A Brief Survey on RIS-Assisted Cognitive Radio Networks

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Abstract

This survey presents ongoing research trends on the integration of RISs into CRNs for highlighting the need for this coordination and indicating its importance in terms of improved spectrum sensing and sharing, energy efficiency, and network performance. Additionally, it discusses the existing challenges in realizing RIS-based CRNs and provides future potential research directions for this rapidly evolving field. The conclusion affirms that RIS technology holds enormous potential for revolutionizing the performance and efficiency enhancement of CRNs in the future.

***Index Terms*—Reconfigurable intelligent surfaces, cognitive radio, 5G/6G communication.**

I. Introduction

The growing demand for wireless data, fueled by the universal use of mobile devices and the emergence of new applications, has caused a serious problem of spectrum scarcity in wireless communication systems. Cognitive Radio Networks (CRNs) have been proposed as an adaptive and intelligent solution to this problem, allowing unlicensed secondary users (SUs) to opportunistically use the spectrum assigned to primary users (PUs) during their times of non-use [1]. Traditional CRNs, nevertheless, are beset by inherent difficulties in accurately sensing the spectrum availability and effectively evading interference with primary users under low SNR and hidden PUs conditions, which may limit their performance and field applicability.

Reconfigurable Intelligent Surfaces (RIS) are an innovative technology in the area of wireless communication, which is featured by planar surfaces comprising numerous low-cost, nearly passive elements. These elements, which are typically sub-wavelength in size, have the special feature of independently controlling the phase and, in some instances, the amplitude of the incident electromagnetic waves, thus allowing the programmable manipulation of the wireless propagation environment [2], [3].

The integration of RISs into CRNs has tremendous potential to overcome the limitations of traditional cognitive radio approaches and achieve more intelligent and effective utilization of the spectrum [4]. The objective of this survey report is to provide a brief but comprehensive overview of the state-of-the-art research on RIS-assisted CRNs, covering the benefits, approaches, challenges, and future development in this exciting and rapidly developing research field.

II. Integration of RIS into CRNs

The integration of Reconfigurable Intelligent Surfaces (RIS) achieves remarkable improvement in the operation and effectiveness of Cognitive Radio Networks (CRNs). Fig. 1 illustrates a typical architectural framework of an RIS-aided Cognitive Radio Network, where numerous Secondary Users (SUs) benefit from RIS-reflected signals for improved spectrum sensing, thereby utilizing available spectrum more effectively.

