# RF-Powered Cognitive Radio Networks: Technical Challenges and Limitations

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## ABSTRACT

The increasing demand for spectral- and energy-efficient communication networks has spurred great interest in energy harvesting cognitive radio networks. Such a revolutionary technology represents a paradigm shift in the development of wireless networks, as it can simultaneously enable the efficient use of the available spectrum and the exploitation of RF energy in order to reduce reliance on traditional energy sources. This is mainly triggered by the recent advancements in microelectronics that puts forward RF energy harvesting as a plausible technique in the near future. On the other hand, it has been suggested that the operation of a network relying on harvested energy needs to be redesigned to allow the network to reliably function in the long term. To this end, the aim of this survey article is to provide a comprehensive overview of recent development and the challenges regarding the operation of CRNs powered by RF energy. In addition, the potential open issues that might be considered for future research are also discussed in this article.


## INTRODUCTION

Harvesting energy from ambient sources and converting it to electrical energy used to power devices is of increasing importance in designing green communication networks. While this approach enables more environmentally friendly energy supplies, it helps realize the vision of long-lived, self-maintained, and autonomous communication systems. In addition to well-known alternative energy sources, such as solar, wind, geothermal, and mechanical, ambient RF signals present another promising source that can be exploited in the future. A clear advantage of this technique, in comparison with other alternative energy sources, is that ambient RF sources can be consistently available regardless of time and location in urban areas. Moreover, RF energy harvesting (EH) systems can be built cheaply in small dimensions, which could be a significant advantage in the manufacturing of small and low-cost communication devices such as sensor nodes.

RF signals can be used by a node to extract information or harvest energy. Scavenging energy from RF signals is broadly known as wireless EH or wireless power transfer (WPT), as it refers to the transmission of electrical energy from a power source to one or more electrical loads without any wires. Investigating techniques for RF-powered mobile networks has received significant attention during the past few years in a number of applications such as wireless sensor networks (WSNs) and cooperative communication systems. Most recently, wireless EH has been flagged as a potential source of energy for cognitive radio networks (CRNs) [1]. The operation of CRNs requires periodical sensing and continuous decision making on the availability of spectrum for secondary users (SUs) in the system. This process, along with subsequent signal processing and data transmissions, result in high energy consumption by CRN nodes. Thus, it is desirable to find techniques that can help prolong the lifetime of CRNs. To this end, deploying RF EH becomes a notable candidate for CRNs, aimed at improving both energy and spectral efficiency of communication networks. In this approach, in addition to the identification of spectrum holes for information transfer, an SU may exploit the ambient RF power to supply an auxiliary source of energy for the CRN nodes. Furthermore, when EH is regarded as a significant source of energy for the operation of CRN nodes, it is crucial that the operation of the system is optimized in order to improve the survival of the system, taking into account the characteristics of the considered energy source. This necessitates the need for redesigning the existing techniques in CRNs in order to simultaneously optimize the EH function and better utilize the underlying RF energy source [2].

This article aims to review the state of the art of RF-powered CRNs and to survey the enabling techniques that have been proposed in recent years. The remainder of the article is organized as follows. The classification of the existing RF EH techniques are discussed. The high-level architecture of an RF-powered CRN is presented. This is followed by surveying the technical aspects that affect the performance of RF-powered CRNs. Furthermore, some of the well-known and promising existing technical solutions in the literature are surveyed. Since this research field is still in its early stages, some of the open technical challenges for possible future investigation are addressed. Finally, concluding remarks are given.

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## Classification of RF Energy Harvesting

Several methods of WPT have been introduced in the recent literature, including near-field short-range inductive or capacitive coupling, non-radiative mid-range resonance, and far-field long-range RF energy transmission. Nonetheless, the latest class of RF energy transmission in the microwave frequency band is the most recently focused technique. In such frequencies, the wavelength of the RF signal is very small, and the WPT system does not require calibration and alignment of the coils and resonators at the transmitter and receiver sides [3]. This renders the technique a suitable solution to power a large number of small wireless mobile devices over a wide geographical area.

Due to the specific communication requirements of cognitive radio nodes and the nature of RF EH, communication techniques and protocols used in traditional CRNs may not be directly used in RF-powered CRNs [4]. In particular, it is important to first identify the sources of RF energy and their different characteristics in order to understand the technical challenges faced by RF-powered CRNs. The mechanisms by which RF energy is obtained can mainly be classified into two categories: non-intended RF EH and intended RF EH. In the following subsections, we provide an overview of these two categories.

