Packet Delay for a New Version of a Simple MAC Protocol for Cognitive Wireless Networks

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***Abstract*— Cognitive radio is a promising technology to improve the performance of wireless networks. Multiple Access Protocol is an important issue to define the performance of the cognitive radio network. In [2] Ghasemi proposed a simple MAC protocol for cognitive wireless networks and analyze its performance based on the throughput parameter. In [3] we proposed an improvement in the Ghasemi's algorithm in order to consider the propagation conditions of each channel in the decision process and compare the performance with Ghasemi's version in terms of throughput. The goal of this paper is to compare the packet delay of both versions of the algorithm.**

***Index Terms*— multiple access, cognitive radio, packet delay, performance.**

I. Introduction

The exponential growth of wireless data networks and its applications demands a better utilization of the frequency spectrum. Cognitive radio is a promising technology to improve the performance of wireless networks. Cognitive radio is defined as a radio that can change its transmission parameters based on interaction with the operating environment [1].

Multiple Access Protocol is an important issue to define the performance of the cognitive radio network. In [2], Ghasemi proposed a simple MAC protocol for cognitive wireless networks and analyze its performance based on the throughput parameter. In [3], we proposed an improvement in the Ghasemi's algorithm in order to consider the propagation conditions of each channel in the decision process. We compare the performance of both algorithms based on throughput, since this was the performance parameter used by Ghasemi in his paper.

The goal of this paper is to compare the packet delay in the Ghasemi's algorithm with the packet delay obtained with the new version of the algorithm presented in [3].

The remainder of this paper is organized as follows: Section II presents the Ghasemi's and Adauto's algorithms; Section III compares the performance of both versions in terms of packet delay; and the conclusions are presented in Section IV.

II. The Algorithms

The Figure 1 show the algorithm defined by Ghasemi in [2].

The Ghasemi's algorithm is based on the rule of least failures,

Each cognitive user follows these steps independently
Initialization: Set W_{max} and $S_j^0 = F_j^0 = F_{2j}^0 = 0$ for $j \in \mathcal{N}$
for $t = 1, 2, \ldots$ **do**
  $v = least\_failure(\mathbf{S}^{t-1}, \mathbf{F}^{t-1})$
  sense channel v
  if busy **then**
    $F_v^t = F_v^{t-1} + 1$
  else
    $S_v^t = S_v^{t-1} + 1$
    exploit channel v
    if exploitation is successful **then**
      $F_{2v}^t = \max\{0, F_{2v}^{t-1} - 1\}$
    else
      $F_{2v}^t = F_{2v}^{t-1} + 1$
      $W = 2^{F_{2v}^t} - 1$
      $B = \min\{W_{max}, ceil(W * rand)\}$
      $F_v^t = F_v^{t-1} + B$
    end if
  end if
end for

Fig. 1. The original algorithm proposed by Ghasemi and Razavizadeh [2].

which is independently deployed by each user. The least failure rule used in Ghasemi's algorithm is based on the counters S_v^t and F_v^t which counts successes and failures, respectively, of each secondary user in a given channel v till the current time-slot t.

The decision process, based on the least failure rule, follow these steps: first of all the secondary user choose the channel which has incurred the less number of failures, if there is more than one channel with less failures, the secondary user chooses the channel that has the most number of successes between channels with less failures. If there is more than one channel with the highest number of successes the user chooses randomly between these channels.

In [2] it is assumed that each secondary user can sense only one channel in a given time-slot. If this channel is in use by a primary user, it is assumed as a busy channel and a collision between a primary and a secondary users occurs. If the secondary user detects the selected channel free it starts the exploitation of the channel. If two (or more) secondary users exploits the same channel a collision between secondary users occurs and, to solve it, a random backoff B is added to the fail counter F_v^t. The backoff is calculated based on the algorithm known as Binary Exponential Backoff [4] [5] and its value is limited by the maximum allowable backoff value (W_{Max}). The backoff is randomly defined between zero and W (limited by the parameter W_{Max}), the function $ceil(x)$ returns the smallest integer not less than x and the $rand$ function returns a random number uniformly distributed between [0;1].

In any wireless networks the propagation conditions and the dynamic behavior of the medium needs to be considered in the decision process. In [3] a small modification on the Ghasemi's algorithm that can improve its performance in a real wireless communications network is proposed.

