The Cognitive Radio and Internet of Things, a Survey

Zozan Azeez Ayoub, and Ammar Abdul-Hamed Khader

Abstract—Cognitive Radio (CR) and Internet of Things (IoT) is an effective step into the smart technology world. Several frameworks are proposed to build CR and IoT. The phases of the interconnection between IoT and CR is; spectrum sensing, spectrum sharing, and spectrum management. This paper presents a survey of CR based IoT and mentions some previous works. It highlights with details the spectrum sensing stage for both narrowband and wideband.

Index Terms—Cognitive Radio (CR), Internet of Things (IoT), Spectrum Management, Spectrum Sensing, Spectrum Sharing.

I. INTRODUCTION

With the passage of time, the technology is evolving to make human life easier, which leads to increase in the number of devices connected to the Internet. This affects the speed of sending and receiving data and the productivity due to the large number of devices, and this causing congestion on the network architecture. So, using CR to enable IoT objects, can effectively utilize the unused spectrum who already owned by primary user (PU). CR is an intelligent wireless communication technique, which realizes his surroundings in all cases. Joseph Motila is the first to propose CR. Using cognitive radio in order to make the best use of the available spectrum and increase productivity. It is considered as a smart radio that knows the spectrum state. It consists of a secondary user (SU) and a PU. The exploitation of the spectrum is done by SUs, provided that it does not interfere with the PUs. When PU needs its channel, the SU must leave the channel and jump to another channel that it is not used [1]–[4]. Remember that the main functions of CR are: Spectrum sensing, Spectrum Sharing, Spectrum mobility and Spectrum management are concluded in Fig. 1 [5], [6].

The new concept IoT means the possibility of connect various things to the Internet through the Internet IPv4 or IPv6. It enables the people to communicate and interact with the things and to service without being in a specific place. The official announcement of IoT in 1999 by Kevin Ashton. There are many IoT connection patterns like: Things-to-Thing (T2T), Human-to-Thing (H2T) and Human-to-Human (H2H). The protocols that can be used for communication in IoT are: Mobile, Wi-Fi, Bluetooth, ZigBee, Radio-frequency identification and Near-field communication) [7]–[12].

The rest of the paper is organized as follows; Section II mentions the applications of CR based IoT. Section III presents a related work of CR and some of detection methods. Section IV deals with the design considerations in cognitive radio system based on IoT and the meeting stages.

II. CR-BASED IOT APPLICATIONS

There are many applications under this new technique, some of them are:

A. Healthcare
There are healthcare applications of IoT that viable space. Shrewd sensors are conveyed on and around a quiet to monitor basic information such as temperature, blood pressure, glucose level, and others. With remote monitoring, restorative staff ceaselessly observes the parameters [13], [14].

B. In-Home Applications
IoT-based arrangements are already within the working space interior a home/ building, and it is imagined that with the evolution in innovation, the time of IoT will be a necessity in the future. Home vitality administration is as of now display in the frame of certain illustrations such as keen fridge and keen lights, respectively,...etc. [15].

C. Smart Grid
Buyers need to know anything at any time and any put related to their energy utilization. This shows the require for IoT in keen network within the future. One major drawback here is the exchange of huge volumes of data from several meters/devices in a limited spectrum transfer speed without obstructions to long distances [16].

D. Smart Cities
Is an urban development paradigm that includes integration of information and communication innovation (ICT) systems and IoT. The inspiration behind shrewd city is the arrangement of e-services to clients for improved lifestyle in an eco-friendly way. To facilitate this, ceaseless network will be fundamental, so a data and communication framework will be the spine. Information gathering and

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client interaction will moreover be an critical perspective. The issue of ceaseless network can be backed by cognitive radio networks CRNs [17].

