ISSN: 2581-3404 (Online)
International Journal of Innovative Research in Technology and Management, Vol-4, Issue-6, 2020.

Spectrum Sensing and Energy Harvesting in Wireless Communication: Survey and Discussions

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ABSTRACT

In a conventional cognitive radio (CR) network, only when the primary user's (PU) frequency bands are sensed to be free, secondary users (SUs) can utilize these frequency band resources. Therefore, spectrum sensing (SS) can improve spectrum utilization. Spectrum sharing means that the SUs are allowed to utilize the licensed spectrum bands belonging to the PU to transmit information with PU simultaneously. Energy harvesting (EH) and cognitive radio (CR) are expected to provide a new solution to deal with the shortage of energy and spectrum, respectively. However, the efficiency of EH is low and the wireless terminals are growing exponentially, which make the research on increasing energy efficiency (EE) and spectrum efficiency (SE) crucial. In this paper we present survey for the energy harvesting techniques in wireless communication.

Keywords:- Access, Energy harvesting, Cognitive radio, Sensor network, Cooperative communications.

INRODUCTION

With the development of wireless communication, the demand for spectrum resources is growing. With the arrival of the 5th generation wireless systems (5G) era, the access of large-scale mobile devices can cause shortage of spectrum resources.

However, in traditional radio network system, once the primary user (PU) has occupied the current spectrum and the secondary users (SUs) cannot access to the channel. The licensed spectrum always performs low utilization, and existing resources cannot be utilized effectively. Cognitive radio (CR) as an emerging technology is proposed to provide high spectrum utilization, in which SUs are allowed to access the spectrum when PU is absent [5].

Recently, energy harvesting (EH) has a notable impact on several applications such as radio frequency identification (RFID) and reusable wireless sensor networks. Initial works on wireless information and power transfer show a new opportunity on recharging devices wirelessly, while keeping information exchange among sensor nodes. For example, RF signals radiated by the ambient transmitter can be treated as ambient sources for EH. With a fixed network, the harvested energy is predictable and relatively stable over time due to fixed distance. Thus, EH prolongs the network lifetime as well as brings a great convenience, especially for mobile users [10].

The radio frequency (RF) spectrum is a finite but exceedingly valuable natural resource that facilitates a tremendous variety of applications and services. As new wireless applications and services emerge, radio spectrum resources will be in ever-greater demand. Cognitive radio (CR) is a promising wireless communication technique that enables greater efficient use of the radio spectrum. The operation of CRs, however, requires periodical sensing and continuous decision-makings on the availability of spectrum, hereafter referred to as spectrum sensing (SS). This process along with subsequent signal processing and data transmissions result in high energy consumption, particularly in densely occupied environments where CRs must spend most of their time searching for available spectrum [1].

Cognitive Radio (CR) can effectively alleviate spectrum resource shortage by performing opportunistic spectrum access in time, frequency and airspace. When the Primary User (PU) is absent, CR allows the Secondary Users (SUs) to access idle channel to improve the spectrum utilization. Since PU has the priority to use the licensed frequency band, the SUs must detect the licensed frequency band occupancy in real time via spectrum sensing [2]. Energy detection is widely used to perform spectrum sensing currently because it is easily implemented and no PU's prior information is required. However, sensing performance may suffer from the effects of hidden terminal problems such as shadow effect and multipath fading. Two main modes, i.e., overlay CR network and underlay CR network, have been widely studied in current researches. For the former, the SUs can utilize the frequency band released by PU so that the conflict with the PU's information transmission can be avoided. For the latter, the SUs can utilize the frequency band with PU as long as the interference with PU is limited below a certain threshold.

Non-Orthogonal Multiple Access (NOMA) [2] is a promising wireless access technique for the coming 5G era. NOMA uses non-orthogonal transmission at the transmitter and users' information is superposed in power domain for higher spectrum efficiency. Different from Orthogonal Multiple Access (OMA), NOMA can serve multiple terminals over the same resource block, thus it can effectively enhance sum rate. Successive Interference Cancellation (SIC) is adopted to decode the users' information at the receiver. Specifically, the user with the best channel condition is decoded firstly, while other users are regarded as interference.

