# Enhancing content dissemination for ad hoc cognitive radio

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***Abstract*—** Nowadays, the channel selection is a challenging task in cognitive radio because of the high radio activity and the preemptive priority of the licensed user, called primary user (PU). In this paper, we propose a DIStributed channel Selection mechanism for efficient content dissemination in COgnitive RaDio ad-hoc networks (DISCORD). DISCORD selects the most appropriate channel for content dissemination based on the PU channel occupancy and the importance of cognitive radio neighbors in the network. Indeed, a sender peer in DISCORD forecasts the channel primary user activity by the mean of the actual and statistical estimation of the channels occupancy and selects the most stable one. Moreover, it makes use of a new Social Networks Analysis (SNA) inspired metric to select the appropriate neighbors for high content dissemination in the network.
The simulation results using NS2 shows that Discord presents highest performance in terms of interferences, PU priority respect and content delivery ratio in multi-hop CRNs comparing to four related protocols.

***Keywords—Ad-hoc; Cognitive radio; QoS; content delivery; social networks analysis; time series***

## I. Introduction

Recent technological advances have given rise to the development of ad hoc wireless devices: self-organized devices that can be deployed without the support of any infrastructure network. These devices usually have a small size with integrated processing, storage, and communication capabilities.

Although ad hoc networks can operate on different wireless standards, the current state of the art has typically limited their action fields in the 2.4 GHz, 900 MHz and the industrial, scientific and medical (ISM) bands. With the increasing proliferation of wireless devices, these bands are getting more and more congested. On the other hand, there are many operators licensed bands, such as 400-700 MHz range, that are used occasionally, mostly under-utilized for transmission [1].

The wireless spectrum licensing is currently carried out for long term periods and over vast geographical regions. So as to deal with the problem of spectrum scarceness, the Federal Communication Commission (FCC) [2] has recently permitted the use of licensed bands by unlicensed devices. Thus, dynamic spectrum access (DSA) mechanisms are investigated to address the current spectrum ineffectiveness problem.

This new research field advocates the development of cognitive radio networks (CRN) in order to enhance the spectrum utilization. The idea behind CRNs is that non-licensed devices (called *Secondary Users* or SU) take advantage of the licensed bands when the licensed users (called *Primary Users* or PU) are not using it. However, this situation leads to many challenges, such as the high fluctuation in the available spectrum as well as users' quality-of-service (QoS) provisioning problem [3]. In addition, the dynamic network topology and the distributed multi-hop architecture of ad hoc networks make the task more and more challenging.

As most of the spectrum is licensed, the challenge in CRN is to exploit the licensed spectrum without interfering with the communication of other licensed devices. The cognitive radio allows to temporarily use unexploited spectrum, referred to as *white space* [4]. Once this band is further used by a licensed device, the SU should move to another band to avoid interferences.

Along with the network architecture, CRNs can be classified into infrastructure-based CRNs and CR Ad Hoc Networks (CRAHNs) [3]. The infrastructure-based CRN relies on a central entity such as a Wi-Fi access point or cellular networks base station, while CRAHN does not have any infrastructure. Consequently, a CR device can communicate with other CR devices in an ad hoc manner using different radio channels.

In this paper we propose DISCORD, a distributed channel selection mechanism for efficient content dissemination in CRAHNs.

978-1-4799-0959-9/14/$31.00 ©2014 IEEE

DISCORD selects the best channels for content dissemination based on the channel primary user occupancy and the importance of each CR neighbor in the network. The main goal of CR sender is to select the best channel which reduces interferences with the PU and ensures a large dissemination of the content. Therefore our solution selects the channel with the lowest PU activity and the channel used by neighbors within strategic location in the network (i.e. central neighbors), ensuring a wide content dissemination in the network. The importance of an actor in its community was widely studied in the social network analysis field. DISCORD is inspired by node centricity metrics in order to select the channel used by strategic neighbors.

We studied the performance of DISCORD using NS-2 simulations and we show that DISCORD selects the best channels for an efficient content dissemination. Indeed, the effectiveness of the channel selection is enhanced by more than 50% compared to four other approaches, namely: Random, Highest Degree, Selective Broadcasting [5], and SURF [6]. The proposed solution ensures also the highest diffusion capacity in multi-hop CRAHNs and enhances the delivery ratio by more than 20%.

The main contributions of this paper are as follow:

1) A channel selection mechanism for ad hoc cognitive radio is proposed. The proposed mechanism is based on two metrics: the stability of the cognitive radio channel, and the strategic position of the neighbors using the channel.

