A Joint Three Compensation round based scheduling Algorithm and a dynamic resource allocation procedure for OFDMA Cognitive systems

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Summary

In this paper we propose a three compensation round based scheduling algorithm and a dynamic resource allocation procedure for OFDMA based cognitive radio. The main contribution of the proposed scheduling scheme is a high interaction with the external environment, to insure on one hand fairness guarantee between the different real time traffic queues and on the other hand, an enhancement in the Quality of Service level offered by the cognitive network. The contribution of our proposed resource allocation algorithm is to allow a maximum number of cognitive users to use the available spectrum holes and to secure cognitive transmissions. The general contribution of the joint proposed scheduling and resource allocation algorithm is to satisfy the Quality of Service requirements of cognitive users and to respect primary user priority. The resource allocation scheme is implemented in a distributed manner and confirmed by the High Capabilities node during the Conflict resolution procedure. The scheduling procedure is composed by a normal scheduling period and three on-demand compensation rounds based on two different virtual start tags. Our results show that the proposed mechanisms can achieve high overall throughput, high fairness degree, and low over all packet loss percentage.

Key words: Cognitive systems, resource allocation, scheduling, conflict resolution, compensation round, virtual start tags, throughput, fairness degree, packet loss percentage

1. Introduction

Empowered by the saturation state of the spectrum band [1] Cognitive radio (CR) systems have emerged as a solution for spectrum underutilization problem. This new technology CR [2] has been standardized by both recent FCC Policy initiatives and IEEE 802.22 activities [3]. So a cognitive radio system can be deployed either as an infrastructure-based network or an ad hoc network. Thus, a Cognitive User (usually referred as secondary user, SU) is allowed to opportunistically utilize unused licensed spectrum (spectrum holes) with respecting the licensed user (primary user, PU) priority, by vacating this spectrum hole once a primary user starts using it. So this CR refers to the potentiality that a wireless system is aware of its radio environment, and capable of dynamically reconfiguring itself based on available (unused) frequency resource. Since the primary user has the exclusive privilege to access the assigned spectrum range, secondary user must act in a way that does not harmfully affect the primary user transmission. So due its very recent emergence, primary user constraint, and the both time and location dependent channel availability, CR has a number of open challenges. In this paper, we concentrate on the scheduling and resource allocation for OFDMA based cognitive radio. First we investigate the problem of resource allocation in OFDMA-based Cognitive radio networks, which is very special and different from traditional radio resource allocation problem. In fact, the traditional resource allocation problem is formulated either as a rate adaptive optimization problem [4] (maximize the overall rate) or as a margin adaptive optimization problem[5] (minimize the overall transmission power). However, In cognitive context the problem of resource allocation must handle with both maximizing the overall rate, to guarantee the requested QoS (Quality Of Service) for Cognitive users, and minimizing the individual transmission power, to respect the primary user privilege. For that purpose we propose a distributed resource allocation scheme, followed by a centralized conflict resolution procedure based on a dynamic scheduling mechanism.

Currently, to our best knowledge, the most important work which are interested to scheduling for resource allocation problem in cognitive radio systems, are [6]—[13]. In [6]authors provide a new resource management algorithm with delay constraints for cognitive OFDMA System. The proposed procedure is characterized by using two step scheduling algorithm for resource allocation, based on controlling the guarantee of service for real time traffic but without guaranteeing fairness between active real time Traffic queues. The problem of scheduling is treated differently in [7], in which scheduling problem is decomposed into a sequence of small optimization problem. In spite of its efficiency, the proposed mechanism is based on channel state and does not take into consideration neither fairness nor traffic priority. In [8], authors handle the problem of scheduling as problem dependent only on the instantaneous channel quality

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(Signal to Noise Ratio: SNR at the secondary receiver) and not on the type of traffic or on the saturation state of traffic Queues. The goal of the proposed algorithm in [8] is maximizing cognitive throughput without guaranteeing fairness between different Real Time traffic queues, however the objective of the proposed scheduling mechanism in [9] and [10], is to consider the issue of fairness without treating the guarantee of service problem.

