Dynamic unlicensed bands access based on the decentralized resource distribution approach.

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Abstract

Dynamic spectrum access is a promising technique to use spectrum efficiently. Without being restricted to any prefixed spectrum bands, nodes choose operating spectrum on demand. Such flexibility, however, makes efficient and fair spectrum access in large scale networks great challenge. This paper presents a dynamic spectrum access decentralized approach. This approach is base on the game theory, mainly on the principle of Homo Egualis. There, it is assumed that operators are averse to unequal payoffs and act unselfishly, enabling a stable and sustainable community. An algorithm is proposed to solve the problems of inefficient use of spectrum and fair dynamic access to the available resources in the unlicensed bands. Numerical results show the performance of this algorithm.

Key words : *Dynamic spectrum access, decentralized approach, Homo Egualis principle*.

1. Introduction

The frequency spectrum is a natural resource very much in demand in our society. However, this resource is limited. Today, radio communication applications are increasingly various and radio- electric frequencies consuming. Recently, the telecommunication industry kept on increasing and innovating in term of wireless technologies, using more and more spectral resources. In view of these new requirements, it has been necessary to establish efficient systems for the spectrum management in order to allocate efficiently the resources while being careful to the interference risks due to the proliferation of actors. It is also widely recognized that wireless systems of digital communication don't operate on the entire available frequency band. The coming wireless systems then will be compelled to make the most of such free frequency bands, thanks to their ability to listen and adapt to their environment. Such ability comes within the concept of "cognitive radio" introduced by Joseph Mitola in 2000 [1]. This concept paves the way to an innovating approach which enables a dynamic and opportunistic but controlled use of the radio electric spectrum in support to the current statistic approach [11]. One of the main aspects of cognitive radio is the software defined radio (SDR) which promises a great flexibility by allowing a single device to access a wide range and various technologies [1]. The concept of "cognitive radio "intends to use the potential of software defined radio to allow more efficient use of spectrum. Cognitive radio devices scan the frequency spectrum dynamically by accessing the portions of the spectrum not used by the primary systems. Access is facilitated by the ability of cognitive radio nodes to adapt the waveform to the technical specifications set by the regulatory authorities.

However, access to radio resources for a secondary use creates other problems such as interference issues and fairness of access between different radio systems involved. If for the interference problem the regulator has found a solution by adopting the limited transmission power, the fact remains that the issue of fairness of access between different radio systems remains unsolved. For that purpose, several approaches have been developed and could be classified according to the criterion of priority access to the spectrum or according to the criterion of architecture. First, following the criterion of the priority access to the spectrum, two approaches can be distinguished: the approach of the vertical sharing of the spectrum where the spectrum is shared at several levels, this is the example of the “spectrum pooling approach” [4] and the approach of horizontal sharing where the spectrum is shared with equal priority as in the case of wireless local areas network (WLAN) [5, 6]. Moreover, under the test architecture, we distinguish the approaches of centralized and decentralized sharing of the spectrum. In the centralized sharing approach, there is a central entity which controls the benefit of the spectrum access procedures. Each entity in the system sends it its status such as its traffic demand in the spectral and temporal domains. So the central entity is responsible for allocating the available spectrum to the other entities by taking into account the aspect of the spectrum efficiency and fairness among the different entities involved. As for the decentralized spectrum sharing approach, “Carrier Sense Multiple Collision Avoidance (CSMA/ CA)” protocols and game theory based on distributed decision making protocols are studied in [7,8]. In these studies, based on a local or global policy, each entity is responsible for the spectrum access and its use. The aim of these studies is to find a minimum policy sets for flexible, scalable, and sustainable for the spectrum sharing dependently from the growth of market demand and amount of traffic. This paper is exclusively focused on the decentralized sharing approach of the available radio spectrum by the high lighting of a method of inter- system cooperation based on the access scheme resulting from the principle of Homo Egualis society and by the suggestion of an algorithm allowing the implementation of this access scheme from the perspective of reaching the spectrum efficiency and the inter-system fairness.

The rest of the paper is organized as follows. In section 2, problem formulation is presented. Section 3 gives the system model, while section 4 tackles the numerical results. Finally the article ends with a conclusion in section 5.