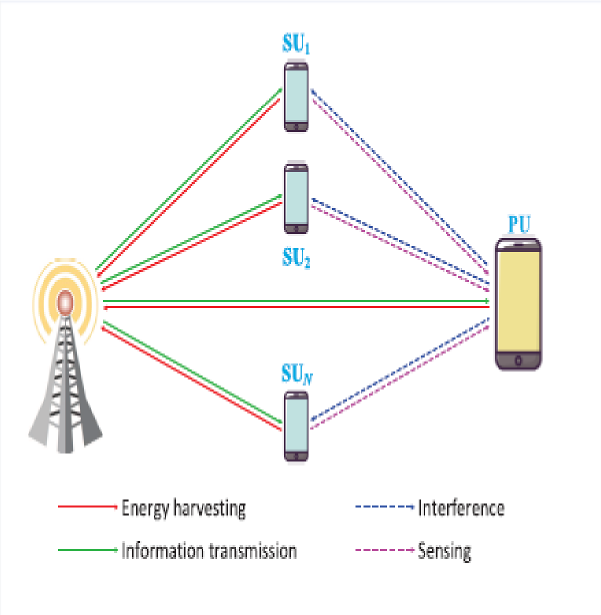

Fig 1: System model of CR-NOMA [2].

In conventional cooperative spectrum sensing (CCS), a tradeoff exists between the sensing accuracy and data transmission duration, called the sensing-throughput tradeoff. Sensing accuracy in terms of probability of detection is hence essential to improve the average throughput, which can be achieved by using the optimal fusion rule, namely, the L-out-of-M rule. However, as the number of sensors increases, the average throughput decreases due to the increase in the reporting overhead, even though the sensing accuracy increases. Therefore, methods to increase the channel available time by reducing the sensing overhead have also received considerable research attention [3]. Spectrum sharing is proposed as a significant strategy to improve system performance effectively. In [5], two typical models for spectrum sharing are presented. One is normal spectrum sharing, wherein SUs and PU are allowed to transmit information simultaneously. In this model, PU can coexist with SUs, and the interference among SUs is restricted to a specific threshold so that the PU's Quality of Service (QoS)requirement is not influenced; the SUs are expected to achieve a high system throughput by developing reasonable power allocation strategy. The other one is opportunistic spectrum access (OSA), wherein SUs sense the channel state and once the spectrum is sensed to be idle, SUs are allowed to access the spectrum licensed to PU.

Energy harvesting is the process by which ambient background energy (e.g., kinetic energy from wind/water flow or motion, solar radiation, structural vibration, temperature or salinity gradients, electromagnetic energy) is recovered to supply small-scale low-power (microwatt to milli-watt power range) electronic devices such as sensors, data-loggers, and data-transmitters for use in distributed sensing, equipment/process monitoring, smart city, and Internet of things applications. Piezoelectric materials, in particular, were quite extensively investigated for harvesting energy from structural and flow-induced movement or vibration. Piezoelectric harvesters typically comprise a structural element realized with a piezoelectric material (or bonded with a piezoelectric patch) that is either connected to a vibrating or moving structure, or exposed to fluid flow in such a way that flow-induced vibration or motion takes place [6].

In the classical mechanism of the spectrum sensing, namely known as the Half-Duplex CR (HD-CR), the activity period is divided into two parts: the first one is reserved for the spectrum sensing and the second one for the transmission. SU should stop its transmission during the sensing operation time, in which a test statistic such as the energy of the received signal is compared to a threshold in order to detect the PU status. If PU is idle, then SU transmits its data. Dedicating a part of SU's activity period for only sensing the channel affects its throughput and may increase the collision time with PU, as PU can return active during the transmission period where no sensing is performed. To avoid this shortcoming, Transmitting-Sensing (TS) CR paradigm has been recently proposed to simultaneously perform transmitting and sensing. TS requires Self-Interference Cancellation (SIC) techniques; SIC let two communicating peers establish an In-Band Full-Duplex (IBFD) communication. By adopting SIC, the receiver circuit can highly suppress the known Self-Interference (SI) generated by the transmitter in order to purely obtain the signal of interest. SIC is generally adopted in CR during the TS mode to minimize the effect of the SI on the received signal. This technique helps SU to be able to detect the noisy PU signal without stopping the SU's transmission. However, due to the imperfect SIC, the minimization of the residual self-interference remains a challenge to obtain a reliable decision on the channel status [4].