III. RELATED WORK

A constrained number of papers studied CR-based IoT and have discussed this theme from diverse points of view [18]– [24]. In [18] the cooperative spectrum sensing output of the proposed scheme was provided with Kullback–Leibler divergence (KLD) technique and traditional scheme with energy detection technique. The proposed system can deliver better sensing performance (41.57%) than the conventional spectrum sensing scheme. In [19] they suggested cognitive choice module outlined for CR based IoTs arrange. It gives the ideal comes about of different transmission parameters for the three gadgets each supporting distinctive mode of operation i.e. e-mail, voice, or video. Other comparisons are illustrated in table 1.

<table>
<thead>
<tr>
<th>Ref. No.</th>
<th>year</th>
<th>Content</th>
</tr>
</thead>
<tbody>
<tr>
<td>[20]</td>
<td>2020</td>
<td>This paper used a strategy depends on adaptive threshold level to determine the spectrum in energy detection method. It is useful to estimate the unoccupied spectrum when the noise is uncertain. The authors used Matlab Simulink to accomplish this.</td>
</tr>
<tr>
<td>[21]</td>
<td>2020</td>
<td>A green Cognitive Internet of Things suggestion to collect the radio frequency of the PU by using energy. The nodes performed to conduct sensing and harvesting energy simultaneously.</td>
</tr>
<tr>
<td>[22]</td>
<td>2020</td>
<td>For accurately detection of PU the authors suggested a model called (Weighted sequential hypothesis test (WSHT)), with less number of samples</td>
</tr>
<tr>
<td>[23]</td>
<td>2019</td>
<td>By using Universal Software Radio Peripheral (USRP) device for screening and monitoring the TV channels, a SU occupy the unused channels for TV White Spaces (TVWS). This device is supported by the GNU Radio Software Use to determine channel properties using Bit Transfer Rate (BTR). Also using Register-Transfer Level (RTL) to the measures the magnitude of frequency incoming, and account the signal to noise ratio.</td>
</tr>
<tr>
<td>[24]</td>
<td>2012</td>
<td>They present a system for the virtualization of genuine world objects and the cognitive management of their virtual partners. The framework consists of three levels of usefulness and each level comprises cognitive substances that give the implies for self-management and learning, permitting for shrewd, adaptable applications and objects.</td>
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</table>

IV. DESIGN CONSIDERATIONS OF CR SYSTEM BASED IoT

CR is a smart technology that enables IoT devices (SUs) to access unused spectra of PUs [25], [26]. CR used in IoT in order to exploit the available spectrum and increase productivity in order to connect more devices with high speed to send and receive data [27]. CR and IoT are meeting in three stages (spectrum sensing, spectrum sharing, and spectrum management) as in Fig. 2. In the design there are some considerations should be taken in the account, they are; the bandwidth needed, the transmitted rate, and the transmitted range [28]. All the details will be mentioned later.

TABLE I: LIST OF THE REFERENCE AND THEIR CONTENTS

<table>
<thead>
<tr>
<th>Technique</th>
<th>Technical specifications</th>
<th>Ref. No.</th>
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<tbody>
<tr>
<td>Energy detection</td>
<td>No need prior information about the PU, Few cost, Uncomplicated and easy to implement, Not appropriate for frequency hopping, The sensing is suffering with high noise and the PUs cannot be found whether or not, if the SNR be low.</td>
<td>[31]–[37]</td>
</tr>
<tr>
<td>Match filter detection</td>
<td>The sensing can be done with a noise and the (PUs) can be found, if the SNR be low, It needs prior information for the PU, Not always practical because the PUs signal sometimes does not know in advance, High cost, It needs a lot of power consumption, Complicated and difficult to implement, The time sensing is short.</td>
<td>[38]–[42]</td>
</tr>
<tr>
<td>Cyclisation-nary features detection</td>
<td>The sensing can be done with a noise and the (PUs) can be found whether or not, the SNR be low, The time for sensing is long, It needs a lot of power consumption, if it is high sampled, High cost, No need prior information for the PU, Complicated method, Good performance, regardless of the SNR value, Strong.</td>
<td>[43]–[46]</td>
</tr>
<tr>
<td>Eigenvalue base detection</td>
<td>Short sensing time, More complicated, Good performance, regardless of the SNR value, Optimum detection probability, It needs a little power consumption.</td>
<td>[47]–[52]</td>
</tr>
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TABLE III: WIDE-BAND TYPE SURVEY