In [11] authors propose a "time efficient" strategy which produces an optimal 2-hope spectrum scheduling in cognitive network. The goal of the work is first, to avoid QoS degradation for SU when the routing table is not rebuilt if the primary user randomly appears in the system, second, to guarantee a spectrum information updating before any traffic transmission. Thus two mechanisms were proposed: the ODSS and the ORSS (Optimal Deterministic Spectrum Scheduling and Optimal Randomized Spectrum Scheduling), which allow each node to learn all information (available channels) from its one-hope neighbors. This collection phase is repeated for each Mesh Cog Node (Mesh-Cognitive-Node) until an overall spectrum hole information updating for every two Cog Mesh neighbors. In spite of its efficiency the proposed mechanism takes important time, which can harmfully affect cognitive decisions. this proposed method suffers also from non-using a compensation mechanism to manage fairness between the Cog-Mesh transmissions. In [12] authors handle the same problem of potential heterogeneity in channel availability among cognitive nodes which can cause either transmissions delay or collisions. This implies that besides the channel sensing problem, transmission coordination is also one of the essential and most challenging functionalities in cognitive radio networks. In this work authors are interested by the multicast problem in cognitive radio, and they propose a three-operation based mechanism to schedule the multicast activity over both time and frequency. The proposed procedure seems to be very efficient to avoid collision and traffic loss. However it's static because the same assistant Cog Mesh Nodes can be chosen for every multicast activity what can affect power consumption of the SU. Finally, a very efficient procedure is proposed in [13], in which authors investigate a joint scheduling and power control for cognitive radio network problem, which was formulated as an optimization problem to maximize the spectrum utilization of SUs without causing excessive interference to active PUs. However, they don't apply any compensation procedure to handle with famine problem for the un-served cognitive users.

Since we are based in our work on the MAC layer proposed in [14] and the Spectrum hole management procedure proposed in [15], the problems of cooperation and Channel information updating are not investigated because they were efficiently solved in [14] and [15] by a high cooperation, double channel reservation procedures. So, in this work we are interested in Scheduling and Resource allocation problems. In fact, in almost all related studied works, the proposed mechanism either for resource allocation and scheduling are static and not very flexible to guarantee both fairness, and Cognitive Quality of service guarantee. Thus, to optimize spectrum utilization by secondary users, we propose an intelligent resource allocation procedure, based on a distributed mechanism and a centralized conflict resolution algorithm. This conflict resolution algorithm, is based on assigning the best carrier to the waiting cognitive nodes based on a *cost function,* which handles with both transmission power minimizing and cognitive throughput maximizing. We distinguish four different periods for resource assigning which are: Normal Scheduling Round, Fairness guarantee based Compensation round, Guarantee of Service based Compensation Round, And an Urgent Compensation Round.

So the organization of the paper is as follow: In section II we describe the system model. The proposed scheduling algorithm is presented in section III. The proposed resource allocation is detailed in section IV. In section V we analyze the performance of the proposed schemes. The paper concludes in section VI.

2. System Model and Assumptions

We consider a Cognitive radio Network with a total of M secondary users, N primary bands and each band is composed by L free sub carriers available for opportunistic use. In this work we use global scheduling strategy in which, first, a transmitting-user selection is applied, and second, a resource allocation method is used to assign available resources to selected users. Our interest in this work is to: (1) maintain QoS and fairness between Cognitive users, (2) avoid famine of some traffic flows, (3) respect primary user limitation (used transmission power), (4) guarantee the required dynamism and flexibility for such cognitive systems. Thus we define, a dynamic strategy for scheduling transmissions based on transmissions emergency, which is dependent either on fairness degree or on guarantee of service level.

So we define the *Cognitive Indicator* $\lambda_{l,i,j}$ of cognitive user l, in the subcarrier (i,j), which means the subcarrier i of the primary user j, as follow:

$$\lambda_{l,i,j}=\alpha_j\varphi_{l,i,j} \qquad (1)$$

Where α_i denotes the activity of primary user i, $\varphi_{l,i,j}$ represents the channel gain of the subcarrier i belonging to the j^th^ primary band for the cognitive user l. So in this framework, we invoke the following assumptions: (1) To choose the more suitable primary band and the best subcarriers, cognitive users utilize "*the Cognitive Indicator*".(2) In this framework we are based on the MAC

(*Medium Access Control*) Protocol proposed in [14]. This protocol is based on a parallel transmission of control information and traffic.(3) The HC node (*High Capabilities node*)[15] is the node who has the highest capabilities in the cognitive network and who transmits the association frame during the Beacon Period (figure 1).(4) Each user has a minimum rate and a maximum power (Primary user limitation) that need to be maintained.

Under this system model we propose a subcarriers allocation scheme, completed by a conflict resolution based on a dynamic scheduling procedure.

3. Proposed Scheduling Algorithm

The proposed algorithm is based on two Virtual Start tags calculated based on the service rate of the queues (to guarantee service) and on the instantaneous transmission rate for the active flows. Thus, based on predefined thresholds, compensation rounds are used to compensate the delay of some urgent transmission or the famine of some traffic queues.

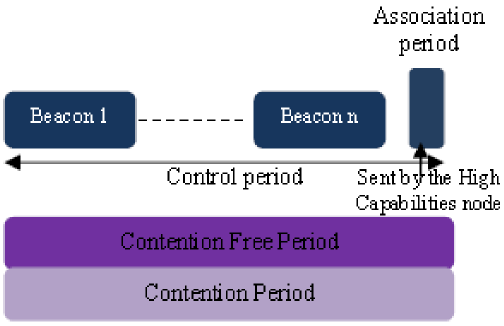

Figure 1. The used MAC Layer

3.1. Fairness Management

Since the problem of resource allocation treated in this paper considers just the real time traffic, so we must respect fairness between the different cognitive users queues. Moreover, the resource allocation in this ad hoc cognitive network [14] is based on a distributed approach. So, a fair opportunistic spectrum access can be realized if cognitive users priority is beforehand known. Thus, we define the fairness degree function (FD), to generate priority indicator for cognitive users. So the bigger is the associated fairness degree the more important is the priority of the cognitive user transmission.

