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Internet of Things with Cognitive Radio – A Technical Survey

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Abstract: This paper discusses the use of cognitive radio in IoT. This paper addresses the cognitive capabilities which increase the efficiency of IoT devices. Further, we present a brief survey of the cognitive internet of things which includes their advantages and disadvantages. The summary of these techniques is also presented in tabular format. This survey will be useful for a new researcher to implement cognitive radios in IoT devices and increase the efficiency of the spectrum.

Keywords—Internet of things; Resource allocation; Cognitive radio; Spectrum Sharing.

I. INTRODUCTION

Internet of Things (IoT) is a computing concept which describes network of interconnected devices or objects through internet. The main idea behind the IoT project is to deploy billions or even trillions of smart objects that can process and distribute data and are embedded with sensors and actuators. It is expected that by the year 2025 there will be around 75 billion interconnected devices. It encompasses many fields of use such as manufacturing, ecology, healthcare, education, the Internet of vehicles, the development of smart grids, smart energy management, intelligent defense, intelligent agriculture, smart mobility, intelligent hospitals and smart homes. Life around us is moving IoT. In healthcare domain it has played an important role. It enables a patient to monitor in real time from anywhere. Patient needs to be embedded with sensors and actuators which senses, processes and transmits the data to the data centre where it can be analysed. In smart homes lights, doors and any others object which is connected with IoT can be controlled by your mobiles or laptop. Homes have been revolutionized by the IoT.
Smart cities are another application area of the internet of things. In this, transportation system, environmental monitoring is being automated. Other applications of IoT include autonomous cars, Industrial IoT and many more.

Cognitive Internet of Things

Cognitive Internet of Things means using the functionalities and capabilities of cognitive radio in the Internet of Things. Cognitive radio is a radio which is programmable and can be dynamically configured to use the best channel possible to avoid any interference and congestion. Cognitive IoT makes it more intelligent and interactive as well. Cloud computing was initially used to handle the large data which is produced from IoT applications. However, it is not a feasible solution mainly due to the slow processing, high latency and distance between the objects and the data centres. Fog computing was later adopted as a conventional cloud extension. The cloud's capability is applied to the IoT artefacts by the fog on the edge of the network. Fog computing but not cloud computing can achieve low latency and fast response time.
IoT is growing exponentially because of the advances in the computing world in industries, smart cities, smart healthcare, etc. These applications of IoT involve a large number of IoT objects which deploys a large amount of data. This may cause bandwidth problems. The additional characteristic of IoT applications, which typically utilize IoT devices in a very large number, exacerbates the bandwidth dilemma, resulting in an unpleasant situation where many bandwidth-hungry devices pursue the very narrow bandwidth within a wide geographic area. IoT will use only a very restricted permitted bandwidth that is likely to be filled by WiFi, Bluetooth, etc.

II. A RECENT SURVEY ON RECENT COGNITIVE INTERNET OF THINGS

SOME RECENT STATE-OF-THE-ART TECHNIQUES ARE PRESENTED BELOW:

Moongilan [1] This paper suggests that modern IoT devices will be connected through wireless networks. This paper also focuses on the challenges that arrive because of the frequencies of the 5G network. These papers give us a theory that is used to explain the observations that they get in the results. It also tells that far-field data that they get can be used to efficiently predict the electromagnetic environment around.
Li [2] This paper discusses the dynamic spectrum access method that is based on Q-learning and with the help of cognitive self-learning technology which helps in solving the difficulty which might occur in distributed and ordered self-accessing for

unlicensed terminals. The first devise a MAC access protocol for non-legitimate users to use the only available channel. This method performs better than the existing traditional accessing methods without cognitive capability and conflict probability.

Zhang [3] In the paper, they discuss that mobile operators are exploiting the existing standards and infrastructures. IoT-based technologies are deployed over the wireless channels which use the existing spectrum. More focus should be given to spectrum sharing, spectrum sensing and interference management. This paper also described the basic tenets and then analysed that spectrum sharing is the solution which will use the bandwidth efficiently.

Ejaz [4] This paper discusses spectrum sensing techniques and resource allocation for IoT in cognitive 5G networks. This paper suggests that 5G technology will increase energy efficiency and will increase spectrum efficiency. They also formulated a problem which can be determined as an optimization problem which determines a minimum number of channels that can be sensed and minimize the energy consumption.

Han [5] This paper addresses that the interconnected devices may increase exponentially which may cause the spectrum allocation problem. This paper also addressed the spectrum utilization problem. They suggest a solution to this problem by concurrent transmission model. They used a genetic algorithm to solve this problem.

