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A Review on Energy Harvesting and Quality of Services in Cognitive Radio Network

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Abstract: *To fulfill ever-increasing demands for wireless services and applications, cognitive radio (CR) technology has been emerged to lighten severe shortage of spectrum resources. CR technology allows the secondary users (SUs) to access the spectrum licensed to the primary users (PUs), based on the premise that the quality of service (QoS) requirement of the PUs must be guaranteed. Radio-frequency (RF) energy-harvesting technology is a good candidate solution for charging the low-power wireless devices, which can conquer the uncontrollability and intermittency of wireless devices powered by the renewable energy sources, such as wind, solar and vibrational energy. This paper addresses the review work of energy harvesting in wireless communication and cognitive radio network. To improve the energy efficiency and spectrum efficiency mentioned above, the use of RF energy-harvesting technology in CR networks has been studied extensively in this paper.*

Keywords: Energy harvesting, Wireless communication, Cognitive radio network, Energy, Smart grid.

Introduction

The remarkable progress in data communication has had a radical influence on wireless networks. Predictably, the quantity of wireless devices has continued to rise at an enormous rate. Shortly, an even more mobile and connected society will emerge, defined by massive increases in connection, traffic volume, and a far larger range of usage scenarios. The amount of traffic will increase dramatically. Wireless communication systems have experienced substantial revolutionary progress over the past years. With the rapid progress of 3GPP 5G phase 2 standardization, the commercial deployment of 5G applications being deployed all over the world cannot fully meet the challenges brought by the rapid increase of traffic and the real-time requirement of services. Cognitive radio (CR) technology helps to overcome the spectrum scarcity problem. The underutilized licensed channels occupied by the primary users (PUs) are exploited by the unlicensed secondary users (SUs) without causing harmful interference to the PUs [1]. The SU can access the PU’s channel using interweave, underlay, or hybrid interweave/underlay mode. In the interweave mode, the SU senses the spectrum for a spectrum hole where the PU is not transmitting. In this mode, the SU can transmit his data with high power and achieve high throughput. In the underlay mode, the SU accesses the PU’s channel at any time with controlled power to keep the PU’s interference below a threshold value. Combining the advantages of the interweave and underlay modes in the hybrid interweave/underlay mode increases the channel utilization. When the channel is free from the PU’s transmission, the SU accesses the channel in interweave mode. However, when the channel is busy with PU's transmission, the SU transmits his data in underlay mode.

Energy efficiency is another important factor in wireless communication which needs to be considered in CR networks. Recently, radio frequency (RF) powered CR networks have been attributed to provide an innovative solution for both the spectrum scarcity and the energy limitation issues. During the PU transmission period, the SU can harvest energy from the PU signal and store it until it is used in the active transmission when the channel is free from the PU signal. This transmission mode is called harvest then-transmit (HTT) mode. The HTT mode is studied for a single SU operating on multiple licensed channels. To maximize the throughput of the SU, an optimal channel selection policy is obtained by formulating a Markov decision process (MDP) problem [2].

Cognitive Radio (CR) technology is developed to solve the spectrum shortage due to increasing wireless devices and networks [4]. It promotes the use of the radio frequency band by permitting Secondary User (SU) to allow the licensed spectrum of the Primary User (PU). Communication between IoT devices requires spectrum bandwidth, and the growing number of connected objects in the IoT poses multiple challenges, including a scarcity in the spectrum. IoT devices currently use Bluetooth and ZigBee for data transmission in the unlicensed ISM(Industrial Scientific Medical) bands. With the increase of Internet of Things devices, the frequency band in ISM is almost entirely occupied, and the transmission distance supported by traditional wireless technologies can reach 100 meters. Therefore, these conventional wireless technologies are unsuitable for IoT applications, such as smart grid, intelligent vehicle transmission, and environmental monitoring, where deployed smart IoT devices need to communicate with remote base stations [3]. The spectrum scarcity problem is also related to spectrum utilization and the technology used. This innovative trend in technological transformation is altering the methods by which we live, work, and interconnect with everyone. We have realized the emergence of extraordinary services and applications-for example, autonomous vehicles, artificial intelligence, smart homes, smart factories, smart cities, and drone-based delivery systems, etc. The collaboration between apparatus and human-based assistance will expand the forthcoming wireless environments with cost effectiveness challenges. Forthcoming increases in cell phone communication capabilities will saturate all aspects of public life and will generate a multidimensional, consumer-related ecosystem. Furthermore, an entire mobile-based linked environment is anticipated, characterized by a greater amount of traffic, a much wider span of running consequences, and an amazing volume of expansion in connectivity. This extraordinary heightening of traffic suggests that mobile networks will have to deliver approximately a thousand times the spectral effectiveness of the current decade's existing structure