We assume that $W_i(t)$ is the occupation rate of the traffic queue for user i, at the scheduling round t, defined as the ratio between the waiting traffic and the total capacity of the cognitive user queue (real time traffic):

$$D(i,t)=\begin{Bmatrix} FD\,(i,t-1)W_i\,(t), \text{ For served Cognitive users} \\ W_i\,(t), \text{ For un-served cognitive users} \end{Bmatrix}$$

Here, the served cognitive users are the users who had made a suitable reservation to their transmissions during the current Beacon Frame, and the un-served users are the cognitive users who did not find suitable subcarriers to their traffic. If an un-served cognitive user still not served after N_{tr} tries, then the cognitive transmission is marked as urgent transmission (FD(i,t) = 1). These transmissions are called *Forced To be Urgent* transmissions (FU transmissions).

3.2. Guarantee of Service Management

For the guarantee of service we define a QoS Indicator function (QI) which calculates for every cognitive transmission the ratio between the Partial Requested Rate (PRR) and the maximum future estimated service capacity of the Network for the user i $C_{max,i}$. In fact, if we assume that every cognitive node, given the available spectrum holes, is able to estimate for a future period Δ_{max} , the capacity of service C_{max} of the cognitive Network. So, if we assume that during a Normal scheduling Round, a cognitive node transmits n_i bits, that the total number of bits to be transmitted is L_{max}, and that the maximum duration of transmission is D_{max}. So if the scheduling round is of duration D_{serv}, the remainder requested rate for user i (RRR_i) is given by (2):

$$RRR_i = \frac{L_{max,i} - n_i}{D_{max,i} - D_{serv}} \qquad (2)$$

Then we define the Partial Requested Rate (PRR_i) of the cognitive user I as the average requested rate during the future Δ_{max}period. So, the PRR_i at the scheduling round t is given by (3):

$$PRR_{i,t} = \begin{Bmatrix} RRR_{i,t}\dfrac{\Delta_{max}}{D_{max} - D_{serv}} , if\ \Delta_{max} \leq D_{max} - D_{serv} \\ RRR_{i,t} \qquad , \ if\ \Delta_{max} \geq D_{max} - D_{serv} \end{Bmatrix} \qquad (3)$$

So, every packet to be served, must calculate a QoS Indicator which is the ratio between the Partial Requested Rate and the maximum future estimated service capacity of the Network for the user i$C_{max,i}$ at the scheduling round t . Then the QoS Indicator is given by (4):

$$QI\,(i,t) = \frac{PRR_{i,t}}{C_{max,i,t}} \qquad (4)$$

Then by controlling the QI value for every cognitive node, the HC node, during the conflict resolution, gives priority to the transmissions with a very important QI value. However, the transmissions which have $QI(i,t) \geq 1$ must not be served, because assigning radio resource to these transmissions leads to a wasting of available resources. These transmissions are marked as reported until the channel availability increases. Then for a given transmission of a cognitive user i, we define a Reported Transmissions Counter RTC_i for the transmission of the user i, which increases when the transmission is reported. Then a cognitive transmission is rejected if the RTC_i exceeds the threshold RTC_{thr} , which is dynamically updated. The increasing of the RTC_i is managed by the following pseudo-code:

```
While (i$\in A_t$& $(0 < RTC_i < RTC_{thr})$
    If (QI(i) $\geq 1$)
        Then $RTC_i = RTC_i + 1$
        Else $RTC_i = 0$
    Enf if
End While
While (i$\in A_t$)& $(RTC_i \geq RTC_{thr})$
    J = arg (i)
    $A_t[J] = [\,]$
End While
```

3.3. Scheduling and Compensation rounds

To schedule cognitive transmissions two Virtual End tags (F_1 et F_2) are sent during the Beacon Frame. In fact, if we assume that p_i^k is the kth packet of the active cognitive transmission I, then the Virtual Start tags, at the scheduling round t, are:

$$\begin{Bmatrix} F_1(p_i^k) = FD\,(i,t) \\ F_2(p_i^k) = QI\,(i,t) \end{Bmatrix} \qquad (5)$$

Then the virtual start tags are respectively :

$$\begin{Bmatrix} S_1(p_i^k) = F_1(p_i^{k-1}) \\ S_2(p_i^k) = F_2(p_i^{k-1}) \end{Bmatrix} \qquad (6)$$

So, by using these two Virtual start tags we are trying to decouple the problems of fairness and service guarantee for cognitive systems. In fact, the more is important the Virtual Start tag S1, the less is served the traffic queue of cognitive user i, and the more important is the Virtual start tag S2, the more urgent is the cognitive transmission i. In consequence, we define a three different rounds to manage the cognitive transmissions scheduling based on both fairness guarantee and QoS Guarantee, which are Normal Scheduling Round, QoS Guarantee based Compensation Round and Fairness Guarantee Compensation Round.

