Energy Efficient Information Sharing in Social Cognitive Radio Networks

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Abstract. The growing usage of the devices and the popular high data rate services is increasing the demand for radio resources and the associated energy consumption. Cognitive radio (CR) technology has been proposed as a solution to improve spectrum utilization, enabling the devices to identify alternate frequency bands and opportunistically use them. We propose a novel social-cognitive radio (S-CR) architecture able to improve the network energy efficiency. The key aspect of the such solution is the resulting indirect form of cooperation. Indeed, the devices only share information about channel availability and device profile information, without any predefined cooperation to perform a common task, such as cooperative spectrum sensing. In this way, it is possible to reduce some energy demanding operations of the cognitive cycle, such as the sensing procedure, since the social information sharing requires less energy. A novel S-CR protocol is developed to share environmental information and allocate spectrum resources to the CRs. Simulation results compare the S-CR protocol with its non-social version and reveal the effectiveness of the proposed solution in terms of energy consumption reduction.

Keywords: Cognitive radio networks · Social networks · Sharing · Energy efficiency

1 Introduction

Over the last years, the data volume through the network is increasing by a factor of ten each five years, contributing to the increment of radio resources demand and the grow of the Information and Communication Technologies (ICT) energy consumption in the range of 15–20 % [1].

The development of new radio and network solutions have become essential to improve energy efficiency and to bring commercial benefits to both end-users and operators [2].

Moreover, given the limited available spectrum, user devices are called to more complex tasks to exploit the best spectrum opportunities, as specified in the concept of cognitive radio (CR). Indeed, the CR framework allows CR users to detect, use and share the available spectrum, in a way that the licensed or primary users (PUs) are not affected [1,3], at the cost of more complex devices.

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Several works have deeply studied the cognitive cycle within each radio device. However, none of them exploits the social network paradigm to reduce the considerable burden at device level.

Social networks have already demonstrated the power of information sharing among users, a characteristic that can be helpful also in this context. We propose to use the social cognitive network concept to shift the work load from individual devices to a network level cooperation and decision making, through cognitive and social networking.

Some studies, such as [3], have already evaluated the energy consumed by a CR to perform some power hungry functionalities like spectrum sensing. The social network paradigm would be able to avoid such energy demanding operations, since spectrum information can be obtained and shared through a social network, improving the overall system energy efficiency.

The main contributions of the paper are:

- a social cognitive radio architecture, with a detailed model and the main definitions, such as the type of information to be shared, the community, and the concept of indirect cooperation;
- a social cognitive sharing protocol to exchange environmental information and allocate radio resources in a fully distributed manner.

The paper is organized as follows: Sect. 2 describes the definition of social network and its application to cognitive radio systems, Sect. 3 shows the proposed social cognitive network architectures and details the model, Sect. 4 focuses on the proposed social sharing protocol, Sect. 5 shows some interesting simulation results, and, finally, some concluding remarks wrap up and close the paper in Sect. 6.

2 Social Structure and Application

Social network concept is attracting the attention of researchers in both academic and industry fields, intrigued by their peculiar features [4].

Here we first present the general definition of social network, useful to fully understand the potential of this type of network, and then describe its application to cognitive radio networks (CRNs).

2.1 Social Network Definition

The authors in [4] describe the characteristics of social network sites (SNSs) and propose a comprehensive definition of it as web-based services that allow individuals to (i) construct a public or semi-public profile in a limited system, (ii) create a list of other users with whom sharing information/connection, (iii) view their list of connections and the ones made by others inside the system.

The main feature of social network sites is not allowing people to meet strangers, but rather enabling users to create and make visible their social connections/networks. Indeed, since friends list contains links to each friend's profile, public connections allow users to sweep the network graph by exploring the friend lists.

2.2 Social Behavior in Cognitive Radio Networks

Some recent research in CRNs is exploiting environmental and relations among the actors to develop more efficient protocols. Two main directions have been developed:

Social Collaboration for Sensing in CRNs. Generally, cooperative sensing assumes that all CRs cooperate for the procedure. In [5] the authors describe a more realistic cooperation willingness according to the social relation between the CRs. Indeed, a CR would sense for a CR that is considered a "friend", while it may not for one considered a "stranger".