1. Problem formulation

Two groups of networks or operators are considered in the 5 GHz unlicensed band; the primary networks or operators and the secondary or cognitive radio networks. The primary networks have an exclusive access to their dedicated spectral bands; while the cognitive radio operators or networks access to the spectrum only when this one is not used by the primary networks. Here, the primary networks choose the radio-location systems such as radar system and the secondary system networks can be represented by wireless operators whose transmission systems are based on OFDM technology (Orthogonal Frequency Division Multiplexing). To allow an opportunistic access to radio resources of primary system, we assume that the secondary networks also have agile spectrum. So the radio cognitive nodes are responsible for localizing the available resources in both spectral and temporal domains [2],[3]. Indeed we precise that the primary networks do not cooperate with other systems. We have m primary networks with m channels; each network having a dedicated channel and exclusively reach it. We also admit the existence of n operators or cognitive radio networks that access to the spectrum only when this one is not used by the primary networks. Depending on a primary network’s spectrum usage pattern, the duration of a spectral opportunity can exceed hours, even days in spectral bands reserved for emergencies; or can be only few milliseconds in heavily-used spectral bands. It will be relatively easy, for the secondary network to use long-lasting opportunities. However, for short-lasting spectral opportunities, a secondary network may not be able to detect their existence and then utilize them before “expire”. Therefore, our study will rule out the short-lasting spectral opportunities.

In the perspective of making the most of these spectral opportunities, a node belonging to a cognitive radio network scans first the spectrum, either periodically or randomly to discover and use of idle spectrum portions. When it will detect all the activities of the primary network, it will automatically release the channels used with the purpose of avoiding interferences. All nodes in a network of cognitive radio operator use the same spectral opportunities to maintain their inter-connectivity at all time. Therefore, the different nodes must also keep the same information on the spectral and temporal environment, so as to make the decision to transfer their traffics on the selected spectral opportunities.

The spectrum is divided into “channels” which represents small units of spectral bands. Let suppose that each cognitive radio node uses a single channel for its basic communication, but has the ability to use several adjacent channels, simultaneously available for a better quality of transmission. The software defined radio will rightly adopt the modulation schemes required for the use of a wide bandwidth. In addition, the secondary network will use these unassuming adjacent channels, as sub-carriers of a multi-carrier modulation scheme such as OFDMA. The temporal use of each channel by the primary network can be characterized by a random process. Any time the primary network will not use its dedicated frequency band, it will leave some idle channels which will be exploited by the cognitive radio networks.

In this paper, we suppose that the different spectral channels are perfect. That is to say that the channel is either busy or idle. Cognitive radio nodes of different operators are trying to access the idle channels left by the primary network nodes to satisfy their communication needs. We consider simultaneously a set of k idle channels among m channels from the spectrum, available for secondary use. In our case, n secondary networks are trying to exploit the k available spectral opportunities, with $n > 1$. Of course, if $n \leq k$, each cognitive radio network will get a channel. Otherwise, these n networks compete for the access to the different channels. It is then that appear other parameters which will enable an efficient and fair access to the available spectrum; knowing that we have kept the decentralized approach for the sharing of these idle channels. In what follows, we will simply refer to secondary networks or cognitive radio by the term operators.

2. System model

2.1. Homo Egualis society scheme

For the decentralized cooperative approach it is important to design policy rules which can control the compromise between the fairness among operators and the spectrum efficiency. For instance, in [10] a punishment policy against selfish users is suggested in the case of CSMA/CA networks, which means that basically all potential operators for a secondary use of the spectrum are selfish. The basic mechanism of this punishment policy must systematically jam the packets from deviating selfish users. This mechanism then reallocates a portion of the shared spectrum with a view to signal transmission, which leads to the deterioration of the spectrum efficiency. On the other hand, another policy based on the altruistic character of the operator is suggested in [9] and known as the "inequality aversion model". In the model, each operator is characterized by its "payoff" which represents its gain. This model is based on the aversion to inequality of payoffs of operators and, was originally established by studies of social anthropology. By using this policy, operators act as altruists and their unselfish behavior allow their community to be stable and sustainable. We focus on this model to examine decentralized available spectrum sharing among operators. We adopt this because it is natural to assume that all the users want a sustainable environment for radio communication. The utility function based on aversion to inequality can be modeled as follows :