1) *Normal Scheduling Round*

Since the Resource allocation Algorithm (Section IV) is distributed, so in the most of the cases, there are many subcarriers reservation conflict, what means that a subcarrier was reserved to more than one cognitive user. The HC node most resolve this conflict and confirm all the cognitive user reservations during the Association Frame. Thus during a normal scheduling round, the HC node resolve the conflict using the general cost function defined by (18).

2) *Urgent Compensation Round*

By controlling the Virtual Start tags for every cognitive node, we compare the virtual start tags to a predefined thresholds $\mathbf{FD}_{thr}$ and a $\mathbf{QI}_{thr}$. Then a transmission is classified Urgent if :

$$S_1(p_i^k) \geq FD_{thr} \ \& \ S_2(p_i^k) \geq QI_{thr} \qquad (7)$$

In this case, a Urgent compensation round starts, based on which the first cognitive served transmissions must verify (7) and are classified based on a descending Emergency Indicator (EI) defined by :

$$E_i = S_1(p_i^k) S_2(p_i^k) \qquad (8)$$

In consequence, if there are any common selected subcarriers, these transmissions are prioritized than the other ones.

3) *QoS Guarantee Based Compensation Round*

By controlling the two virtual start tags of the Active cognitive transmissions, we can find transmissions verifying (9). In that case these transmissions are classified based on a descending Virtual start tag S_2. In consequence, this Compensation round starts after the Urgent compensation round.

$$S_1(p_i^k) \leq FD_{thr} \ \& \ 1 \geq S_2(p_i^k) \geq QI_{thr} \qquad (9)$$

Since, these transmissions, don't suffer from famine, the problem of QoS degradation is caused by active primary users(Since $S_2(p_i^k) \leq 1$). Then, the HC node can in this case make reallocation [15], to avoid transmission interruption.

4) *Fairness Guarantee Based Compensation Round*

The last compensation round starts when some transmissions suffer from famine. In this case the Virtual start tags verify (10). So the transmissions are classified based on a descending virtual start tag S_1.

$$S_1(p_i^k) \geq FD_{thr} \;\&\; S_2(p_i^k) \leq QI_{thr} \quad (10)$$

Thus, During the association period, the HC node classifies the different transmissions based on the occupation rate of the traffic queues W_i . Then, if (7) , (9) or (10) is verified a Compensation round starts and the relative transmissions are privileged.
During a compensation round, the HC node make Spectrum hole Allocation to the urgent transmissions, and then make a conflict resolution based on the remainder available spectrum holes to the other transmissions. Thus, after, a Compensation round there is always a Normal Scheduling Round(Fig. 2). If an active transmission have a bad radio channel state for more than RTC_{thr} , the cognitive node must be disassociated from the cognitive Network.

4. Proposed Resource Allocation Model

4.1. Resource Allocation Problem Formulation

The first goal in a cognitive radio context is to optimize the spectrum utilization. Thus, each cognitive user must use opportunistically the available spectrum holes. So, The resource allocation problem must target: (1) minimizing the total and the individuals transmit power (2) maximizing the total and individual rates (3) Conflict resolution (4) maintaining fairness across all active secondary users. Thus we can formulate our problem as:

$$\text{Maximize } \sum_u \frac{r_u}{p_u},\ u=1..M \quad (11)$$

Subject to:

$$r=(r_1,r_2,\dots,r_M) \geq \acute{r}=(\acute{r}_1,\acute{r}_2,\dots,\acute{r}_M) \quad (12)$$

$$p=(p_1,p_2,\dots,p_M) \leq \Pi=(\Pi_1,\Pi_2,\dots,\Pi_3) \quad (13)$$

$$p \geq 0 \quad (14)$$

Where, r and p represent respectively the rate vector and the transmission power vector of the M cognitive users , ŕ is the vector of the minimum rate to guarantee the QoS requested by the M cognitive users and Π the maximum allowable transmission power vector (primary user limitation). While, Constraint (12) represents the minimum suitable rate to guarantee the QoS requested by the secondary users transmissions, Constraint (13) corresponds to the limitation of the maximum allowable transmission power required by the primary user. These problems are categorized as *NP hard* [16]. Them resolution is very complicated , and the optimal solution is very difficult to find if we want to serve all waiting cognitive users. Here, the idea is to serve the more urgent transmissions, to increase the fairness degree for the un-served cognitive transmissions and to make Partial double reservation for urgent transmissions if there is not enough radio resources.