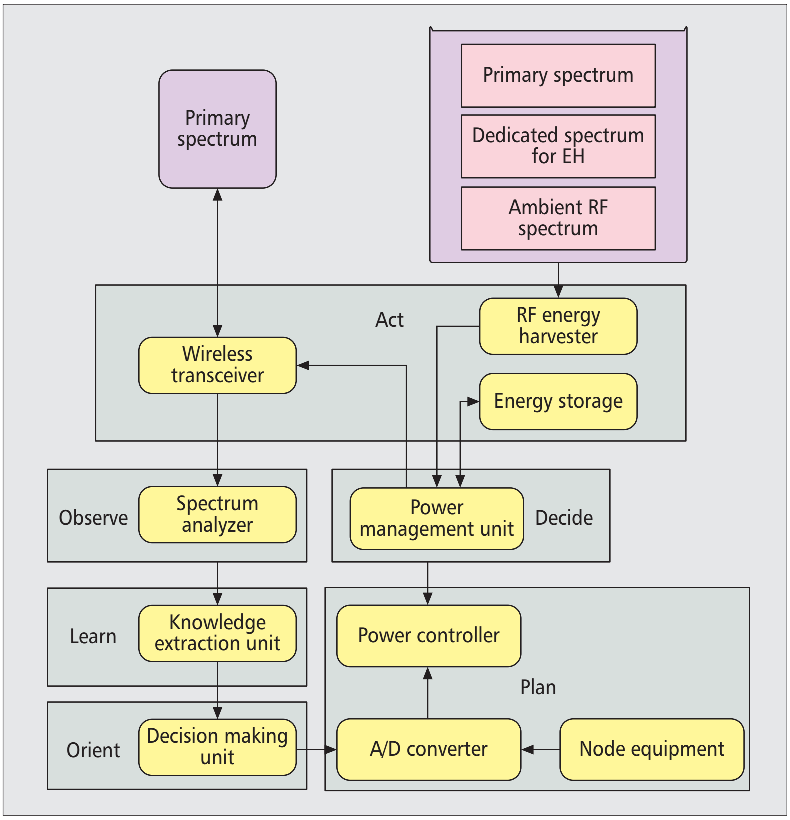


**Figure 1.** RF-powered CRN node operation cycle block diagram [2].

### Non-Intended RF Energy Harvesting

Non-intended RF signals are ambient RF sources not originally intended for energy transfer. This includes signals radiated due to wireless telecommunication services, such as cellular systems, mobile devices, and wireless local area networks (WLANs), or from public broadcasting systems, such as TV and radio. These ambient signals, if not received by their intended receivers, are dissipated as heat, resulting in a waste of energy. Instead, they could be used as a sustainable and low-cost source from which to harvest energy [5]. A device that harvests energy from ambient RF sources can have separate antennas or antenna arrays for an RF transceiver and an RF energy harvester. Harvesting energy by this means is subject to long-term and short-term fluctuations due to radio tower service schedules, node mobility and activity patterns, and fading. Therefore, cognitive radio terminals should employ new schemes that consider the trade-off among network throughput, energy efficiency, and RF energy supply, given the dynamic availability of the RF energy.

### Intended RF Energy Harvesting

This method can be divided into two types. In the first, the receiver obtains wireless power transferred from a dedicated source that only delivers power without transmitting information to it, as in directive power beamforming.[1] The second method uses the same emitted RF signal to transport energy and information simultaneously, known as simultaneous wireless information and power transfer (SWIPT) [6].

A number of receiver designs have been proposed for SWIPT. The two most adopted designs in literature are the integrated and co-located receiver designs. The co-located receiver design can be based on either time switching or power splitting [7]. A power splitting block divides the received signal into two portions, one for EH and the other for information decoding, while time switching allocates dedicated time slots to EH and the rest to data processing. By employing this approach, controllable and efficient on-demand wireless information and energy can be simultaneously provided. This permits a low-cost alternative for sustainable wireless systems without further hardware modification on the transmitter side.