The modification proposed in [3] uses the propagation conditions of the medium to change the value of the counter F_v^t, as this is the first counter consulted by the secondary user to choose the better channel to transmit. Therefore, the channel quality is considered in the decision process in terms of propagation conditions, represented by packet error probability. The Adauto's version is presented below in Figure 2 (the proposed modifications are highlighted with underscore lines).

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Each cognitive user follows these steps independently
Initialization: Set W_max and S_j^0 = F_j^0 = F_2j^0 = 0 for j ∈ N
for t = 1, 2, ... do
  v = least_failure(S^{t-1}, F^{t-1})
  sense channel v
  if busy then
    F_v^t = F_v^{t-1} + 1
  else
    S_v^t = S_v^{t-1} + 1
    exploit channel v
    if exploitation is successful then
      F_2v^t = max{0, F_2v^{t-1} - 1}
      if transmission is successful then
        F_v^t = max{0, F_v^{t-1} - 1}
      else
        F_v^t = F_v^{t-1} + 1
    else
      F_2v^t = F_2v^{t-1} + 1
      W = 2^{F_2v^t} - 1
      B = min{W_max, ceil(W * rand)}
      F_v^t = F_v^{t-1} + B
    end if
  end if
end for
```

Fig. 2. The new version of Ghasemi's algorithm, proposed by Adauto and Brito in [3].

III. The Delay Computation

In [6] QoS is defined as a set of requirements that specifies some guarantees in the level of network performance. In practical terms, is the mechanism that has as objective to ensure that the data flows in the network with certain guarantees based on their requirements. Two important parameters to define the QoS are the delay and its variation (called jitter).

In both versions of the algorithm analyzed in this paper the delay can be caused by any of these problems: collisions between primary and secondary users, collisions between two (or more) secondary users or errors due to bad propagation conditions.

In this paper, the delay was defined as the required number of time-slots to transmit a packet successfully. We compute the average delay and, as an estimation of the jitter, standard deviation.

In the delay computation the simulation setup use the same conditions used in [2]: the number of secondary users varies from 2 to 20; the network has 20 non-overlapping channels, the probability of the channel is in use by a primary station is randomly selected from the range [0.1 0.5], except for channel 10 which this probability is fixed as 0.05; and the maximum allowable backoff (W_{Max}) for each channel is set to 256 which was the value that results in the best performance for Ghasemi's version.