II RELATED WORK

[1] This paper proposes a new simultaneous spectrum sensing (SS) and energy harvesting (EH) scheme, called integrated SS-EH, where all of the incoming radio-frequency (RF) power is used for EH. Then, SS is performed based on a fraction of the harvested power. The proposed approach does not require a separate energy detector, which needs a power-hungry radio front end. Therefore, the energy consumption and hardware complexity for SS can be reduced significantly. Furthermore, it can increase the harvested energy over the conventional separated SS-EH scheme, where SS and EH are performed separately, and thus, only a fraction of the incoming RF power can be used for EH. The combined benefit of reduced energy consumption for SS and increased energy harvest allows more energy to be available for communication, which results in an increase of the throughput. The probability of false alarm and missed detection, the average harvested energy, and the average throughput are analyzed in Rayleigh fading channel and compared with the conventional separated SS-EH scheme.

[2] In this article, a Non-Orthogonal Multiple Access (NOMA) system with Simultaneous Wireless Information and Power Transfer

(SWIPT) for CR network is studied. The frame structure is designed with two subslots. In the downlink subslot, the Secondary Users (SUs) harvest wireless energy from Radio Frequency (RF) signals and sense the spectrum state simultaneously. In the uplink subslot, SUs transmit their independent information to Base Station (BS). Two modes are considered in this article: overlay network and underlay network. A CR-NOMA system model is presented and the approximate expressions of EE for two modes are obtained. Based on the subslot allocation, two optimization problems aiming to maximize EE are formulated. In the overlay network, the constraints are transmit power and total transmission slot. In the underlay network, instead of sensing the spectrum, SUs utilize the channel with primary user (PU) simultaneously. Thus, the constraints of interference threshold and channel gain of PU are also taken into considered. The proposed optimization problems can be regarded as nonlinear fractional programming.

[3] In this paper they investigate the performance of conventional cooperative sensing (CCS) and superior selective reporting (SSR)-based cooperative sensing in an energy harvesting enabled heterogeneous cognitive radio network (HCRN). In particular, they derive expressions for the achievable throughput of both schemes and formulate nonlinear integer programming problems, in order to find the throughput-optimal set of spectrum sensors scheduled to sense a particular channel, given primary user (PU) interference and energy harvesting constraints. Furthermore, they present novel solutions for the underlying optimization problems based on the cross-entropy (CE) method, and compare the performance with exhaustive search and greedy algorithms. Finally, they discuss the tradeoff between the average achievable throughput of the SSR and CCS schemes, and highlight the regime where the SSR scheme outperforms the CCS scheme. Notably, we show that there is an inherent tradeoff between the channel available time and the detection accuracy.

[4] In this paper, a Transmitting-Receiving-Sensing (TRS) mode of OFDM-based Full-Duplex Cognitive Radio (FD-CR) is proposed. The new mode aims at monitoring the Primary User (PU) activities on the operating channel while establishing an in-band full-duplex communication between two communicating Secondary Users (SUs), i:e: SUs transmit and receive simultaneously on the same frequency band. Assuming that the primary activity covers all the operating band when PU is active, Spectrum Sensing is performed on some Sub-Carriers (SCs) which are neutralized by the two communicating SUs. Letting some SCs null by both SUs helps to accurately performing the spectrum sensing on these SCs since no residual self-interference neither secondary transmission are present. When PU is detected on these SCs, then they consider that he becomes active again; Then SUs should vacate the channel. For the proposed mode, false alarm, detection and collision probabilities are derived in addition to the throughput rate.

[5] In this paper they proposed a NOMA-based CR network with SWIPT scheme for two different modes, overlay and underlay network respectively. In the proposed model, the operation frame is divided into two slots, the users perform spectrum sensing and energy harvesting during the first slot and then transmit independent information in the next slot 1-ɿ. They implement NOMA for CR secondary network to improve spectrum efficiency. Moreover, we analysis the system throughput performance, and derive the concrete expressions of system throughput. In the following, they formulate the optimization problem by optimizing the time slot such that system throughput is maximized.