## Overview of RF-Powered CRNs

There has been recent interest in exploitation of RF-based EH for CRNs. As it is the main focus of this article, in the following, we elaborate on this application in further detail. A general block diagram of the functions performed by a cognitive radio node with RF EH capability is illustrated in Fig. 1 [2]. The role of each component is described related to the major functions of a cognitive cycle, that is, observing, learning, orienting, planning, deciding, and acting, as follows:

- Wireless transceiver: a software-defined radio for data transmission and reception
- Energy storage: could be a battery or capacitor to store the harvested energy
- Power management unit: decides whether the harvested energy should be stored in energy storage or forwarded to other components

[1] The Powercast transmitter is one example that is already commercialized. Interested readers may learn more at http://www.powercastco.com/

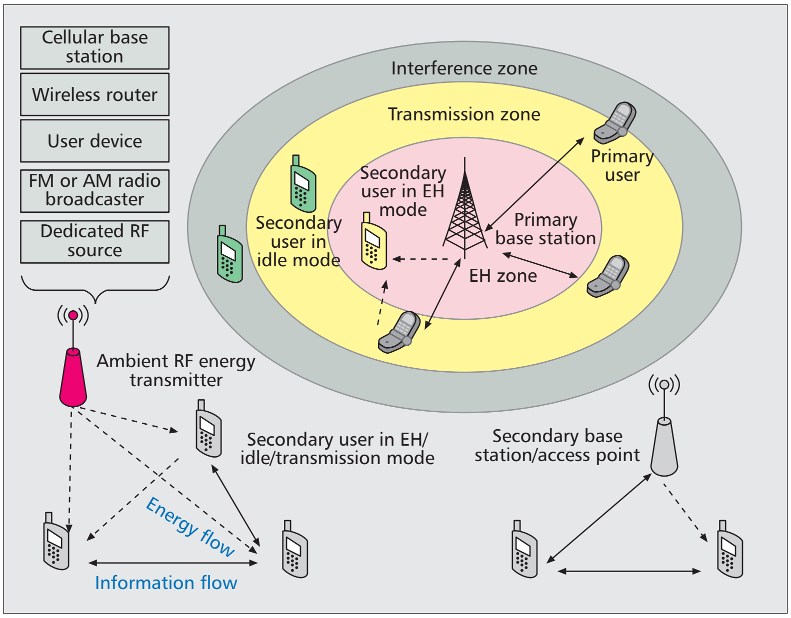


**Figure 2.** A general architecture of an RF-powered CRN.

- RF energy harvester: replenishes RF signals and converts them to electricity
- Spectrum analyzer: provides instantaneous analysis of the activity of spectrum usage
- Knowledge extraction unit: maintains a record about the spectrum access environment
- Decision making unit: decides on spectrum access
- Node equipment: implements device applications
- A/D converter: digitizes the analog signal produced by the node equipment
- Power controller: processes the output of the A/D converter for network applications

A general architecture of CRN powered by either ambient RF signals, energy transmitted from an intended RF source or via SWIPT, is shown in Fig. 2. When SUs harvest RF energy from the primary network, the primary base station can be associated with three zones [1] that define the SUs activity. Secondary users that are not fully charged and are located in the EH zone can harvest energy from the RF signals received from the primary base station or nearby primary users (PUs). SUs that are located inside the interference zone cannot transmit unless the spectrum is unoccupied by the PUs. Furthermore, it can be seen from Fig. 2 that the secondary network can also harvest ambient RF energy. RF-powered CRNs can adopt either an infrastructure-based or an infrastructureless communication architecture.

## Technical Challenges of RF-powered CRNs

As discussed in the previous sections, CRN nodes may be powered by two different categories of RF energy sources. In this section, we provide an overview of the technical challenges that arise in both scenarios.

In the scenario where a cognitive radio node harvests energy from unintended RF energy, the energy available randomly varies over time in a random process known as the energy profile, which can be described by certain mathematical models. This inherent randomness of the energy source is a major factor that affects the performance of an EH node. On the other hand, an SU can also receive RF energy from either ambient transmissions of the primary network or a particular PU with activity known to the SU. In this case, the cognitive operation of the SU is powered solely by the RF energy from the PU. Therefore, both the occupied and idle spectra are essential for the operation of a SU. In both the aforementioned cases, the performance of a CRN is restricted by the *collision constraint*, which requires that the probability of colliding with the primary transmission is always kept below a predefined threshold. When an SU operates in a time-slotted manner, its frame structure is divided into several time slots to perform different cognitive radio tasks. The performance of each of them is directly affected by the available energy at the time it is to be executed. The total consumed energy should be equal to or less than the total harvested energy; this is called the *EH constraint* [1]. Putting those two constraints together implies the fundamental limitations on the throughput of an EH CRN.