Liang [6] In this paper they discuss the problem of designing the sensing time to optimize the achievable secondary network performance in the light of the fact that the primary users are adequately covered. They mathematically formulate the problem of sensing-throughput transaction and use the energy detection method to show that the problem formulated has an optimum sensing time with the maximum secondary network performance.

Liu [7] This paper considers a cognitive radio network which is of wideband that can reuse different free sub-bands. This network then uses spectrum sensing and thereafter analyses the total throughput of the SU over all the sub-bands. They then propose an optimization problem which contains multiple variables and this problem is non-convex. This optimization function maximizes the total throughput.

Tian [8] In this paper they address the improvements that can be made in IoT. Their main focus is to reduce interference and manage the network to reduce congestion. Their main effort is on the two-tier networks where different IoT devices use the same spectrum with the pre-existing macro cell with the help of cognitive radio.

Khan [9] This paper discusses the privacy challenges in CR-based IoT. This paper suggests that smart objects may introduce new privacy issues. The misuse of the application causes privacy issues. Privacy is the most important thing and needs to be preserved. So cognitive radio-based IoT needs to protect this data. Data is collected using wireless networks like cellular networks, and mobile phones and may lead to privacy-related threats.

Wu [10] In this paper address mainly the essence of experiences between five cognitive fundamental tasks: the response period of interpretation, large data analytics and exploration of information, intelligent decision-making and on-demand resources. They explored in-depth the main approaches to cognitive tasks.

Shigueta [11] This paper uses opportunistic spectrum access via cognitive radios. This paper uses the history of traffic which guides the allocation of channels in a well-distributed manner. This paper presents that the use of the history of network traffic as criteria for decision results in better results which are not the same with simple networks.

Lu [12] In this paper discusses a cloud/fog-computing paradigm. It also studies the IoT AI service framework. They proposed a solution for autonomous driving. This solution is cross-domain. This paper also focuses on the technologies for communication. The solution they provided achieves intelligent and flexible autonomous driving task processing. It enhances the transportation performance which uses the Cognitive Internet of Vehicles.

Wang [13] A modern definition of conflict settlement in CRAHNs is presented in this paper. A 'multi-round' conflict settlement process has been discussed. Computer emulation quantifies results. They explored the issue of saving time that can increase data efficiency. It is more effective and easier to solve contend than to use smaller rounds but fewer mini-pads per round The rounds are lower but less.

Vlacheas [14] This paper offers a cognitive management system for optimizing the sustainable development of smart cities through the Internet of Things. In it, the heterogeneity between artefacts must be discussed. The virtual object concept was implemented as a complex virtual representation of objects and the Hybrid VO concept was proposed as a means for dynamically aggregating VOs to satisfy the needs of users resiliently. Anticipation of the durability and diverse provision of related resources.

Alhussein [15] In this paper they proposed a method which uses smart EEG sensors. These sensors record and transmit signals from epileptic patients. Then the decision is made on future activities by the cognitive framework. The system which is proposed in this paper uses the patient's movements, gestures, and facial expressions to determine the patient's state. The findings are passed to physicians or other stakeholders who will track the patient and take action to support the patient in crucial situations.

Haykin [16] This paper studies challenges in the risk control in cognitive IoT. Both complicated topics include the mediation of cognitive function with cognitive interpretation and the formulation of a risk control protocol. By using probabilistic logic, the first dilemma can be overcome. The second problem is the possibility of unintended environmental damage, the risk is regulated by the prediction and pre-adaptation functions.

Zhang [17] This paper discussed the main idea behind cognitive IoT. They proposed that cognitive capabilities can cause IoT to make intelligent decisions. They modelled the cognitive internet of things network topology and designed technologies related to the cognition process. They analyzed this game theory model, which reveals the innovative designs that can enhance intelligence and the efficiency of the system.

Gai [18] This paper has the main goal of cost-saving and efficiency and provides different approaches to achieve so. They introduced a model for cost efficiency. The model works on cognitive wireless communications. In this model edge, computing techniques and reinforcement learning algorithms are combined. The results also address the computing saving issue in cloud-based IoT. They then formulate an optimization problem.

Dhevi [19] This paper proposed a Multiple-input Multiple-output (MIMO) based multi-user medical image transmission system. This system uses the cognitive capabilities of cognitive radios. It also studies Multicarrier Code-division-multiple-access (MC-CDMA) system to monitor the information of the patient. They then investigated the performance of these systems in the different layers of the internet of things (IoT).