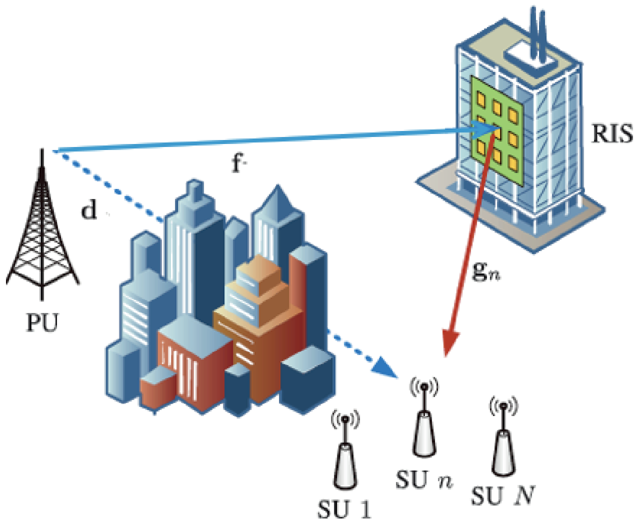

Fig. 1: General structure of RIS-assisted CRN

Reconfigurable Intelligent Surfaces (RIS) can be effectively used in cooperative spectrum sensing (CSS) to improve the spectrum sensing capacity of secondary users (SUs). RIS technology significantly improves the sensitivity of spectrum sensing, which is a key aspect of the opportunistic access model under cognitive radio networks (CRNs), especially under harsh environments with weak primary signals or severe signal degradation. The PSM optimization problem is explored in [5] to enhance the cooperative detection performance in RIS-empowered cognitive radio networks. Further, in [6], the sensing performance of cognitive radio networks (CRN) is enhanced with the help of two cooperative reconfigurable intelligent surfaces (RISs) in the network by utilizing successive convex approximation (SCA) and penalty convex-concave procedure (CCP) methods. Data security is of much concern problem in Cognitive Radio Networks (CRNs), thus, the capability of Reconfigurable Intelligent Surfaces (RISs) in altering signal propagation can be exploited for malicious intentions, e.g., eavesdropping or jamming legal communications. A technique based on a Semi-Definite Relaxation (SDR) algorithm is suggested in [7] to improve the secure transmission for primary and secondary users in RIS-aided spectrum-sharing CRNs. One of the performance measures of CRNs is the quantity of attainable throughput. The average achievable sum rate (AASR) maximization problem of the CUs in an RIS-assisted multi-user MISO downlink CRN is presented in [8], while ensuring the transmit power budget of the cognitive base station. The use of Simultaneous Transmitting and Reflecting RIS (STAR-RIS) technology achieves full space coverage and improved spectrum efficiency with effective interference management between SUs and PUs. In [9], a STAR-RIS-empowered multiple input, multiple output (MIMO) CR system is developed to improve the sensing and data rate of SUs through the beamforming solution with an independent phase-shift and a coupled phase-shift model. Energy efficiency is another very important parameter to optimize the performance of CRNs. Studies have been directed towards devising energy-efficient designs for transmit power allocation and RIS phase shifts in CRNs with a goal of minimizing the power consumption of secondary users in order to achieve their communication demands while protecting primary users. In [10], a energy efficiency maximization problem is solved by taking into account the joint active RIS beamforming and the transmit power control mechanism. In [11], intelligent reflecting surface (IRS) is employed to enhance the spectrum sensing and the secondary transmission accuracy in a CRN to access the spectrum opportunistically. A nonconvex optimization problem for maximizing the average throughput of a cognitive radio network (CRN) by jointly optimizing RIS phase shifts, transmit power, and UAV trajectory, employing Block Coordinate Descent (BCD) and Successive Convex Approximation (SCA) algorithms [12]. Moreover, machine learning (ML) and artificial intelligence (AI) are being used more and more to optimize the performance of RIS-assisted CRNs. AI algorithms can be utilized to adjust the phase shifts of the RIS elements dynamically in such a way that maximize the power received from secondary users or to minimize interference to primary users based on real-time spectrum sensing [13], [14].

III. Challenges and Future Directions

Although there have been tremendous developments in the area of RIS-assisted CRNs, there are a number of challenges that must be overcome to facilitate their ubiquitous adoption. Some of the notable challenges and potential research areas in this regard are the development of more sophisticated channel estimation methods specifically for RIS-assisted CRNs, incorporation of higher AI/ML methods for real-time optimization, investigating the effects of hardware constraints, and the development of robust security protocols for RIS-enabled CRNs. The application of RIS-assisted cognitive radio networks in next generation wireless communication systems, i.e., 6G and beyond, needs to be investigated in more detail.

IV. Conclusion

The integration of Reconfigurable Intelligent Surfaces and Cognitive Radio Networks is a future-oriented and revolutionary technique to solve the problems of spectrum scarcity. By intelligently controlling of the wireless environment, RISs impart precious benefits to CRNs, for example, improved spectrum sensing accuracy, better spectrum sharing efficiency, better energy efficiency, and longer network capacity and coverage for secondary users without sacrificing the protection of primary users. Various novel approaches are under investigation that exploit RISs for spectrum sensing and sharing. Although various issues related to channel estimation, deployment of RIS, control overhead, hardware limitation, and security are yet to be addressed, research and development in this field continues to lead towards a bright future for RIS-aided CRNs as a critical enabler of next-generation wireless communication systems.

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