Several studies focused on exploring the impact of EH on CRNs. A seminal work in this area is [1], which proposes a novel framework, enabling SUs to opportunistically harvest ambient RF energy as well as reuse the spectrum of PUs. Also, the transmission probability of SUs and the resulting system throughput of the CRN were derived when a stochastic-geometry model was considered. The results presented in [1] revealed key insights about the optimal network design. Moreover, the authors in [8] derived the upper bound on the achievable throughput as a function of the energy arrival rate, the temporal correlation of the primary traffic, and the detection threshold for a spectrum sensor.

We aim in this section to discuss techniques that should be revisited in order to optimize system configurations to accommodate the newly introduced requirements of RF-powered CRNs. In addition, we review the relevant solutions proposed in literature.

### Mode Selection

An SU harvesting ambient RF energy usually operates in either an active or a sleep mode. In the former, it performs spectrum sensing and then data transmission if the detector decides that the PU is absent. In the latter, the SU remains silent and only harvests energy. On the other hard, when an SU needs to exploit the existence of the PU to harvest RF energy, it selects either the spectrum access mode (including sensing the idle spectrum and then transmission, or sensing the occupied spectrum and then harvesting) or the harvesting mode, which only incorporates the process of EH. There is a tradeoff for each node between utilization of the spectrum and exploitation of RF energy. The more time a node spends on sensing spectrum holes and using the opportunities for transmission, the higher the energy consumption rate and the fewer opportunities for EH. Therefore, in order to simultaneously enhance network performance and energy utilization, an optimal mode selection policy may be investigated. Motivated by this trade-off, the work in [9] considers a cognitive radio sensor network where SUs perform either RF EH or opportunistic spectrum access at one time. Under this assumption, the authors developed an optimal mode selection policy in the framework of a partially observable Markov decision process (POMDP). Built on the concept of hybrid underlay-overlay spectrum access, the work carried out in [10] proposed a mode selection strategy where the SU can be in one of three states: transmission mode (either underlay or overlay), sleep mode, or EH mode. The objective is to find a balance between the system throughput and the harvested energy for future use.

Since the transmitted power attenuates according to the reciprocal of the distance, to ensure a certain EH efficiency, the decision to select the harvesting mode has to consider both the availability of the PU and its distance from the SU, as studied in [1].

### Sensing Duration

The main question here is to determine how the duration of spectrum access is constrained by the sensing process, which is crucial to system performance. Longer sensing duration results in higher probability of true detection of the spectrum and thus lower interference caused to PUs. However, it simultaneously decreases the chances of an SU to access the spectrum. The total energy consumption behavior varies from one frame to the other according to the variation in the sensing duration. Not only does this behavior depend on the sensing duration; it is also affected by the sensing-to-transmission power ratio. Both the opportunities of accessing the idle spectrum and the energy consumed by sensing increase as the sensing duration increases. This also elevates the energy consumed by more frequent data transmissions. Nonetheless, if the sensing duration is too long, the time left for transmission becomes short; and accordingly, the total amount of energy consumption (sensing plus transmission energies) is reduced, due to the decreased opportunity for data transmission. The aforementioned conflicting factors collectively imply coming up with an optimal sensing duration that would take into account the available energy and the effect on the performance of both CR and primary networks. In [11], for example, the authors derived a mechanism that jointly optimizes the harvesting, sensing, and transmitting durations, and the number of sensed channels based on mixed-integer nonlinear programming with maximizing the achievable throughput serving as the objective function. Recently, the study of [12] suggested a new policy for determining both the sensing duration and the detection threshold that maximizes the average throughput. The proposed technique aims to find an optimal pair of sensing duration and detection threshold that can increase the spectrum access opportunities within the permissible range of collision probability for a given average harvested energy.