Licensed spectrum detection approaches can be classified into many groups, including non-coherent spectrum sensing, coherent spectrum sensing, Non-Cooperative Spectrum Sensing (NCSS), and Cooperative Spectrum Sensing (CSS). In a non-coherent spectrum sensing, for the purpose of spectrum sensing it is not require any previous knowledge about the PU signal. In a coherent detection scheme, PU signal detection requires perfect prior knowledge of the PU signal, e.g. synchronization message, presenter, spectral scattering sequences, training and pilot patterns. In non-cooperative detection, CR- IoT users do not need to exchange sensing information with other CR-IoT users. In this method, the performance of spectrum detection is reduced due to concealed terminal issues, multi-path fading, and shadow impact. In CSS techniques, where group of CR-IoT users cooperatively execute spectrum detection to mitigate the multi-path fading, hidden terminal problem, and shadowing effects. In CSS technique, each CR-IoT user sends the spectral detection result of the PU signal to the respective Fusion Center (FC) individually. Thereafter, the FC uses the fusion rule on the collected spectrum detection outcomes of the CR-IoT users to take a final global decision.

II. Literature Review

During spectrum handoff, SU needs to find an idle channel to continue transmission. In the process of finding the inactive channel, it needs to spend its own energy to detect the idle channel until the available channel is obtained or the timeout is interrupted, which will also cause transmission delay. For time-critical transmission requirements, the importance of fast idle channel discovery is even more critical.

[1] In this paper, the hybrid interweave/underlay channel access mode is studied for an energy harvesting (EH) cognitive radio network with multi-class secondary users (SUs). The hybrid channel access mode combines the benefits of interweave transmission (opportunistic access with high throughput) and that of the underlay transmission (any time transmission with controlled power). EH upgrades the SUs' devices to be self sustainable. Additionally, classifying the SUs helps to meet their different quality of service (QoS) requirements. The system is modelled as a mixed observable Markov decision process (MOMDP) to handle the uncertainty in the primary user (PU) activity and consider future rewards. The MOMDP model is solved to maximize the SUs' throughput using two algorithms, namely, the point-based value iteration and the heuristic search value iteration (HSVI). Moreover, skipping the schedule of some SUs is proved to increase the channel utilization. The HSVI is proved to be efficient and reduces the time complexity significantly.

In RF-powered backscatter cognitive radio networks, while the licensed channel is busy, the SU can utilize the primary user signal either to backscatter his data or to harvest energy. When the licensed channel becomes idle, the SU can use the harvested energy to actively transmit his data. However, it is crucial for the secondary user to determine the optimal action to do under the dynamic behavior of the primary users. In this paper [2], they formulate the decision problem as a Markov decision process in order to maximize the average throughput of the secondary user under the assumption of unknown environment parameters. A reinforcement learning algorithm is attributed to guide the secondary user in this decision process. Numerical results show that the reinforcement learning approach succeeds in providing a good approximation of the optimal value.