A. Without consider the Propagation Conditions

First, we compare the two versions of the algorithm considering that all channels are error free. The Figure 3 shows the results for average packet delay and Figure 4 shows the standard deviation of the delay.

Based on Figures 3 and 4, we can see that the Adauto's

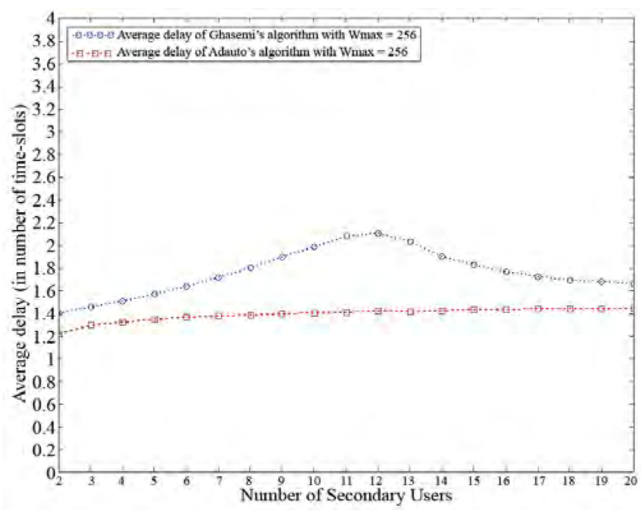

Fig. 3. Comparing average delay between Adauto's and Ghasemi's versions.

version always performs better than the Ghasemi's version, in terms of average delay and jitter.

According to [2], when the secondary collisions are the main reason of the performance degradation (about 11 secondary users) the algorithm encourage users to exploit the same channel in consecutive time-slots, decrementing the collisions counter ($F_2^t v$) and managing users to avoid collisions. Therefore, when the network has about 11 secondary users the throughput starts to increase. This behavior explain why the delay (and jitter) in Ghasemi's algorithm decrease

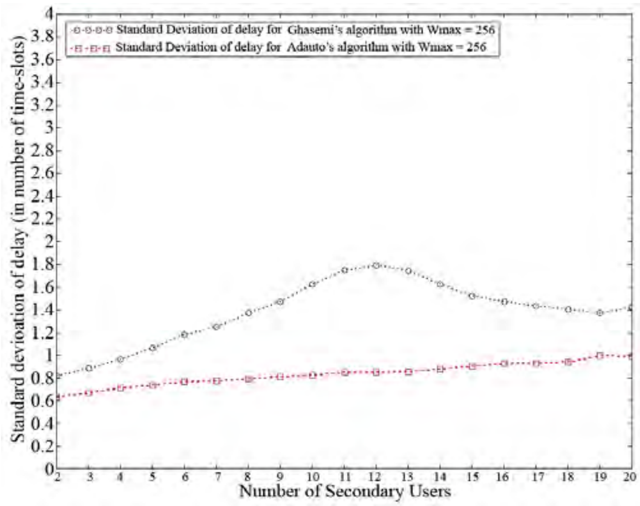

Fig. 4. Comparing the standard deviation of delay between Adauto's and Ghasemi's versions

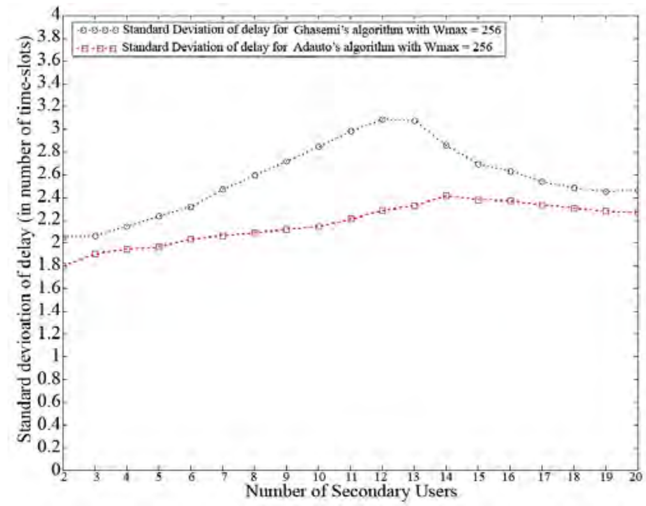

Fig. 6. Comparing the standard deviation of delay between Adauto's and Ghasemi's versions, with packet error probability equal to 0.3 in all channels.

with the number of secondary users (after 11 secondary users).

B. Considering the Propagation Conditions

To consider errors due to bad propagation conditions on the available channels, we compare the performance of both versions of the algorithm considering the same packet error rate for all channels. In [7] the packet error rates reported varies from 0.018 to 0.738. In our analysis we consider a packet error rate equal to 0.3. The Figure 5 shows the average delay and the Figure 6 shows the standard deviation of delay in this condition.

Based on Figure 5 and 6, we can see, as expected, that the average delay and the standard deviation of delay increases when the packet error rate is considered. We can see also that the Adauto's version performs better than the Ghasemi's version.

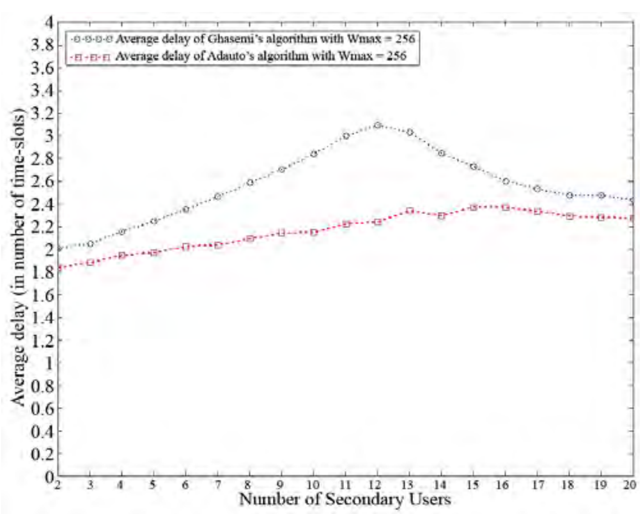

Fig. 5. Comparing average delay between Adauto's and Ghasemi's versions, with packet error probability equal to 0.3 in all channels.