After denoting a CR by some parameters, such as community, cooperation tendency, friend list, sympathy list, and cooperation score list, a cooperation set selection procedure is developed to define the CRs involved in the sensing operation [5]. Finally, specific scores are updated for each CR according to its behavior in the cooperative sensing procedure.

Social Recommendation System for CRNs. The collaboration among CRs in terms of channel recommendation has been investigated in [6]. The recommendation procedure consists in sharing channel preferences of CR users, which can change over time, and results in a behavior propagation in a social network. The dynamics of such social behavior in CRNs has been studied as a stochastic dynamical system [6].

3 Social CRN Model

Unlike some recent solutions in CRNs that exploit only some features of social concept [5,6], the proposed social CR (S-CR) scheme has been developed starting from the general definition of a social network to properly exploit all its capabilities. As shown in Fig. 1, we consider a distributed CR network without any centralized base station (BS) to coordinate the resource allocation for CRs. In this scenario, CRs send sensing information each other in accordance to a novel social framework.

Specifically, we assume N primary users (PUs) and M CRs in a certain location. The CRs are allowed to access the unused spectrum resources of PUs, but, as soon as a PU is detected in the same channel, a CR has to vacate the spectrum band to avoid interference towards PUs.

We consider that CRs may transmit different traffic types and organize them in communities according to the traffic type they use mostly.

In the proposed social framework, a CR that needs to transmit, first requests the information about the available channels to the CRs belonging to its communities, and, only if there is non-reliable information, the CR will start the sensing operation.

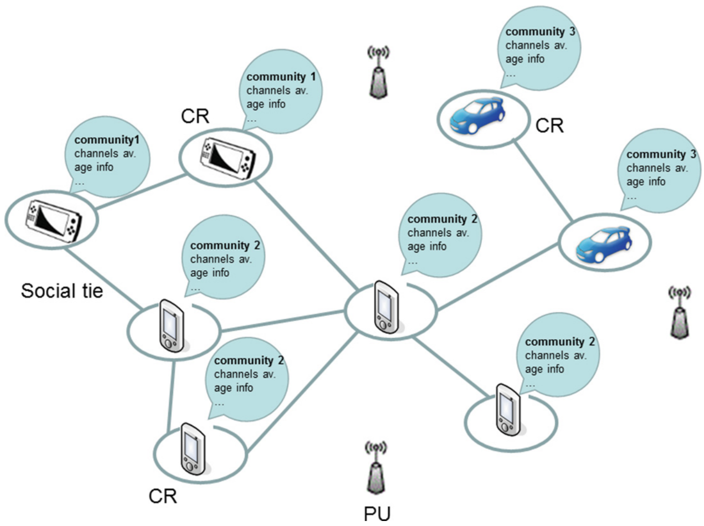

Fig. 1. Social CR architecture

In particular, the main features of the proposed social CRN framework are:

- a device-centric social framework, where the social ties are considered among the devices, not humans.
- As stated in [4], the main concept of SNSs it that the actors of the network share their profile. Thus, differently from classical CRNs, besides environmental information, like the available channels, we propose to share CR device information, such as the required bandwidth.
- A fully distributed system is considered, where each CR has its own repository about channels availability and a possible different age of information for each channel.
- Finally, in line with human social networks we develop an indirect type of cooperation. Specifically, CRs will not directly be involved in a common operation, such as cooperative spectrum sensing, but rather they will just share their own information about channels, as users in human social network have the option to share information without direct cooperation.

3.1 Social CRN Definitions

In the following we outline the main definitions of the proposed social CR framework.

Types of Sharing Information: we consider both environmental and CR device profile data, which are then exploited in the S-CR protocol to improve the overall performance of the network (see Sect. 4). We here list some possible types of data, although in the S-CR protocol we use only some of them:

- environmental information:
  - available channels,
  - age of information,
- profile information:
  - power battery level,
  - traffic type commonly used by the user (video, call, text),
  - required bandwidth,
  - will to share.