In Cognitive radio-based Internet of Things (CR-IoT) systems, the return of the primary user (PU) causes the secondary user (SU) that is communicating to face the spectrum handoff problem. In the process of spectrum handoff, the user terminal can't get the idle channels in time because of the unknown channel usage state. To solve this problem, a hybrid spectrum handoff algorithm based on the channel idle probability is proposed [3]. The algorithm considers the regularity of PU activities in space and time, defines the idle probability of channels from the perspective of week attributes and time periods, obtains the optimal time period length using genetic algorithm, generates a channel idle probability table, and provides the target channel sequence for SUs in combination with the proposed channel ordering scheme.

Spectrum sensing plays a very important role in Cognitive Radio based Internet of Things (CR-IoT) networks for utilization of the licensed spectrum accurately. However, the performance of the conventional Energy Detector (ED) method is compromised in a noise-uncertain environment owing to interference constraints, i.e. the CR-IoT user interference with the licensed Primary User (PU) on the same licensed band. To overcome this drawback, they proposed an energy efficient Cooperative Spectrum Sensing (CSS) for a CR-IoT network with interference constraints using a novel ED method. In this Method [4], each CR-IoT user is capable of spectrum sensing that makes both the local decision and the weight factor based on the sequential approach; they calculate the weight factor against each CR-IoT user based on the Kullback Leibler Divergence award score.

In this review [5] they focused on the various enhanced capabilities that 6G has to offer, but also to the solutions that ML has to offer to the emerging 6G wireless communication challenges. They have summarized the state of-the-art 6G applications and the deployment of ML algorithms in various fields and applications. The most important ML were explained in detail, focusing on their advantages in dealing with upcoming 6G wireless communications challenges and enhancement of different systems. The interest in exploiting ML in 6G wireless communications challenges will sky rocket in the upcoming years, as 6G networks will soon be realized and the various challenges in the networks can be effectively addressed using ML approaches and models. Finally, they outlined out a handful of open problems and directions worth future research efforts.

In recent power grids, the need for having a two-way flow of information and electricity is crucial. This provides the opportunity for suppliers and customers to better communicate with each other by shifting traditional power grids to smart grids (SGs). In this paper [6], demand response management (DRM) is investigated as it plays an important role in SGs to prevent blackouts and provide economic and environmental bene_ts for both end-users and energy providers. In modern power grids, the development of communication networks has enhanced DRM programmes and made the grid smarter. In particular, with progresses in the 5G Internet of Things (IoT), the infrastructure for DRM programmes is improved with fast data transfer, higher reliability, increased security, lower power consumption, and a massive number of connections. Therefore, this paper provides a comprehensive review of potential applications of 5G IoT technologies as well as the computational and analytical algorithms applied for DRM programmes in SGs. The review holistically brings together sensing, communication, and computing (optimization, prediction), areas usually studied in a scattered way.

Fifth-generation (5G) communication technology is intended to offer higher data rates, outstanding user exposure, lower power consumption, and extremely short latency. Such cellular networks will implement a diverse multi-layer model comprising device-to-device networks, macrocells, and different categories of small cells to assist customers with desired quality-of-service (QoS) [7]. This multi-layer model affects several studies that confront utilizing interference management and resource allocation in 5G networks. With the growing need for cellular service and the limited resources to provide it, capably handling network traffic and operation has become a problem of resource distribution. One of the utmost serious problems is to alleviate the jamming in the network in support of having a better QoS. However, although a limited number of review papers have been written on resource distribution, no review papers have been written specifically on 5G resource allocation. Hence, this article analyzes the issue of resource allocation by classifying the various resource allocation schemes in 5G that have been reported in the literature and assessing their ability to enhance service quality.

Distributed machine learning (DML) techniques, such as federated learning, partitioned learning, and distributed reinforcement learning, have been increasingly applied to wireless communications. This is due to improved capabilities of terminal devices, explosively growing data volume, congestion in the radio interfaces, and increasing concern of data privacy. The unique features of wireless systems, such as large scale, geographically dispersed deployment, user mobility, and massive amount of data, give rise to new challenges in the design of DML techniques. There is a clear gap in the existing literature in that the

DML techniques are yet to be systematically reviewed for their applicability to wireless systems. This survey [8] bridges the gap by providing a contemporary and comprehensive survey of DML techniques with a focus on wireless networks. Specifically, they review the latest applications of DML in power control, spectrum management, user association, and edge cloud computing. The optimality, scalability, convergence rate, computation cost, and communication overhead of DML are analyzed.