2) A PU user estimation model based on time series is proposed, to forecast the channel PU activity and consequently the channel stability

3) A new centrality metric is proposed to characterize the strategic position of a node in an ad hoc network

The rest of the paper is organized as follows. In section II we give an overview of the state of the art on cognitive radio in ad hoc networks. Section III describes in details the proposed channels selection for content dissemination in CRAHNs. In Section IV, we present some illustrative simulation results. Finally, section V provides the conclusion and future work.

## II. Related works

In this section we review the main works related to channel selection for content dissemination in cognitive radio networks. In [8] authors propose a policy based mechanism for channel selection. The proposed mechanism is performed by a centralized base station. The base station maintains centralized channels utilization state registry and selects the appropriate communication channel from the free channels set based on one or combined criteria. The main drawback of this approach is the single point of failure which consists in the centralized selection entity. A distributed channel selection mechanism is proposed in [9], where each node selects independently the communication channel using a stochastic approach to estimate the channel occupation. The channel with low probability utilization is selected. A game theory based approach has been proposed in [10] where channel negotiation protocol is proposed where each node tries to achieve its QoS requirement. The authors show the Nash equilibrium of their proposal. The main drawback of all these protocols is the fact that they are dedicated to single hops communication and they are not adapted to the content dissemination scenarios where the collision due to retransmissions should be taken into consideration.

Research on content dissemination in multi-hop CRAHNs is in its infant stage. Indeed, a few works tackling channel selection in the context of content dissemination over multi-hop CRAHNs have been proposed such as [5], [6], [12] and [13]. In [5], each node selects a minimum sub-set of channels which covers all its neighbors without any consideration to the PU activity. In [13], a common control channel (CCC) for the entire network is considered. We note that most of these works consider unrealistic assumptions which make them inappropriate to be adopted in real scenarios. Indeed, in [5], [12] and [13] authors assume that the network topology and the channels information of all SUs are supposed to be known.

SURF [6] is the most related work to our proposal, a distributed channel selection approach for content dissemination in multi-hop CRAHNs. In this work available channels are categorized, based on the PU channel unoccupancy and the number of CR neighbors using the channels. However this work does not take into consideration the diffusion capacity of the selected CR neighbors in the channel selection decision process.

Unlike the main existing solutions, in our proposed solution DISCORD: 1) no global common control channel is supposed to exist; 2) the overall network topology is not known, the CR node is only aware of its one-hop neighbors; 3) Only information about active channel of one-hop neighbors is supposed to be known, no global information on SUs channel is available. DISCORD selects the channel which can be as long as possible utilized by SU, based on the time series estimation of the channel PU activity. In addition the selected channel is the one used by CR neighbors with a high dissemination degree in the network.
The proposed mechanism is presented in details in the next section.

## III. Model and solution

### A. Assumptions

In DISCORD, we consider a CRAHN network of a set of PU licensed devices and a set of SUs non-licensed devices. We assume that the network does not rely on any centralized network entity that could perform some network operations, such as channel selection decision, spectrum sensing coordination, etc. All these tasks are performed by CR devices themselves in a distributed and a cooperative manner [14].
We assume a set $F$ of radio channels, licensed and non-licensed ones. The licensed channels are used exclusively and

preemptively by the primary user. If the channel is PU free then it can be used by a SU.
We consider that the PU activity detection and spectrum sensing are out of scope of DISCORD. These tasks are performed by a physical layer entity [15], which provides instantaneous PU spectrum unoccupancy information. DISCORD will work on the provided list of available channels.
We also assume that a CR node does not have a global knowledge of the network, and does not need any CR local state to be broadcast on the network. A CR node only needs to get information about its one-hop neighbors CR nodes. To do that, DISCORD relies on a local Common Control Channel.

### *B. Channel selection mechanism*

DISCORD is a channel selection mechanism for content dissemination in CRAHNs. It selects the best available channel in terms of PU unoccupancy and content diffusion capacity of CR neighbors. DISCORD promotes channels that can be as long as possible utilized by the SU. This initial channels classification is then refined by selecting the channel utilized by the neighbors that can disseminate the widest possible content into the network to ensure a large dissemination of the content in the network and in a minimum of hops.
Every CR neighbor, receiving the packet, undertakes the same mechanism to select the appropriate channel for carrying the packet to its neighbors.