[6] This paper presents results from experiments and simplified numerical simulations on the flow-induced dynamics and power generation of inverted flags that combine flexible piezoelectric strips with photovoltaic cells to simultaneously harvest kinetic wind energy and solar radiant energy. Experiments were conducted in a wind tunnel under controlled wind excitation and light

exposure, focusing in particular on the dynamics and power generation of the inverted flag harvester. Numerical simulations were carried out using a lattice-Boltzmann fluid solver coupled with a finite element structural solver via the immersed-boundary method, focusing in particular on minimizing the simulation run time. The power generated during the tests shows that the proposed inverted flag harvester is a promising concept, capable of producing enough power (on the order of 1 mW) to supply low-power electronic devices in a range of applications where distributed power generation is needed.

[7] This paper reviews the combination of CoR and SWIPT. From basic to advanced architectures, applications and taxonomies of CoR and SWIPT are presented, various forms of resource allocation and relay selection algorithms are covered. The usage of CoR and SWIPT in the fifth-generation wireless networks is discussed. This paper focuses on the integral aspects of the CoR and SWIPT to other next-generation wireless communication systems and techniques such as multiple-input-multiple-output, wireless sensor network, cognitive radio, vehicular ad hoc network, non-orthogonal multiple access, beam forming technique, and the Internet of Things. Some open issues and future directions and challenges are given in this paper.

[8] This letter analyzes the performance of simultaneous wireless information-and-power transfer (SWIPT) in a cognitive radio sensor network (CRSN) under Nakagami-m fading. A pair of sensor nodes (SNs) is considered in which one SN facilitates relay cooperation for communications between two primary users (PUs). In return, SNs make use of primary users' signals for energy harvesting (EH) and realize their own communications. In such a network, bidirectional communications between the two PUs and unidirectional information exchange between the SNs can be performed in three phases. A power splitting (PS) based approach is adopted for enabling SWIPT. The relaying SN applies an amplify and forward (AF) protocol to broadcast primary and secondary signals, whereas the PUs perform selection combining to access the active direct link.

[9] This paper discusses the performance of probability of energy detection with different values of false alarm and SNR values to evaluate the performance of the cognitive network system. It is clearly from results that there is a great chance of false detection at higher Pd. This is because of the increasing number of sharing spectrum when Pd increased where the probability of the new sharing applying is decreased (false alarm increased). The simulation of the path loss exponent effect shows that there is no effect of changing the path loss because the cognitive operation depends on distance between operators and available spectrum to hare not on the surrounding area.

[10] This paper presents strategies for energy harvesting (EH) in an amplify-and-forward (AF) relay system. In order to increase capacity and coverage, we use a relay-aid network with spectrum sensing and EH, thus provide a better quality of service. A relay is deployed to assist communication between a source node and a destination node and to decode information/harvest energy from incoming signals at the same time by using a power splitting scheme. They propose two strategies for EH relaying design in terms of EH capacity and number of relay transmissions. Based on that setting, they derive the total throughput of all relay transmission respect to the received signal-to-noise ratio of the relay link.

III PROBLEM IDENTIFICATION

In CR network, sensing mode, sensing time and some other factors will affect the CR network's performance. In recently years, considerable attentions have been paid to the sensing-throughput tradeoff problem. The system achieves a maximum throughput by optimizing the sensing time under the constraint of total transmission power. SS can be regarded as an energy detection essentially and it can be applied to many areas such as wireless sensor network (WSN) [5] and traditional CR network. Energy efficiency (EE) is significant in wireless communication system and it can reflect the performance of a system from the side. Non-orthogonal multiple access (NOMA) has been an important wireless communication access technique for the coming 5G networks. Related works have obtained many detailed analysis and important conclusions between NOMA and other multiple access techniques. Unlike conventional multiple access techniques, NOMA can meet users' QoS requirements and improve fairness by allocating resource dynamically, in which users with poor channel conditions are allocated more power and considerable total throughput can be achieved.

IV CONCLUSION

Next generation wireless networks (NGWNs), such as 5G, will bestow numerous applications and conveniences to make lives easier, smoother and more comfortable with the better quality of service (QoS) at low cost and complexity. Sharing concept and heterogeneity process in wireless communication takes the consideration of most of researchers today to enhance the network capacity. Sharing between services or coverage area of radio access in 5G opens new challenges in optimizing users' access to the networks. The concept behind the sharing properties is that the mobile user does not connected only with its operator, but also has the ability to link with other operator near the previous one by using sharing resources.

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