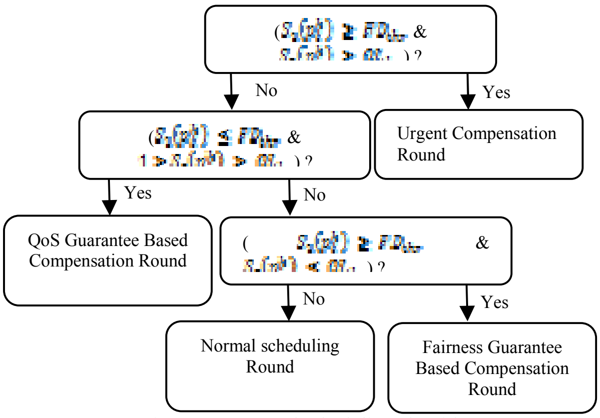

Figure 2. Proposed scheduling algorithm

4.2. Proposed algorithm

The first step in the proposed algorithm is the distributed Sub-carriers Allocation. Thus, we define the *Rate to Power Ratio Indicator:* RPRI of the subcarrier i, as the ratio between the transmission rate $r_{u,i}$ and the transmission power $p_{u,i,}$ if the cognitive user u utilizes the subcarrier, i, i=1..NL *:*

$$RPRI = \frac{r_{u,i}}{p_{u,i}} \quad (15)$$

Then, During the Beacon period every cognitive node sends the matrix of the available subcarriers and the relative RPRI. At the beginning, based on the collected information the cognitive nodes , select the best subcarriers to them transmissions by choosing the subcarriers with the highest RPRI. In every step, cognitive users calculate the estimated transmission rate and the estimated Transmission power, and compare with the relative threshold. If one of the thresholds is reached (transmission rate or power), then the Allocation procedure changes. There are two cases:

1. If currently we have($r_u \geq \acute{r}_u$)&($p_u > \Pi_u$), Then the cognitive node, chooses the Subcarrier

which most decreases the transmission power : min $\sum p_{u,i}$

2. If currently we have$(r_u < \acute{r}_u)$&$(p_u \leq \Pi_u)$, then the cognitive node chooses the subcarrier which most increases the transmission rate: max $\sum r_{u,i}$

The Resource allocation procedure is stopped either if the transmission rate and the transmission power thresholds are both reached, or all the available subcarriers are used. In the second case, the cognitive node can, if the requested QoS is not insured, changing the primary band or waiting (if the transmission is not urgent) , to have more available spectrum holes. In the first case, the cognitive node sends during its Beacon the set of the reserved subcarriers. In the most of the cases, there are many subcarriers reservation conflict, what means that a subcarrier was reserved to more than one cognitive user. The HC node most resolve this conflict and confirm all the cognitive user reservations during the Association Frame. For that purpose, we propose a *General Dynamic Cost Function (GDCF)*, to determine to which cognitive node a conflicted subcarrier must be reserved. This GDCF is defined during a normal scheduling period, during an urgent compensation round, during QoS guarantee based compensation round and during a Fairness guarantee based compensation period respectively by (19)—(22). So, we define two sub-functions the *Rate Cost sub-function* (RCF) and the *Transmission Power Cost sub-Function* (TPCF) as:

$$RCF = \left|\frac{\acute{r}_u - r_u}{\acute{r}_u}\right| \tag{16}$$

$$TPCF = \left|\frac{p_u - \Pi_u}{\Pi_u}\right| \tag{17}$$

$$GCF = \frac{RCF + TPCF}{2} \tag{18}$$

$$GDCF_1 = GCF \times W_i \tag{19}$$

$$GDCF_2 = GCF \times E_i \tag{20}$$

$$GDCF_3 = GCF \times S_2(p_i^k) \tag{21}$$

$$GDCF_4 = GCF \times S_1(p_i^k) \tag{22}$$

The GCF represents the resolution rate of the optimization problem in term of transmission rate and transmission power. During a Normal scheduling round, a conflicted subcarrier will be reserved to the user who has the most important GCF. If two nodes have the same GCF, then the HC node reserves the subcarrier to the node who has the most important $DGCF_1$ value, otherwise it randomly allocates the subcarrier. However, during a Compensation round either an Urgent, Fairness Based or a QoS guarantee based one, the HC node must allocate resources to the most urgent transmissions, without caring about the other transmissions. So, If there is any common allocated carriers between these urgent transmissions the HC node allocates the sub-carrier to the most urgent transmission based on the Correspondent Virtual Start tag unless the Virtual start tags are equal. In this case, the HC node use the DGC Function to resolve the conflict, otherwise, it randomly allocates the subcarrier.