In particular, given a CR repository, the ages of information about the channels may be different, as shown in Fig. 2. Indeed, as an example, as soon as a CR finds an available channel through sensing, the CR stops the spectrum sensing on the other channels. Thus, the information of the spanned channels is younger and more reliable than the channels not involved in the sensing process.

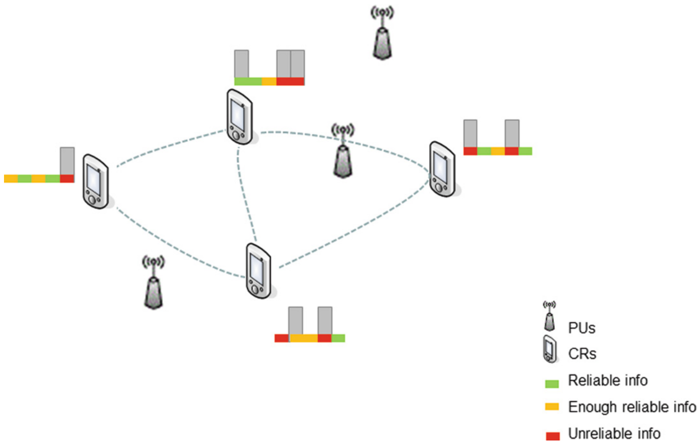

Fig. 2. Ages of shared information

Community: the friends list is used to define the community a CR belong to. We define three communities depending on the CR traffic type, among video, call and text. For the time being, we do not consider location restriction, assuming that all CRs belonging to the same community can interact with each other.

We assume that the CRs share their information, about the environment and their profile, only with the users belonging to their same community. In this way we limit the channels to sense and the information sharing is performed only among the interested CRs. As an example, the CRs interested in video traffic will not need information about all the available channels, but only about the ones with larger bandwidth.

Fully Distributed Social CRN: following the definition of SNs, we consider a fully distributed network where each CR has its own repository. A CR may obtain information about available channels in two ways: (i) through social sharing, (ii) through its spectrum sensing operation.

Indirect Social Cooperation: the social framework differentiates from cooperation since CRs do not perform together a common operation, such as cooperative spectrum sensing. Also, if a CR requests available channels, the other CRs do not perform any sensing operation on its behalf. In this sense, there is no direct cooperation among the CRs. A CR just share information already stored in its repository if another CR requests them.

3.2 Spectrum Sensing Procedure

A CR that needs to transmit, first asks for information about the available channels among the CRs in its community, then, if there are no reliable information, starts sensing the channels. As soon as the CR finds a channel free from PU transmissions, it stops the sensing operation and uses that channel to transmit. As consequence, each CR will have on its repository a different age of information per each channel.

The CRs may employ any type of detector for spectrum sensing, such as an energy-based detector, to detect PU signals. The energy detector measures the energy of the received signal, i.e., the output signal of bandpass filter with bandwidth B is squared and integrated over the observation interval [7]. The output of the integrator Z_y is then compared with a threshold λ, to decide if a PU is present or not [7]:

$$\begin{cases} Z_y > \lambda & decide\ H_1 \\ otherwise & decide\ H_0 \end{cases} \tag{1}$$

where H_0 and H_1 represent respectively the hypothesis that the PU is inactive and active.

According to recent findings, we assume PU activities with death rate α and birth rate β. We can estimate the a posteriori probabilities as follows [7]:

$$\begin{aligned} P_{on} &= \frac{\beta}{\alpha + \beta} \\ P_{off} &= \frac{\alpha}{\alpha + \beta} \end{aligned} \tag{2}$$

where P_{on} is the probability of the period used by PUs, and P_{off} is the probability of the PU idle period.