<table>
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<tr>
<th>Technique</th>
<th>Technical specifications</th>
<th>Ref. No.</th>
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<tbody>
<tr>
<td>FFT-based detectors</td>
<td>It needs higher sample rate</td>
<td>[53]–[55]</td>
</tr>
<tr>
<td></td>
<td>The interval between one frequency and another is very little</td>
<td></td>
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<tr>
<td></td>
<td>Uncomplicated easy to implement mathematically</td>
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<tr>
<td>Wavelet based detection</td>
<td>Complicated</td>
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<td></td>
<td>Determines the hole in the spectrum and determines its location in the spectrum</td>
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<td></td>
<td>Fast switching from one channel to another will increase the system speed and increase productivity</td>
<td>[56]–[62]</td>
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<td></td>
<td>Low Power consumption</td>
<td></td>
</tr>
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<td></td>
<td>Spectrum division is uniform</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Very accurate in detection method</td>
<td></td>
</tr>
<tr>
<td>multi-coset sensing</td>
<td>Spectrum division is not uniform.</td>
<td>[63]–[68]</td>
</tr>
<tr>
<td></td>
<td>The sample take as Sub-Nyquist.</td>
<td></td>
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<tr>
<td></td>
<td>It allows rebuilding the spectrum signal.</td>
<td></td>
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<tr>
<td></td>
<td>The techniques used must be synchronous.</td>
<td></td>
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<tr>
<td></td>
<td>Easy to handle ADC</td>
<td></td>
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<tr>
<td>compressive sensing</td>
<td>Needs few power</td>
<td>[69]–[70]</td>
</tr>
<tr>
<td></td>
<td>Much complicated</td>
<td></td>
</tr>
<tr>
<td></td>
<td>The sensor are very accurate results.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sampling at a rate of Nyquist.</td>
<td></td>
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<tr>
<td></td>
<td>Take more sampling</td>
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</table>

B. Spectrum Sharing

It is the process whereby the spectrum holes are reasonably distributed to the unlicensed user. If many unlicensed users try to access the spectrum, then the access to the cognitive radio network should be coordinated to prevent multiple users from colliding in overlapping portions of the spectrum, one extraordinary challenge for the open remote range is spectrum sharing. Not similar to spectrum sensing, that is used in the physical layer, and spectrum management, which is closely connected with upper layer networks, spectrum sharing identical to multi-user multi-access and resource distribution techniques in the MAC layer of current communication systems [71].

There are two types of spectrum sharing:

1. Overlay spectrum sharing: In the spectrum sharing method, a parcel of the range that’s not utilized by the licensed user is gotten to by the CR users. As a result, impedances to the PU is minimized, as in Fig. 3.

2. Underlay Spectrum sharing: CR user starts sharing Connection at a certain section of the spectrum belonging to a spectrum allocation map with transmission power which the licensed user considers being noise. Compared to the overlay technique this technique can use increased bandwidth, as in Fig. 3.

C. Spectrum management

It is responsible for selecting the best available spectrum holes according to the quality of service for communication. In CR frameworks, range gaps detected may spread in a wide frequency range which will incorporate both licensed bands and unlicensed groups and differ in time, space and frequency domains. For illustration, they may have different central frequencies, different bandwidths, or they are accessible in different times. It is used to arrange or discover the optimal out of all accessible groups for the users, and to meet users’ different QoS requirements [71].

V. CONCLUSION

This survey has given the existing systems of CR-based IoT frameworks, investigated the later spectrum sensing and spectrum sharing spectrum management methods. Moreover, the study has identified the basic requirements of CR-based IoT frameworks and highlighted the plan variables. Besides, the components of cognition cycle of CR-based IoT frameworks have been displayed and discussed. The main focus of this survey has been on spectrum sensing. Also the detection methods for PU signal are tabulated depending on their bands, either narrowband or wideband sensing. It was mentioned their types and technical characteristics for each one.

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