In real wireless networks the propagation conditions can vary on each channel. Thus, now we consider a situation in which the propagation conditions are not the same for all channels. To exemplify this condition we consider that 10 channels are error-free and 10 channels has a packet error rate equal to 0.5. The Figure 7 shows the average delay and the Figure 8 shows the standard deviation of delay in this condition.

In Figure 7 when the network has 10 or less secondary users, the value of average delay for Adauto's version has the same behavior of Figure 3 with the same number of secondary users, because the users tends to exploit channels with better propagation conditions in the Adauto's algorithm. The Ghasemi's version does not consider the propagation conditions and, due to this, has the average delay increased

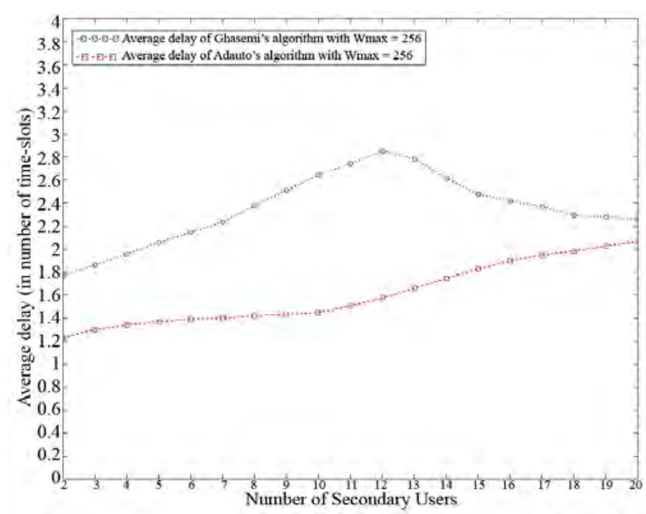

Fig. 7. Comparing average delay between Adauto's and Ghasemi's versions, with half of channels error-free and half of channels with packet error probability equal to 0.5.

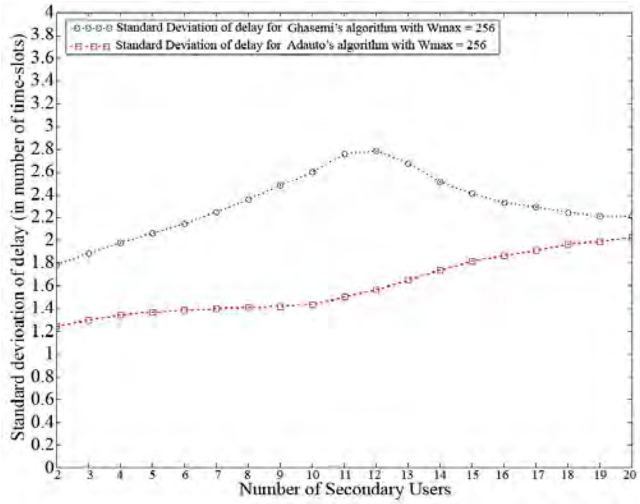

Fig. 8. Comparing the standard deviation of delay between Adauto's and Ghasemi's versions, with half of channels error-free and half of channels with packet error probability equal to 0.5.

if this value is compared with Figure 3 for any number of secondary users. This consideration can be extended to the standard deviation of delay, as we can see comparing Figure 4 and Figure 8.

When the network has more than 10 users, the average delay and the standard deviation of delay starts to increase in Adauto's version, because some users will exploit channels with bad propagation conditions. However, the Adauto's version performs better than Ghasemi's algorithm in all considered scenarios.

IV. Conclusions

In [2], Ghasemi proposed a simple MAC protocol for cognitive wireless networks and analyze its performance based on the throughput parameter. In [3], we proposed an improvement in the Ghasemi's algorithm in order to consider the propagation conditions of each channel in the decision process. The performance of Ghasemi's and Adauto's algorithms is compared in [3] based on the throughput parameter. However, in terms of QoS, is important to know, besides the throughput, the delay and jitter experienced by the user.

In this paper we compare the performance of both algorithms based on the average delay and jitter. We concluded that Adauto's version performs better than Ghasemi's version in all analyzed scenarios.

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