From the definition of maximum a posteriori detection [7], PU detection probability P_d and false-alarm probability P_f are given by

$$\begin{aligned} P_d &= Pr[Z_y > \lambda | H_1] \cdot P_{on} = \bar{P}_d \cdot P_{on} \\ P_f &= Pr[Z_y > \lambda | H_0] \cdot P_{off} = \bar{P}_f \cdot P_{off} \end{aligned} \tag{3}$$

where $\bar{P}_d$ and $\bar{P}_f$ are the detection and false-alarm probabilities of a CR using an energy-based detector, respectively [7].

4 Social CRN Information Sharing Protocol

The proposed solution allows to reduce the number of burden sensing operations performed by each CR, by using the information about available channels shared in the social architecture, which is less energy demanding (see Table 1).

4.1 Description of CR States

At each round, a CR can be in *busy* or *idle* mode. A CR is in *busy* state if:

- the CR was transmitting its data in the previous round and the transmission has not finished yet. If so, at the current round, the CR continues the transmission on the channel it is already assigned, on the condition that no PU starts transmitting on that channel.
- the CR was not transmitting in the previous round but:
  - its data were queued in the previous round because, after sensing all the channels, no free channel was available;
  - a PU starts transmitting in the channel on which the CR was transmitting, so its data are queued until a new free channel becomes available.

A CR is in *idle* state if it finished/did not need to transmit in the previous round, meaning that it is waiting for new data to transmit.

4.2 S-CR Protocol

Figure 3 shows an overview of the developed S-CR procedure to find the available channels and to share available spectrum resources. At the beginning, a CR checks the reliability of its own information and the one received from the social sharing. If the information are not reliable, the CR performs spectrum sensing to obtain the available channels. Then, the CR posts such information on its repository, along with its own device profile information and share them on the social network. We assume that only the CRs belonging to the same community are allowed to see that information.

Going in more details, the CR k that needs to access a channel first checks its own repository about available channels information. If none of the available channels has information age below a certain threshold T_{th}, the CR considers its data as unreliable and asks for information in the social system. The acceptable age threshold T_{th} defines how old an information can be before becoming unreliable.

Only the CRs belonging to its community will be involved in the social process. For the time being, we consider only the will of sharing information and the community a CR belongs to as profile information.

In particular, the CR k sends a request to the other CRs at the energy cost $E_{tx_k} = P_{tx_k} \cdot T_{tx_k}$, which is significantly less than the energy $E_{s_k} = P_{s_k} \cdot T_{s_k}$ needed to scan a channel. This is mainly due to the different time necessary to send a request packet and the one to sense a channel (see Table 1). The time to

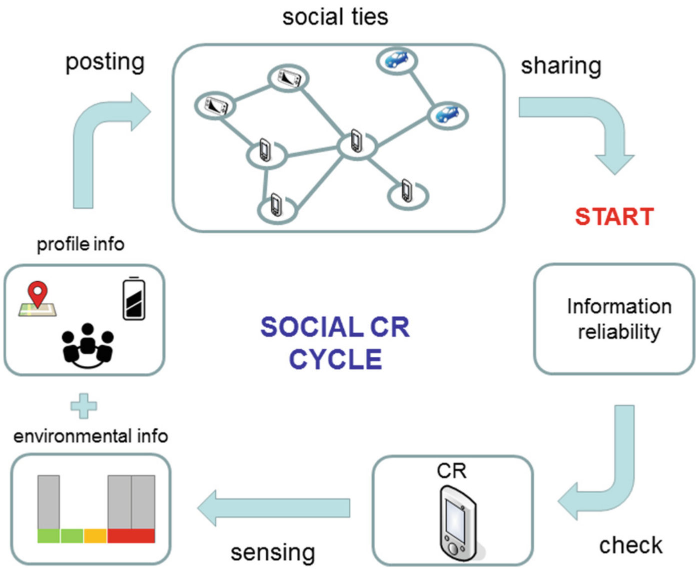

Fig. 3. S-CR protocol

sense a channel T_s has been set in order to achieve good detection probability P_d and low false alarm probability P_f [3].