This paper [9] firstly introduces common wearable sensors, smart wearable devices and the key application areas. Since multi-sensor is defined by the presence of more than one model or channel, e.g. visual, audio, environmental and physiological signals. Hence, the fusion methods of multi-modality and multi-location sensors are proposed. Despite it has been contributed several works reviewing the state of the art on information fusion or deep learning, all of them only tackled one aspect of the sensor fusion applications, which leads to a lack of comprehensive understanding about it. Therefore, they propose using a more holistic approach in order to provide a more suitable starting point from which to develop a full understanding of the fusion methods of wearable sensors. Specifically, this review attempts to provide a more comprehensive survey of the most important aspects of multi-sensor applications for human activity recognition, including those recently added to the field for unsupervised learning and transfer learning.

This paper focuses on the issue of joint time and power allocation in multi-channel energy harvesting CR networks (EH-CRNs), where the multi-antenna secondary transmitter (ST) opportunistically accesses the licensed sub-channels by a hybrid overlay/underlay transmission approach [10]. To improve spectrum efficiency and energy efficiency of the EH-CRNs, the ST scavenges energy from the radio-frequency signal radiated by the primary transmitter, and exploits the harvested energy for data transmission through sub-channels of different states in overlay/underlay mode simultaneously. Moreover, under the interference power constraint, energy constraint, and maximum power constraint, the secondary throughput is improved by optimising the allocation of sub-channels, the time scheduling between energy harvesting and data transmission, and the power allocation of the ST among different sub-channels. A sub-channel allocation scheme with low time complexity is proposed, and the secondary throughput optimisation problem is formulated with respect to the time scheduling and power allocation of the ST.

III. Energy Harvesting

Recently, the conception of Internet of Things (IoT) has been widely applied in many areas, and brings great benefits to our daily life. According to Cisco annual internet report, IoT devices will account for 50% of all global networked devices in 2023, and the ever-increasing number of IoT devices has led to a significant growth of mobile data. The huge data traffic has led to scarcities of both spectrum and energy [10]. However, as reported by Federal Communications Commission (FCC), more than 70% of the licensed spectrum in USA is under low utilisation at a certain time and spatial domain . Therefore, improving spectrum efficiency is an effective approach to alleviate spectrum scarcity. As a promising network technology, cognitive radio (CR) improves spectrum efficiency significantly by allowing spectrum reuse. In CR networks (CRNs), secondary users (SUs) could opportunistically access the spectrum licensed to PUs, as long as the primary data transmission is protected to a certain extent. Along with the solution to spectrum scarcity, energy harvesting (EH) technology is an effective approach to alleviate energy scarcity, which allows IoT devices with EH functionality to harvest energy from ambient energy resources, e.g. solar, wind, ambient radio-frequency (RF) energy, and so on. The EH-CRNs have been widely studied since the issues of spectrum and energy scarcities can be alleviated. In EHCRNs, the RF signals radiated by PTs could be viewed as energy resources to secondary networks, and STs with EH functionality are able to convert the energy of RF signals into electrical energy.

IV. Conclusion

Cognitive radio is a wireless communication system that intelligently utilizes any available side information about the activity, channel conditions, codebooks, or messages of other nodes with which it shares the spectrum. CR detects the unused spectrum in the surrounding radio environment during the cognitive cycle and allocates the unused spectrum to low-priority secondary users in an opportunistic or cooperative manner. Cognitive radio networks (CRNs) with energy harvesting has been promising solution for wireless industrial networks and seems a promising solution for the spectrum scarcity problem. However, it is critical the wireless spectrum should carefully be managed in order to fulfill the tight requirements on the trustworthy and minimum delayed delivery of information. This paper present the survey work in near future we plan to implement a model for energy harvesting in cognitive radio network and improve the performance of existing system.

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