In DISCORD, a cognitive radio *i* locally computes weight $W_f$ for each sensed frequency channel $f \in$ F using the following formula:

$$W_f = W_f^{PU} * W_f^{DC} \quad (1)$$

Where $W_f^{PU}$ represents the channel *f* weight related to its freedom from the PU activity and $W_f^{DC}$ represents the diffusion capacity of all CR *i* neighbors utilizing channel *f*. Channels are then ordered based on their weight and the selected channel for transmission is the channel having the highest weight. DISCORD is composed then of two modules: *Channel primary user activity forecast module* and *Channel diffusion capacity* module.
In the following sub-section, we present the two modules.

#### 1) *Channel primary user activity forcast*

DISCORD makes use of time series [16] to predict PU activity, i.e. the occupancy of channel by the PU. This module allows to compute the $W_f^{PU}$ weight of the channel.
In DISCORD, a CR forecasts the PU activity based on its previous activity in order to select the best channel to transmit content. The selected channel is a free channel that can be utilized by SU as long as possible. This is why CR should forecast the PU occupancy of each available channel and predict its unoccupancy time, modeled as a time series process.

We define random variables $x_t$, $y_t$ as the time duration, over which the PU is active/inactive on a channel *f*.
In order to study channel PU occupancy comportment and on the basis of the successive values of the random variables $x_t$ and $y_t$, we biuild the times series $\{x_t\}_{t\in N}$, $\{y_t\}_{t\in N}$ where $x_i$ denotes the duration of the $i^{th}$ PU activity period and $y_i$ denotes the $i^{th}$ PU inactivity period.
In our study, we used the data set resulting from the spectrum measurement study performed in Aachen (Germany) [17]. The measurements, collected from December 27th, 2006 to January 2$^{nd}$, 2007 concern the 20MHz to 6 GHz bands, where most of wireless services work nowadays.
We applied the Box-and-Jenkins [18] approach in order to analyze the time series. We had, before, to check the stationarity of the time series $\{x_t\}_{t\in N}$ and $\{y_t\}_{t\in N}$. The obtained results showed that the two stationarity conditions [18] are satisfied in all the time series (of the different channels) resulting from the data analysis. Consequently $x_t$ and $y_t$ can be analyzed using Box-and-Jenkins ARMA analysis method. This process includes three main steps: model identification, model parameters estimation and time series values forecasting.
After analyzing the autocorrelation (ACF) and the partial autocorrelation (PACF) functions of the activity/inactivity duration of the PU, we conclude that the time series model is ARMA(1, 3) for $\{x_t\}_{t\in N}$ and ARMA (2,1) for $\{y_t\}_{t\in N}$.
Based on these models, a node can predict the activity and inactivity duration of the PU. Consequently, it will be able to predict when the PU utilizes the channel and for how long it will last. This information is exploited to perform channel selection.

For each available channel, the CR computes the next PU activity date and computes the $W_f^{PU}$part of the channel weight presented in equation (1) as follows:

$$W_f^{PU} = \beta \left| \sum_{i=0}^{i=k} y_i - t \right| \quad (2)$$

$\beta$ is a Boolean variable defined as follows:

$$\beta = \begin{cases} 1 \; if\ the\ channel\ f\ is\ not\ utilised\ by\ PU \\ 0 \; otherwise \end{cases}$$

*t* : the current time
*k* is the activity period or inactivity period that covers the current time *t*.

#### 2) *Channel diffusion capacity weight*

In order to select the best channel to disseminate the content in CRNs, DISCORD selects the channel used by the CR nodes which ensures a large dissemination. Our target is then, the discovery of the CR nodes that are more "central" in the CRN.

In Social Network Analysis (SNA) [19], the node degree and the Shortest-Path Betweenness Centrality (SPBC) have been widely used as a centrality metric. In Figure 1, we note that the nodes C,D,F and G are equally central (in terms of degree); they all have a degree equal to 4. In addition, if we calculate the SPBC [19], for each node in the graph, then node G is the most central, followed by nodes C, D and finally node F. This is somewhat unexpectedly, since node F has all network nodes at its reach (at distance 2-hops). Based on this observation, we have proposed in [7] a new centrality metric, named the dissemination capacity (DC), defined as follows:

**Definition:** The dissemination capacity DC($v$) of a node $v$ is the maximum degree $n$ which ensure that each 1-hope neighbor of node $v$ has a degree greater than or equal to $n$.

Using the Dissemination Capacity as defined, CR nodes which have more connections (larger degree) are more likely to be "powerful" to disseminate the content in the network, since they can directly touch more other CR nodes. But, their power also depends on the degrees of their 1-hop neighbors. Large values for the DC($v$) of a CR node $v$ indicate that this the node $v$ can reach others on relatively short paths.