### Detection Threshold

The performance of detecting the existence of primary signals is linked to the chosen value of the detection threshold. The choice of this value becomes even more crucial when the SU is an EH node [4]. In general, a high detection threshold increases the probability of detecting the spectrum as idle and leads to more frequent spectrum access. Not only does this increase the probability of colliding with the PU transmissions, it also causes a large waste of energy resulting from more transmissions. On the contrary, a low detection threshold alleviates unnecessary energy waste and the probability of accessing the occupied spectrum, but may in turn restrain an SU from transmitting data, even when the spectrum is idle. In [4], the authors propose a technique by which an optimal detection threshold is derived, using the probability of accessing the idle spectrum and the probability of accessing the occupied spectrum to maximize the expected total throughput while satisfying both the EH and collision constraints. They have also demonstrated that, depending on the selected threshold, the system can be characterized as a *spectrum-limited regime* and an *energy-limited regime*. In the first, the harvested energy enables continuous spectrum access, while in the second, the amount of harvested energy restricts the number of spectrum access attempts. This work was followed by that presented in [13] where they extended the problem in [14] to a joint optimization problem of a spectrum sensing policy and a detection threshold subject to the EH and collision constraints. In the framework of a POMDP, this strategy is able to achieve efficient usage of the harvested energy by exploiting the temporal correlation of the primary traffic. In addition to deriving the upper bound on the achievable throughput in [8], the authors have also explored a new technique which is able to find the optimal detection threshold that maximizes the derived upper bound.

If an SU employs SWIPT in order to simultaneously use the received RF signal to store energy and detect the presence of the PU, it is challenging to choose the optimal detection threshold. For example, in the power splitting approach, where the received signal at the SU is split into two portions, one for EH and the other for energy detection, the value of the detection threshold used in a non-EH SU receiver will not be viable. The reason is that the minimum acceptable signal energy at the input of the energy detector is divided according to the power splitting ratio. Hence, the detection threshold should correspond to the value of the received power after being split. This raises a question about the choice of energy threshold when the power splitting ratio is varying.

### Energy Management

A careful allocation of power over sensing and data transmission slots is of high importance, due to its effect on the system throughput, capacity, and outage probability. In a CRN powered by ambient RF energy, the energy available at the beginning of a time slot is divided between the spectrum sensing and data transmission phases. Therefore, the harvested energy has to

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In a CRN powered by ambient RF energy, the energy available at the beginning of a time slot is divided between the spectrum sensing and data transmission phases. Therefore, the harvested energy has to be efficiently expended over a specific number of time slots in order to enhance system performance.

be efficiently expended over a specific number of time slots in order to enhance system performance. The mechanism proposed in [14], for instance, enables an EH cognitive radio node to optimize its sensing and transmit energies while accounting for the detection reliability-throughput trade-off. Another method to achieve energy management is via knowledge of the previous or current statistics of the energy arrival rate, the statistical description of a PUs's activity, or the channel state information (CSI). For example, in [15], the proposed scheme allocates more energy for transmission when the channel state is good in a particular time slot. In contrast, less or no energy is allocated to a transmission slot in which the probability that the PU occupies the spectrum is anticipated to be relatively high.

The problem of energy management in a CRN applying SWIPT differs substantially from one that harvests ambient RF energy. The reason is that in some scenarios in SWIPT, the receiver has no battery to store energy, and as a result, the processes to be executed in a certain time slot directly draw energy from that available by the received RF signal. In this situation, it is challenging to optimize the parameters of the SU receiver such that energy is distributed spontaneously and efficiently between the different tasks of the cognitive cycle.

### Channel Selection

Traditional channel selection schemes, which are mainly aimed at identifying the idle channels with high quality, may not be effective anymore for RF-powered CRNs. In particular, if the energy level available at the SU is low, it might select the channel that tends to be occupied by a PU and has a strong RF signal to harvest. On the other hand, if the SU has a high energy level, and there is a need for data packet transmission, it should identify the channel that is likely to be idle with a favorable channel quality. The research work reported in [16] studied a channel selection criterion that maximizes the average spectral efficiency of an SU. The proposed method jointly exploits knowledge of the PU occupancy and channel conditions, and the dependence of the decision of the SU to sense and access the PU spectrum on the probabilistic availability of energy at the SU. Similarly, in [2], the authors developed a channel selection policy used by the SU that maps the SU's state (i.e. number of packets in the data queue and the energy level in the energy storage) to the channel to be selected. This is done prior to sensing the channel and is based on statistical information such as probabilities of the channel being idle or busy, the probability of successful packet transmission if the channel is idle, and the probability of successful EH if the channel is busy.