We have to say that, a cognitive user must reserve subcarriers belonging to the same primary band. At the end of the conflict resolution procedure, the HC node must verify that all urgent transmissions was served, otherwise the least priority transmissions will be sacrificed. In fact, in this case the HC node try to make subcarriers reallocations based on comparing the GCF of the served cognitive transmissions and the GCF of the urgent and un-served cognitive transmission. We denote GCF (u,i) is the GCF of the transmission of user u if it uses the subcarrier i , and ǔ the already non-urgent cognitive user, $S_{ǔ}$ the set of subcarriers reserved to the user ǔ , n(u) and n(ǔ) represent respectively the subcarriers number of user u and user ǔ, then the pseudo-code of the reallocation procedure is:

```
While ( $i \in S_{ǔ}$ )&($r_u < \acute{r}_u$)
    $GCF^* = \min GCF(ǔ,i)$
    If ($GCF(u,i) - GCF^* \geq 0$) then
        ( $n(u) = n(u) + 1$
        $n(ǔ) = n(ǔ) - 1$ )
    End if
End While
While ( $i \in S_{ǔ}$ )&($p_u > \Pi_u$)
    $TPCF^* = \min TPCF(ǔ,i)$
    If ($TPCF(u,i) - TPCF^* \geq 0$) then
        ($n(u) = n(u) + 1$
        $n(ǔ) = n(ǔ) - 1$)
    End if
End While
```

The other important point in our proposed algorithm is the double reservation procedure. In fact, in [14], we proposed that every real time traffic transmission must be secured by a double radio resource allocation. So based on the available resources and the transmission priority, cognitive users can make either a full, or partial secondary resource allocation. In fact, since the secondary resource allocation must be made in a different primary band, the cognitive nodes choose for every already reserved subcarrier (primary subcarrier), a secured subcarrier, among the subcarriers belonging to the primary band chosen for the secondary radio resource allocation. Then, to explain the secondary resource allocation procedure, we define for a given already reserved subcarrier i to a cognitive user u the Rate to Power Ratio Margin RPRM (u) as the difference between the transmission rate if the cognitive user utilize its primary subcarrier, and the transmission rate if it uses a secondary subcarrier among the set of available subcarriers in the second primary band S_{sec} , as follow:

$$RPRM\,(u,i) = RPR\,(u,i) - RPR\,(u,l)\,,l \in S_{sec} \tag{23}$$

So, based on the RPR Margin parameter, we can summarize the different steps of the secondary resource allocation procedure as :

1. Select all subcarriers with RPRM (u,i) ≥ 0, we denote $S_{sec,suit}$ this set of subcarriers

2. Reserve the subcarrier j = arg (min (RPRM(u,i))

3. Calculate at every step , the transmission rate and the transmission power if the cognitive user utilizes the secondary set of subcarriers.

4. if all reserved subcarriers have an associated secondary subcarrier (what we call full secondary reservation), The procedure is stopped .

5. Otherwise, the cognitive node select the subcarriers with (RPRM ≤ 0) and reserve the subcarrier $j = arg\left|\min(RPRM\,(u,i)\right|$,

6. If all reserved subcarriers have an associated secondary subcarrier , then the cognitive user calculates the Rate Margin RM and the Power Margin. The Rate Margin is defined as the difference between the minimum transmission rate r_u and the transmission rate if it uses the secondary set of subcarriers, when the Power Margin PM is defined as the difference between the maximum allowable transmission power Π_u and the transmission power if the cognitive user utilizes the secondary set of subcarriers, if (RM <0) or (PM >0) then the secondary reservation is called a Partial reservation.

7. The Partial secondary resource allocation, is used only for a restricted period and must be completed during the future Beacon Period.

5. Performance Evaluation

5.1. Simulation Environment and Assumptions

We consider a cognitive network composed by 8 cognitive nodes, who share the spectrum band with 8 primary users. Each primary user band is composed by 128 subcarriers. The primary users activities vary From 0.3 to 0.6. The channel attenuation coefficients for the different subcarriers vary from 2 to 3. To calculate the rate offered by a subcarrier, we use the function proposed in [16], which gives the SNR in function of the transmission rate as: SNR = $0.6r^3$ where r is the transmission rate. We summarize the simulation parameters in table 1.

To evaluate, the performance of the proposed Scheduling and resource allocations algorithms, we make simulations for different scenarios. The same scenarios are used to study the impact of the proposed algorithm with and without using the scheduling algorithm. Thus, We easily evaluate the impact of the scheduling algorithm on enhancing the performance of the resource allocation procedure.

Parameter	**Value**
M	8
N	8
Subcarriers/Primary band	128
Power/subcarrier	1—40mW
Channel attenuation coefficient a	2--3
Primary user activity	0.2—0.7
OFDM Symbol length	100µs
Subcarrier width	10.93 KHz
Rate(r)/subcarrier	Calculated using the function SNR=$0.6r^3$
Trafic priority	1--3
$D_{max,1}$	50ms
$D_{max,2}$	100 ms
$D_{max,3}$	150 ms