All the CRs belonging to the community will spend $E_{rx_m} = P_{rx_m} \cdot T_{rx_m}$ to decode the request. Among them, only the CRs with free channels in their repositories and whose age of information is below the threshold could answer to the request. The CR k will pick randomly a CR m among those CRs.

CR m will consume $E_{tx_m} = P_{tx_m} \cdot T_{tx_m}$ to send its repository information to CR k. On the other side, CR k will spend $E_{rx_k} = P_{rx_k} \cdot T_{rx_k}$ to decode such information.

The information about the available channels sent by CR m to CR k will have different ages of information since each channel could have been updated at a different stage. Figure 2 illustrates the repository of each CR, showing a possible different age of information for each channel.

Among the available channels sent by CR m, the CR k will choose the free channel with the most reliable information for its transmission. Moreover, CR k will update its repository according to the received information by CR m.

However, if there is not a CR in the community that replies to CR k, it will start the sensing operation a the cost of $E_{s_k} = P_{s_k} \cdot T_{s_k}$ for each channel sensed. As soon as CR k find a free channel, it starts transmitting on that channel.

Note that only the information and the age of the channels scanned during the sensing operation will be update in the repository of CR k. Thus, at the next round, the information about those channels will be more reliable than the one of the other channels.

5 Simulation Results

5.1 Simulation Environment

We simulate as much as possible a real environment with heterogeneous ad time varying conditions, where the number of transmitting CRs, the number of PUs occupying the channels, the length of data to transmit, the available channels, etc., may vary at each event, while it is time constant during a single event. The number of channels is set equal to 250, while the number of CRs ranges from 10 to 220.

The probability P_{on} that a PU transmits and the probability P_{off} that a PU finishes its transmission are set according to the case of high opportunity for CR transmissions, as defined in [7]. Specifically, each channel shows $P_{on} = 0.3$ and $P_{off} = 0.6$, which results, on average, in one third of the channels occupied by PUs at each event. In the current simulation set we assume perfect spectrum sensing estimation, i.e. $P_d = 1$ and $P_f = 0$, so that the unreliable information may occur only through social network in case old information is shared.

The CR probability to start a new transmission is set equal 0.8. This applies only when the CR already finished its previous data transmission. Thus, the CR transmission probability at each event is even higher than this value, since it accounts for both the already ongoing transmission and the new ones. Given the high CR transmission probabilities, the average number of free channels per event is inversely proportional to the number of CRs in the system. Simulations show that it varies from an average value of 160, when there are only 10 CRs, to zero when the total number of users (PUs and CRs) exceeds the total number of channels.

As explained in Sect. 3.1, we consider three communities, one for a different CR traffic type. The traffic type is distinguished by the required bandwidth. Moreover, we consider that different traffic types need a different amount of events to be completely transmitted, which we set equal to 3, 10 and 25 events.

The following Table 1 shows the main variables definition and value settings. The value of energy and time parameters to transmit/receive reports (shared on the social network) and to sense a channel are chosen according to [3]. Note that the time and power to receive a report refers to the information sharing through the social network, i.e. for control messages about the available channels, it does not concern CR traffic transmissions. We compare the proposed S-CR protocol with its version without social interaction. In order not to cause interference towards PUs, in the proposed S-CR protocol we made conservative assumptions by setting the acceptable age threshold T_{th} equal to 1. In this way only the information calculated at the previous event is considered reliable. As an example, if a CR performed sensing in the previous event and shares its own information about available channels in the current event, such information is considered reliable. On the contrary, the information is unreliable if calculated at previous events, thus the social interaction is not reliable and sensing operation would then be necessary.

Table 1. Simulation parameters

Parameter	Symbol	Value
Time for sensing one channel	T_s	50 ms
Time to transmit a report	T_{tx}	0.08 ms
Time to receive a report	T_{rx}	0.08 ms
Power for sensing one channel	P_s	700 mW
Power to transmit a report	P_{tx}	750 mW
Power to receive a report	P_{rx}	750 mW
Energy for sensing one channel	$E_s = P_s \cdot T_s$	350 mJ
Energy to transmit a report	$E_{tx} = P_{tx} \cdot T_{tx}$	0.06 mJ
Energy to receive a report	$E_{rx} = P_{rx} \cdot T_{rx}$	0.06 mJ
Number of CRs	M	$[10 - 220]$
Number of channels	C	250

The non-social protocol has T_{th} equal to 0. Indeed, non-social information will fulfill the reliable requirement if T_{th} is set to 0, and only sensing will be performed to obtain information about the available channels.