Table 1 shows a summary of existing configuration policies for RF-powered CRNs.

## Future Research for RF-Powered CRNs

CRNs may be deployed in different scenarios such as multiple-input multiple-output (MIMO), cooperative, and relaying CRNs. Existing mechanisms for conventional CRNs need to be extended, modified, or even replaced to suit the newly emerged RF-based EH technology. We focus next on discussing some issues that can be explored in the future.

### Sensing Imperfections

Protecting the primary network from unbearable interference is the key to successful operation of a CRN. Therefore, a high probability of correct decisions generated by the energy detector is vital. In practice, however, those decisions are prone to errors, leading the performance of the primary network and the CRN to dramatically deteriorate. This becomes of higher concern in the presence of EH in those networks. In particular, if the channel is sensed as idle while it is actually busy, and if an SU decides to transmit, this results in unnecessary dissipation of energy, causing interference to the PU and missing a chance to harvest energy if needed. On the other hand, if the channel is sensed as busy while it is in fact idle, the SU might preserve energy but abolishes an opportunity to provide a better rate to its intended receiver. This necessitates research studies to explore the limitations caused by imperfect sensing on the performance of RF-based EH CRNs.

### CRNs with Multiple Antennas

Multiple antennas in CRNs can be utilized to provide the secondary transmitter with more degrees of freedom in space in addition to time and frequency. Multi-antenna CRNs gained attraction, especially in the underlay spectrum sharing scheme, where SU and PU transmissions can be concurrent. In line with this, it is known that higher wireless energy transfer efficiencies can be achieved when multiple antennas are employed. Furthermore, in a multi-antenna RF-powered CRN, beamforming techniques can be exploited by the SU transmitter to steer RF signals toward SU receivers having different information and/or EH requirements. The problem of maximizing the SU rate subject to both the PU rate and the secondary transmitter power constraints is critical. Therefore, beamforming techniques should be redesigned to consider those conflicting objectives. The work presented in [17] is a major development in this field, where a multi-antenna EH secondary network makes use of both the spectrum and the energy of the primary network, in return to assist the primary transmissions. The main focus of this research is to design a beamforming technique that characterizes the achievable primary-secondary rate region based on power splitting and time-switching for SWIPT.

Beamforming performance optimization is tightly dependent on the acquisition of CSI. As a result, new mechanisms have to be proposed to account for the trade-off between data transmission, EH, and channel state estimation duration.

### Cooperative CRNs

The concept of cooperative spectrum sensing has been proven to combat sensing errors and channel fading, and to overcome the hidden terminal problem due to shadowing. Nevertheless, conventional cooperative schemes do not take into consideration the DC power levels produced by the RF energy conversion process, which resemble