The DC, as defined, offers many advantages, because each CR node, in order to compute its DC, needs to get from its 1-hop neighbors only their degrees, imposing less communication and computational cost.

In order to select the transmission channel, the CR node calculates the diffusion capacity of channel $W_f^{DC}$ as follows:

$$W_f^{DC} = \sum DC(CR_f) \quad (3)$$

For each CR neighbor $CR_f$ using the channel *f*.

# IV. Performance Analysis

## A. Baseline strategies for comparison

In order to evaluate the performance of DISCORD, we conducted comprehensive simulations using the Cognitive Radio Cognitive Network (CRCN) patch of NS-2 [20]. We compare DISCORD with random strategy (RD), highest degree strategy (HD), selective broadcasting (SB) [5] SURF [6].

In RD, channels are randomly chosen by CR node to disseminate content, regardless of the PU activity over these channels.

HD approach selects the channel with the highest CR degree, namely the channel used by maximum number of neighbors. However in SB, the CR node selects a minimum set of channels for transmission, Essential Channel Set (ECS). The CR node transmits in round robin fashion over these channels until all the neighbors are reached.

In SURF, channels are classified based on PU channel unoccupancy and the number of CR neighbors using the channels. In this approach, all neighbors' nodes are considered equivalent regardless of their diffusion capacity.

## B. Simulation setup

We compare DISCORD with the previous approaches in terms of the following metrics:

a) Average Delivery Ratio: Defined as the ratio of packets received by a CR node to the number of original packets diffused in the network.

b) Harmful Interference Ratio (HIR) [6]: Defined as the ratio of times where the selected channel is found used by the PU. HIR measures the respect of the approach towards the PU activity.

c) Ratio of Accumulative CR Receivers [6]: defined as the ration of CR receivers to the number of neighbors in each hop. i.e. when a node $x$ diffuse a content how much CR nodes in the network will receive the content ?

The number of CR nodes is 100, randomly deployed within an area of 700m x 700 m, with a transmission range of 250m. Simulations are performed for 1000 seconds. Every 1 second a packets is sent by a randomly selected node. Obtained results are with a confidential interval of 95%.

## C. Results and discussion

### 1) Average Delivery Ratio

Figures 2 and 3 compare the average delivery ratio of RD, HD, SB, SURF and DISCORD, for 5 available channels (ch=5) and for 10 available channels (ch=10) respectively. DISCORD significantly outperforms the other approaches. For ch=5, DISCORD enhances the delivery ratio of SURF by approximately 20%. Indeed the overall average delivery ratio goes from 26% for SURF to about 44% for DISCORD. The other strategies (RD, HD and BS), exhibit a low delivery ratio (less than 5%). In fact SURF does not select the best neighbor to disseminate the content. It selects the channel that is more used in the neighborhood. But it is not guaranteed that these neighbors are good candidates to disseminate content, they can be borders nodes. However in DISCORD, the transmitter CR node is "far sight", it looks to the neighbors of the neighbor node and selects the channel used by high diffusion capacity nodes.

The delivery ratio is very low in the case of RD, HD, and SB because they are not aware of the PU activity on the channel. Thus a severe decrease in the delivery ratio is observed.

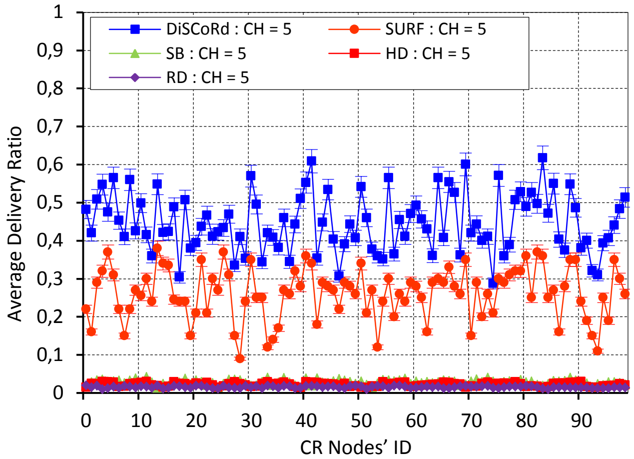


Figure 1: CR Nodes' ID and average delivery ratio (5 channels)