$$u_i = \frac{x_i}{A_i} + \frac{\alpha_i}{n-1} \times \sum_{\frac{x_j}{A_j} > \frac{x_i}{A_i}} \left(\frac{x_j}{A_j} - \frac{x_i}{A_i} \right) - \frac{\beta_i}{n-1} \times \sum_{\frac{x_j}{A_j} < \frac{x_i}{A_i}} \left(\frac{x_i}{A_i} - \frac{x_j}{A_j} \right)$$

where u_i is the utility of the i^{th} operator, and x_i and x_j ($i \neq$j) respectively indicate the payoffs of the i^{th} and j^{th} operators. Payoffs are numbers which represent the motivations of the operators such as their profit, quantity, or other continuous measures. In this paper, the payoff shows the amount of spectrum used for their signal transmission. Term n represents the number of operators sharing the spectrum. A_i is the priority level of the i^{th} operator among all the operators for the payoff. When some operators have priorities over other operators in (1) are reduced in accordance with their priority level. In addition, α_i and β_i show the reaction factor of the i^{th} operator respectively against those which receives a higher payoffs and against the operators which receive lower payoffs. Knowing that the utility functions express the satisfaction level of operators, each operator adopts a behavior allowing it to maximize its own utility function independently. Based on an anthropological study [9], it is also shown that a sustainable community where each operator receives the same payoff can be established by the setting $\alpha_i > \beta_i$. This parameter setting model of the operator' preference when his payoff is less than that of the other operator is different from that when his payoff is more than that of the other operators.

Here, we assume that each operator can receive information about the payoff value and the priority level of the others through a backbone network to which all the operators are connected. It is also possible for each operator to measure individually its payoff by monitoring all transmitted signals from users and by detecting to which operators the users belong by using signal headers which contains their affiliation identities.

2.2. Application to wireless communication systems

In this section, we describe how cognitive radio nodes access the channel and how do they collect information in order to avoid collisions and signal interferences between the various stakeholders of the system. Since the channels are in a perfect condition, signal loss occurs only when there is a collision with the primary users or equivalently when the state of the channel is busy during the signal transmission time of an operator.

The operator should then use each channel appropriately by transmitting its own signals between the busy states. In addition, we consider that cognitive radio system go through the simple principle of the protocol "Listen Before Talking (LBT)" to access the channel. In this protocol, first the node senses the selected channel to check if it is idle or busy. In practice, this can be done by the detection of energy. The sensing of the channel is only an option when the cognitive radio nodes have knowledge of the characteristics of the physical layers signals from primary users. When a cognitive radio node finished its communication, it automatically releases the radio resources used.

We also make the assumption of perfect coordination between cognitive radio nodes. In other words, if the channel is occupied by pair of transmitter and receiver, all other cognitive radio nodes in the area are aware of it so as to avoid a collision between their signals. The protocol access to the spectrum is not persistent, which means that if the channel is found busy in the sensing, the transmission cycle ends and statistic data concerning the occupation of the channel are recorded, and the node tries other attempts to use another channel. Otherwise, the node transmits its signals. Thus, from the scheme of society Homo Egualis, we define the transmit probability. This probability for each operator i at time t is given by :

$$\Delta P_i(t) = \frac{\alpha_i}{n-1} \times \sum_{\frac{x_j}{A_j} > \frac{x_i}{A_i}} \left(\frac{x_j}{A_j} - \frac{x_i}{A_i} \right) - \frac{\beta_i}{n-1} \times \sum_{x_j \,\_\, x_i} \left(\frac{x_i}{A_i} \frac{x_j}{A_j} \right) \quad (3)$$

W[illegible]n f[illegible]e i^{th} operator, and L_i is the traffic demand for the i^{th} operator.

By controlling the probability of access of each operator based on equation 2, the rules laid down on the access to the shared spectrum may reflect the behavior of each operator.