| Configuration element | Literature | EH model | Constraints | Objective | Framework |
|---|---|---|---|---|---|
| Mode selection | [9] | Opportunistic EH of RF signals from primary network | 1) Residual energy at the SU<br>2) Spectrum occupancy state partially observable to the sensor node | Maximize expected total throughput delivered by an SU sensor node over a time slot | POMDP |
| | [10] | EH of RF signals from primary network and ambient RF sources | 1) Residual energy at the SU<br>2) Required transmission energy<br>3) Spectrum occupancy state partially observable | Enhance throughput of the SU and obtain QoS of primary network by selecting overlay or underlay transmission mode | POMDP |
| Sensing duration | [11] | EH from ambient RF sources | 1) EH rate of the SU<br>2) Collision constraint to the primary network<br>3) Channel sensing energy cost | Optimize saving-sensing-transmitting structure that maximizes the achievable throughput of the SU | Mixed-integer nonlinear programming |
| | [12] | EH from ambient RF and other energy sources | 1) Channel sensing and data transmission energy cost with respect to the residual energy at the SU<br>2) Collision constraint to the primary network | Maximize expected average throughput of the secondary network | Several optimization problems are formulated to give an insight on the joint configuration of sensing duration and threshold |
| Detection threshold | [4] | EH from ambient RF and other energy sources | 1) Energy arrival rate<br>2) Channel sensing and data transmission energy cost with respect to the residual energy at the SU<br>3) Collision constraint to the primary network | Maximize expected total throughput of the secondary network | Deriving the probability of accessing the idle spectrum and the probability of accessing the occupied spectrum and their bounds |
| | [13] | EH from ambient RF and other energy sources | 1) Spectrum occupancy state partially observable<br>2) Energy arrival rate<br>3) Temporal correlation of the primary traffic<br>4) Collision constraint to the primary network | Maximize the upper bound of the probability of accessing the idle spectrum | Unconstrained POMDP |
| | [8] | EH from ambient RF and other energy sources | 1) Energy arrival rate<br>2) Channel sensing and data transmission energy cost with respect to the residual energy at the SU<br>3) Temporal correlation of the primary traffic<br>4) Collision constraint to the primary network | Maximize the upper bound of the achievable throughput | Several optimization problems are formulated to give an insight on the joint configuration of spectrum access policy and detection threshold |
| Energy management | [14] | EH from ambient RF and other energy sources | 1) Energy arrival rate<br>2) Residual energy at the SU | Maximize expected total throughput of the secondary network | Markovian decision process |
| | [15] | EH from ambient RF and other energy sources | 1) Observed information (harvested energy, fading CSI, spectrum occupancy state) in the past and present only | Maximize expected total throughput of the secondary network | Sliding window approach |
| Channel selection | [16] | EH from ambient RF and other energy sources | 1) Probabilistic availability of energy at the SU<br>2) Channel conditions<br>3) Primary network belief state | Maximize expected total throughput of the secondary network | POMDP |
| | [2] | EH from RF signals of the primary network | 1) Number of packets in the data queue<br>2) Residual energy at the SU | Maximize the long-term average throughput of the SU | Markovian decision process |

**Table 1.** Summary of proposed techniques for RF-powered CRNs.

the only source of energy available at the CR terminal. To be more specific, an SU might refrain from participating in the process of spectrum sensing because it does not receive sufficient RF energy due to its distance from the PU. However, the more SUs that participate in sensing, the better spectrum discovery outcome is guaranteed and the more energy will be consumed. As a consequence, centralized cooperative spectrum scheduling, in which a cognitive base station or a fusion center decides which SUs should participate in the sensing process and which channels to sense, should take into account the amounts of harvested energy at the SUs. In addition, the distances between a PU transmitter and different SUs are often different. Also, the signal propagation environment differs from a PU transmitter to different SUs, making both the signal-to-noise ratio (SNR) and the harvested energy from the same primary signal dissimilar at different SU receivers. Therefore, new cooperative mechanisms that fit this environment is thus essential.

The recent interest in simultaneously achieving spectrum and energy efficiency has led to the concept of RF-powered CRNs. Integrating the capability of EH into the functionality of cognitive radio devices infer nontrivial challenges in their designs.

### CRNs with Relays

In a CRN, a single or multiple relay(s) assist the SU source to sense and/or transmit data to the SU destination. All the CRN nodes or only the relay/s might be RF-based EH. In the second scenario, relays harvest energy from the SU source, the PU, or both. Under this setting, the quality of relaying the data to the SU destination is directly affected by the power received at the relay(s) from the SU source or the PU signals. This problem seems to be even more complex if the relay(s) and the SU source deploy SWIPT. In such a case, both the SU source and the relay(s) have to precisely select their receiver parameters (power splitting or time switching ratios) in order to optimize the overall system performance, while satisfying their energy needs. As a consequence, more research focus has to be directed toward exploring new relaying protocols and relay selection schemes.

## Conclusions

The recent interest in simultaneously achieving spectrum and energy efficiency has led to the concept of RF-powered CRNs. Integrating the capability of EH into the functionality of cognitive radio devices infer nontrivial challenges on their designs. This article presents an overview of the architecture of CRNs that operate based on RF energy harvesting. Mainly, two methods by which CRNs can harvest RF energy were discussed: intended and non-intended RF energy harvesting. Several factors that do not exist in non-RF-powered CRNs impose fundamental limitations on their performance. As a result, the article lists key configuration parameters that need to be redesigned to achieve a desirable balance between the energy availability constraint and the system performance. Furthermore, the article surveys promising techniques that can enable successful spectrum sensing, spectrum access, and spectrum management in RF-powered CRNs. Finally, some open technical challenges that may be studied in the future are addressed.

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