Table 1. Simulation parameters

To evaluate the performance of the proposed algorithm, we first analyze the impact of the resource allocation procedure on guaranteeing fairness between all cognitive queues, on minimizing the rate outage, the power outage and on maximizing the throughput. The rate outage (respectively power outage) means the probability that after applying the radio resource allocation procedure the cognitive radio user is assigned a transmission rate inferior to the minimum requested one (is assigned a transmission power superior to the maximum allowed transmission power).So, while the rate outage metric, analyzes the impact of the proposed model on satisfying the requested QoS of cognitive nodes, the power outage metric verifies the impact of this model on respecting the primary user limitation. Then, the first scenario is scheduling the cognitive transmission based only on the fairness degree function. Thus, to analyze the cognitive queues fairness , we define a *Service Rate Ratio* SRR for every cognitive node queue which is defined as the ratio between the number of served cognitive packets $N_{serv,i}$ (packets successfully sent) and the total number of packets waiting in the cognitive user queue $N_{tot,i}$:

$$SRR_i = \frac{N_{serv,i}}{N_{tot,i}}, i=1..M \qquad (24)$$

Then we define the Global Fairness Indicator GFI as :

$$GFI = \frac{\min(SRR_i)}{\max(SRR_i)} \qquad (25)$$

So, an ideal fairness management leads to a GFI equal to 1. Then , we investigate the evaluation of the performance of the proposed scheduling algorithm. In fact, we study the simulation results of the same scenarios by controlling the different virtual start tags and by applying the different compensation rounds.

5.2. Results and Discussion

To evaluate the performance of the different proposed mechanisms, we distinguish different scenarios.

1) Scenario 1: Guarantee of Fairness Evaluation

In this scenario we simulate the implemented cognitive network during 500s (100000 iterations, each one is for 0.005 s). We evaluate the GFI every 2 s. In the first case, we use flows with the same priority 1, with an arrival rate of packets of 0.6. In the second, we use traffics with 2 priorities 1 and 2, with packet arrival rates of 0.4.
The flow with priority 1 is privileged. To simulate the two priorities we define a maximum delay of packet transmission for each type of flows $D_{max,1}$ and $D_{max,2}$ respectively for the flow of priority 1 and the flow of priority 2. In fact, a packet who takes a transmission delay superior to the relative maximum transmission delay will be dropped. The collected results are shown respectively in Fig.3 and Fig.4.

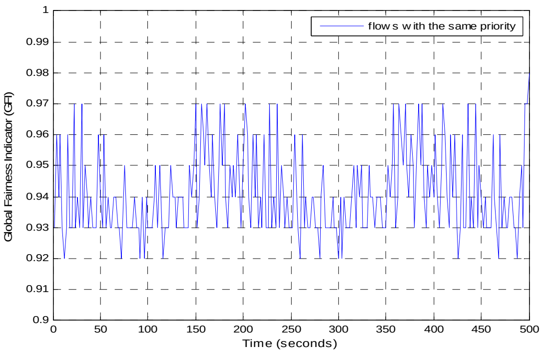

Figure 3. General Fairness indicator in the case of flows with the same priority

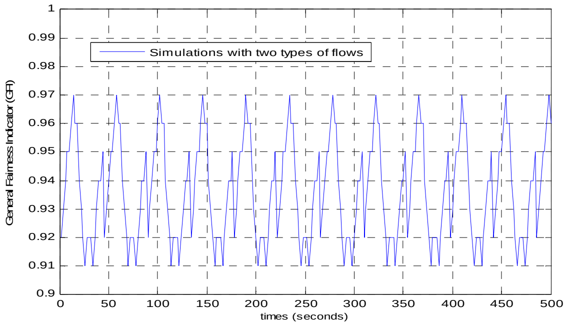

Figure 4. General Fairness Indicator in the case of flows with different priorities (1 & 2)

By analyzing the two figures, we first remark that in the two cases the GFI is comprised between 0.92 and 0.97. This implies that, even there are two types of flows in the second case, we guaranteed, by using the proposed scheduling mechanism and the proposed resource allocation procedure, fairness between the two types of flows. However, to reach the maximum GFI, the algorithm takes less time in the first case (Fig.3), than in the second case (Fig.4).
This can be explained by the fact that if the flows in the network are of the same priority the allocation resource algorithm take the same time for serving the different queues (we have the same packet arrival rate for the two queues). However, if the flows are of different priority, there are three compensations rounds which can take place: the QoS Guarantee Based Compensation Round, or the Urgent compensation round or the guarantee of service based compensation round. The two first compensation rounds are usually in favor of the privileged flow. What implies that to guarantee fairness, between the flows with different priorities the algorithm takes more time than if the flows have the same priority.