2.3. Proposed algorithm

We have below, the proposed algorithm for the transmit probability for decentralized dynamic access to the available spectral resources according to Homo Egualis model :

Function PROBA_ACCESS_HOMO_EUGALIS

```
BEGIN
        ARRAY Alpha (Number_operator2) into REAL
        ARRAY Beta (Number_operator2) into REAL
        FOR a ← 1 to Number_operator2
                READ Alpha (a)
                READ Beta (a)
        END FOR
        ARRAY Xi (Number_operator1) into REAL
ARRAY Pi (Number_operator1) into REAL
        FOR i ← 1 to Number_operator1
                [vi, xi] ← CALL PAYOFF FUNCTION
                Pix ← 1
                lxi ← LEN (xi)
                READ Xi(Xi,xi)
                h ←1
                som ← 0
                WHILE   Xi(i,h)  <  Xi(i,lxi)
                        som ← som + (Xi(i,lxi) -
        Xi(i,h))/(Xi(i,lxi))
Palphai ← Alpha(1,i)/
Number_operator1)*som
                h ← h+1
                END WHILE
                WHILE   Xi(i,h)  >  Xi(i,lxi)
                som ← som + (Xi(i,h) -
                Xi(i,lxi))/(Xi(i,h))
                        Pbetai ← Beta (1,i)/
Number_operator1)*som
                h ← h+1
                END WHILE
                Pi = MAXIMUM (0, (MINIMUM(1,
(Pix + Palphai - Pbetai)))
```

RETURN Pi

END FOR

FIN

We shall proceed to the evaluation of this algorithm in the following section.

3. Numeric results

For the evaluation of our algorithm giving the transmit probability for a secondary usage of the available spectrum among several radio cognitive operators, we consider that each channel alternates between the busy state and the idle state.The durations of busy and idle states are given by random distributions with unknown mean. We analyze two scenarios where the number of primary users is 12 ($m = 12$).The main reason for choosing this number is that there are 12 (non-overlapping) channels in the 5 GHz band for the IEEE 802.11a. In both scenarios, we consider the same traffic demand for all operators; with $\alpha = 1$ and $\beta = 0.01$.General parameters such as the number of idle radio resources, the number of cognitive radio operators, are given for each scenario. The reduction factor W_i is set to 1 for all operators.

Scenario 1 : The number of operators is lower or equal to the number of idle channels ($n = 5$ and $k = 6$).

In this scenario, there are five operators who wish to reach the frequency spectrum with 6 idle channels. The figure 1-a shows the payoffs of these five operators.perator number 3 presents the highest payoff, while operator number 4 has the lowest payoff.This situation not influences the spectrum access of the whole of these operators.Here, the number of radio cognitive operators being lower than the number of idle channels, as announced in the problem formulation, we observe very well that each operator reaches a channel.t justifies the transmit probability value of all the operators which is 1 as shown in the figure 1-b.