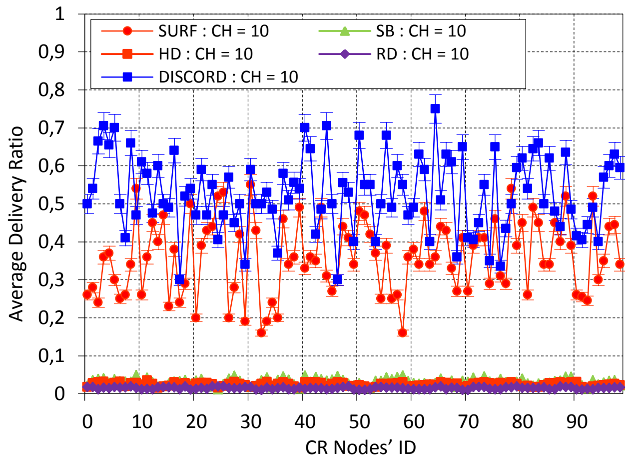


Figure 2: CR Nodes' ID and average delivery ratio (10 channels)

2) *Harmful Interference Ratio (HIR)*

We now study the PU harmful interference ratio for the five approaches i.e. RD, HD, SB, SURF and DISCORD for Ch=5 and Ch=10. In Figure 4, we note that in DISCORD, interferences with the PU are very low compared to RD, HD and BS because DISCORD takes into consideration the PU activity in the channel selection process, while the above mentioned approaches do not. Moreover, DISCORD lightly outperforms SURF which demonstrates the effectiveness of our ARMA based PU activity forecast model.

Furthermore, we note that the HIR value decrease with the increase of the number of channels. Indeed, when we vary the number of channels from 5 to 10, we note that the HIR in DISCORD goes from 0.06% to 0.03%. We explain this by the fact that the probability to find a free channel is higher when the number of channels increases.

3) Ratio of Accumulative CR receivers

In Figure 5 we study the ratio of accumulative receivers for each transmission hop in RD, HD, SB, SURF and DISCORD. The results are represented until the 6th hop.
We note that DISCORD presents better performances than all four other approaches and for all the hops. Indeed, in the first hop, in the case of DISCORD 98% of CR nodes receive the original message when using 10 channels (96% for 5 channels), however this ratio is 95% SURF very low values (<15%) for the other mechanisms.
We note in Figure 5 that when the number of hops increases, the number of receivers decrease which can be naturally explained by the increase of collision probability with other retransmissions. Despite that, DISCORD provides a better dissemination ratio than other strategies. This is obtained thanks to the retransmission selection mechanism proposed.


Figure 3: PU harmful interference ratio

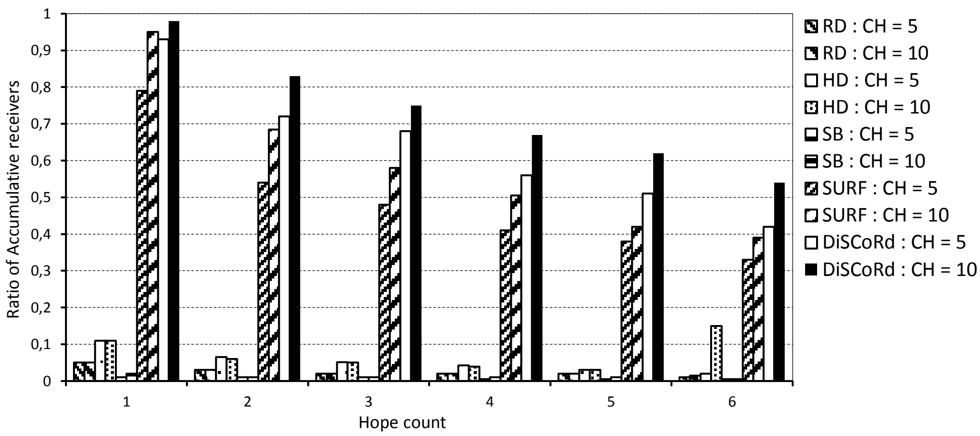


Figure 4: Ratio of accumulative receivers

## V. CONCLUSION

In this paper we presented DISCORD, a channel selection mechanism for content dissemination in multi hop cognitive radio ad hoc networks CRAHNs. Discord is based on a new channel selection metric. This metric depends on the primary user (PU) activity forecast and the strategic position of the channel user in the network. DISCORD forecasts the PU activity using a time series model (ARMA), and measure the centrality of a node in the network using a new SNA inspired metric called diffusion capacity (DC).

Simulation results show that DISCORD outperforms SURF, selective broadcasting, highest degree and random-based approaches in terms of delivery ratio, number of retransmission and interferences.

As a future work we plan to extend our work for more QoS demanding traffic such as real time video streaming and in more challenging networks such as vehicular ad hoc networks (VANET).

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