaches the values of the original CB-MAC protocol. So using the high channel usage threshold is useless.

6 CONCLUSION AND FUTURE WORKS

In this paper; a spectrum sharing technique for cognitive radio networks is proposed. This protocol depends on three parameters for the allocation of the channels to various SUs. The three parameters are: the number of collisions each packet encounters, the estimated probability for channel availability and the estimated probability of channel usage by each PU. So the
proposed MAC protocol is named CUCB-MAC. A simulation program was built for comparing the proposed protocol to an old one named CB-MAC that uses only the first two parameters for the allocation process. The evaluation of the proposed CUCB-MAC protocol is done with the usage of three different scenarios. For each scenario a simulation parameter is changed either up or down to examine the impact of this change on both the proposed CUCB-MAC protocol and the original CB-MAC protocol.

From the results, it is concluded that the proposed CUCB-MAC protocol overcomes the original CB-MAC protocol on all the measured performance metrics; average throughput, average delay, average number of PUs’ packets collided, percentage of channel utilization and finally percentage of dropped packets.

As future work, 1) try to mathematically prove the values used as channel usage threshold and the packet dropping time, 2) try using another collision statistics measure and 3) try to omit the usage of the central spectrum manager by proposing a decentralized MAC protocol.

7 REFERENCES