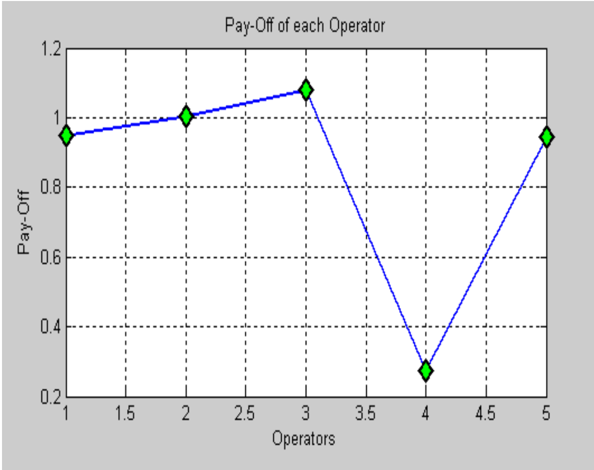

Figure 1-a : Payoffs of different operators for scenario 1

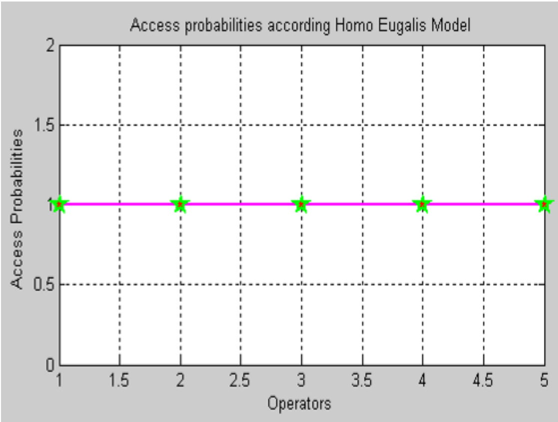

Figure 1-b : Transmit probability of different operators for scenario 1

Scenario 2 : The number of operators is higher than the number of idle channels ($n = 6$ and $k = 5$).

In this second scenario, there are 6 operators who wish to reach the frequency spectrum with 5 idle channels.The figure 2-b shows the payoffs of these 5 operators. The operator number 1 presents the highest payoff, while the operator number 5 has the lowest payoff.The number of cognitive radio operators being higher than the number of idle channels, the access to the idle channels will be given by the various values of the transmit probability of the operators. As we can see on the figure 2-b, only, the operator number 6 does not reach the spectrum.On this figure, its transmit probability is equal to zero while knowing that it does not have the lowest payoff among the six operators. That is due to the high levels of priority from the operator number 2, 3 and 5, compared to that of the operator number 6 whose payoff is the largest among the four operators.

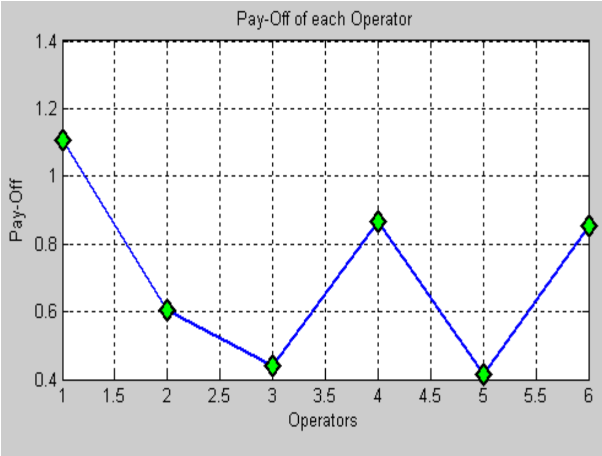

Figure 2-a : Payoffs of different operators for scenario 2

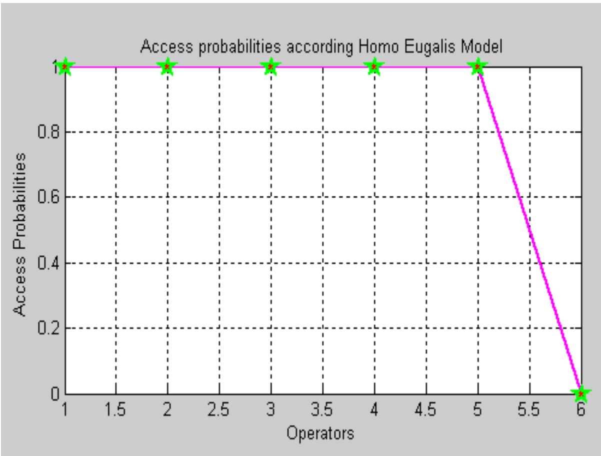

Figure 2-b : Transmit probability of different operators for scenario 2

Then, we have also to carry out the changes the number of operators and the idle channels number while remaining within the framework of this scenario and we ended to the same remark.

4. Conclusion

In this article, we exposed the model of dynamic access to the spectrum based on the principle of the game theory. In this particular case, we used Homo Egualis model. This model allows a decentralized and fair sharing of the available radio resources between the various operators. Besides, we proposed an algorithm for implementation of this dynamic spectrum access scheme. We also evaluated our algorithm through two scenarios which show the resolution of spectrum under use problem by giving additional opportunities to the operators and the resolution of fairness problem among different operators

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