5.2 Performance Evaluation

We evaluate the proposed S-CR protocol in terms of energy consumed by the whole system and compare it with its non-social version (see Fig. 4).

Figure 4 shows that the energy saving of the S-CR protocol is negligible when the social system includes just few members (number of CRs M = 10), while, when the number of CRs increases, the S-CR protocol reveals relevant energy savings of the system. However, when the total number of users, including both CRs and PUs, exceeds the total number of channels, the system saturates and tends to re-balance itself to a situation where no relevant energy saving is possible.

This imitates the behavior of common social networks [8]: when the number of users is low, interactions among members are unlikely and the perceived system value is scarce. On the contrary, when the number of users increases and exceeds a certain threshold (usually defined as critical mass), the exchange of useful information increases too, causing an increment of the perceived value of the system by the users.

In the considered scenario, the number of CRs representing the critical mass is in the range of [10–40].

Simulation results show that the average energy saving of the proposed S-CR protocol over the classic non-social procedure is around 13.3 % (see Table 2). This average value corresponds to save 131.43 J for the whole system and 1.30 J for a single CR (see Table 2).

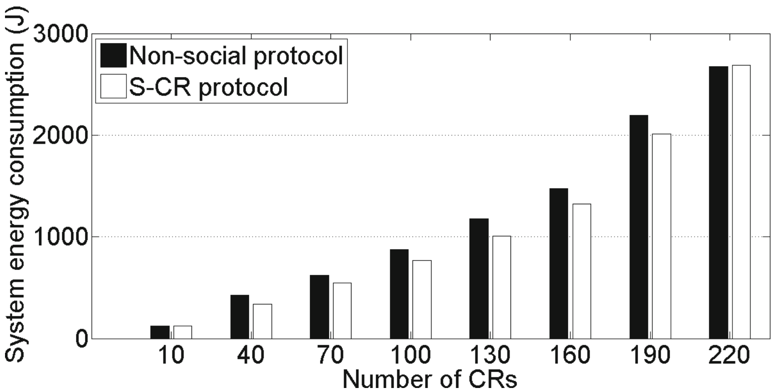

Fig. 4. System energy consumption varying the number of CRs

Table 2. Energy consumption

# CRs	Non-social consumption (J)	S-CR consumption (J)	System saving (J)	System saving (%)	Single CR saving (J)
10	125.00	121.13	3.88	3.10	0.39
40	427.96	337.50	90.47	21.14	2.26
70	625.17	543.46	81.72	13.07	1.16
100	875.92	769.60	106.31	12.14	1.06
130	1175.50	1005.05	170.44	14.50	1.31
160	1475.97	1320.29	155.67	10.55	0.97
190	2195.95	2012.01	183.94	8.38	0.97
220	2677.04	2689.00	−11.96	−0.45	−0.05

Such average result accounts for several simulation settings, given a number of CRs between 40 and 190. However, as soon as the number of CRs reaches 190, the system saturates and it is not possible to achieve any energy saving. The number of CRs that saturates the system is related to the number of channels and the probability that PUs occupy the channels.

6 Conclusion

In this paper we have proposed a new social-cognitive radio architecture to improve the energy efficiency of the overall network. By sharing some information about device profile and available channels, the CRs are able to reduce some energy demanding operation of the cognitive cycle, such as spectrum sensing.

A novel S-CR protocol have been developed to share environmental information and to allocate spectrum resources to the CRs in the network. Simulation results confirmed that social information sharing combined with spectrum sensing is less energy demanding than the pure spectrum sensing operation. Moreover, results reveal the effectiveness of the proposed S-CR solution in terms of energy consumption.

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