2) Scenario 2: Guarantee of service Evaluation

In this scenario we simulate a network with flows of different priorities. The different flows are of priority 1, 2 and 3, where the flow of priority 1 is the most urgent one. The priority is simulated by using three different maximum packet transmission delays $D_{max,1}$, $D_{max,2}$ and $D_{max,3}$. To evaluate the guarantee of service we define the percentage of dropped packet of flow with priority i $D_{p,i}$ (26) as the ratio between the total number of dropped packets with priority i and the total number of sent packets with priority i. So if we assume that $d_{r,i}$(u) is the number of dropped packets with priority i for every cognitive user u and $T_i(u)$ is the total number of sent packets with priority i of every cognitive user u.Then D_p can be given by the following equation:

$$D_{p,i} = \frac{d_{r,i}(u)}{T_i(u)} \tag{26}$$

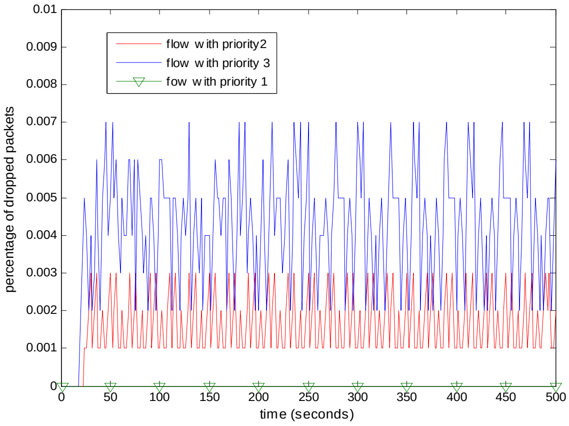

Figure 5. Percentage of dropped packets for flows with different priorities

We calculate every 2s the percentage of dropped packets for every flow in the network. Results are presented in Fig.5.

By analyzing the Fig.5, we can say that by applying the proposed algorithms, we guaranteed the QoS for both the privileged flows and the other flows in the network since the percentage of dropped packets for the different traffic types is comprised between 0 and 0.007.

However, the most privileged flow has a percentage of dropped packets equal to 0, which means that, we sacrificed the traffic with the less priority (percentage of dropped packets reaches 0.007) to save the urgent transmissions. Besides, we can say that the percentage of 0.007 is acceptable in a cognitive radio context, and with this percentage of dropped packets a Real Time transmission can reach its requested QoS. Thus, the proposed algorithm is able to both saving the most urgent transmissions and guaranteeing QoS of the other real time transmissions by using the different proposed compensation rounds.

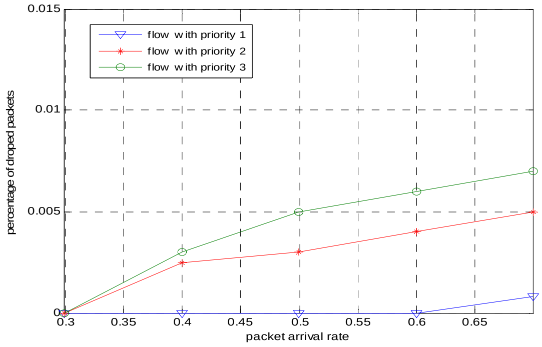

Figure 6. impact of the packet arrival rate on the percentage of dropped packets

The figure 6, shows that even when the packet arrival rate increases the percentage of dropped packets of the urgent transmissions is very weak. However, the No-urgent transmission dropped packet percentage increased to reach the value of 0.007 for a packet arrival rate of 0.7, which is relatively not very important. This result confirms the good impact of our proposed scheme in guaranteeing the requested QoS to all Real time traffic transmissions.

3) Scenario 3: Comparison between the proposed algorithm and the one proposed in [7]

First we compare the impact of our proposed model on increasing the throughput comparing to the model proposed in [7]. For this purpose, we simulate a cognitive network composed by 10 cognitive nodes and 128 carriers belonging to one primary user whom activity rate is for 0.4. the results shown in Fig. 7 and Fig.8, confirms the performance of our proposed model, since the throughput when we apply our proposed model reached 14.2 Mb/S , whereas the throughput reached by applying the schemes proposed in [7] is comprised between 1Mb/s and 6Mb/s after 80 iterations.

6. Conclusion

In this work we proposed a resource allocation and scheduling algorithms for OFDMA based cognitive radio networks. The both schemes are performed based on a distributed exchange of basic information. In the case of the resource allocation algorithm, the main task is the conflict resolution made in a centralized manner by the HC node, based on the distributed resource assignment and on the relative priority of every cognitive transmission. In the case of the scheduling algorithm, the compensation rounds are performed by controlling the virtual start tags exchanged during the Beacon period. The main contribution of the proposed procedures is the high level interaction with the external environment. Thus the cognitive decisions were based on both the traffic queues status and the radio environment changes.

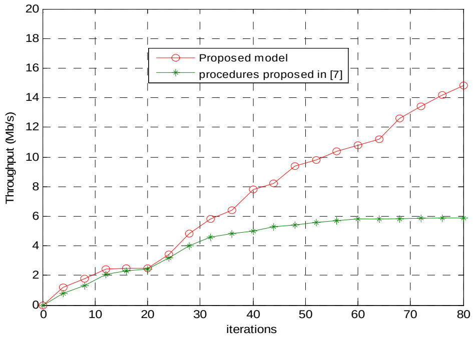

Figure 7. throughput comparison (proposed model and procedures proposed in [7])

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