Pranaya [20] This paper addresses the application of IoT in smart cities. For achieving this they proposed a framework which is based on IoT solutions for smart-grid. Their main aim is to improve energy consumption. This paper also suggests ways to increase the quality of services and customer satisfaction. They purposed a three-layer cognitive architecture consisting of a Perception layer, Attention-Memory layer and Decision layer. This architecture can play a big role in the future of smart cities.

Samanta [21] This paper addressed the lope holes in the dynamic spectrum access. This paper suggests that the 5G networks and DSA-based networks have high throughput and are very cost-effective but there are some vulnerabilities in DSA. Sensing Data Falsification (SSDF) attacks can be executed by hackers who wish to alter your data and exploit it. It suggests that they can have a bad impact on the performance of spectrum sensing in IoT applications. They also designed a utility-based mimicking model which will mimic the hackers and collaborative SSDF attack in a cooperative spectrum sensing scenario.

Deng [22] This paper explores a structural structure for complex spectrum exchange. They used this hybrid access sample exchange platform in the cognitive macro-femtocell networks based on OFDMA. The approach discussed aims to gain hybrid access to two-tier macrofemtocell neural networks in both MBS and FAP. In this context, the MBS discharges certain macro consumer equipment (MUEs) into FAP to increase drive speed and minimize energy efficiency. To solve the problem of optimization, the spectrum exchange method is used.

Liu [23] This paper addresses the challenges in security when using SDN in IoT. They addressed this challenge by designing an SDN-based data transfer security model Middle Box-Guard (M-G). Its main goal is to lower latency in the network and management of the data flow which ensures the network is working safely. In this, they revealed that the presented M-G model and management of dataflow in middleboxes is done effectively, and it is possible to improve the security and stability of IoT networks.

Khalid [24] This paper suggested a system for sensing focused on spectral space and time. This system is used in the spectrum-heterogeneous CR IoT setting for FD-SU TXs. They also provided an overview of the spectrum utilization (UoS) method for FD-SU TXs and its assessment of it. To measure the responsiveness of various parameters, the effects obtained are analyzed in heterogeneous networks and sensing parameters. These findings indicate that self-intervention, primary consumer behaviour and sensor outcomes play an important role in the use of spectrum in spatial and temporal fields.

Khan [25] This paper studies the cognitive capabilities of CR radio. This paper suggests that objects with cognitive capabilities tend to make intelligent decisions. These intelligent decisions are made by the self-learning functionality of cognitive radio. In this paper, they discussed cognitive functionalities, such as spectrum sensing, spectrum sharing, and self-learning solutions for some IoT applications.

Table 1 Summary of the Literature review on Cognitive Radio-based IoT.

Sr. No.	Author name	Key Idea	Positive Points
1.	**Moongilan [1]**	Cognitive IoT with 5G Network.	• Introduction of 5G networks in IoT. • Increase in efficiency of bandwidth usage.
2.	**Li [2]**	Dynamic spectrum access with Q-Learning.	• Provides IoT devices learning capabilities. • Spectrum efficiency is increased.
3.	**Zhang [3]**	Spectrum sharing, Spectrum sensing.	• Spectrum is shared for better use of bandwidth and to provide real-time data. • Devices can sense the idle channels and use them.
4.	**Ejaz [4]**	Resource allocation, interference management and energy efficiency.	• Resource allocation to efficiently use resources and reduce latency. • Use less energy in IoT devices.
5.	**Han [5]**	Spectrum utilization problem.	• Problems may occur when sharing the spectrum. • The efficiency of the spectrum may reduce.
6.	**Liang [6]**	Spectrum sensing and its problems.	• IoT devices can get the ability to sense idle channels. • And can use it according to the priority of data.
7.	**Liu [7]**	Cognitive radio network, spectrum sensing.	• Introduction of cognitive radios in IoT. • Cognitive capabilities like spectrum sensing, spectrum sharing and self-learning.
8.	**Tian [8]**	Interference management, reducing congestion.	• Methods to reduce interference and congestion. • Increasing the efficiency.
9.	**Khan [9]**	Privacy challenges in cognitive IoT.	• Privacy challenges in IoT. • Methods to reduce security risks.
10.	**Wu [10]**	Cognitive networks, self-learning.	• Introduction of cognitive radios in IoT • Capabilities of cognitive radio.
11.	**Shigueta [11]**	Opportunistic spectrum access via cognitive radios.	• Opportunistic spectrum access using cognitive radios.
12.	**Lu [12]**	Cloud/fog computing paradigm, communication technologies.	• Fog computing paradigm for IoT. • Communication technologies used in IoT.
13.	**Wang [13]**	Increasing data transmission efficiency, and spectrum efficiency.	• Transmitting data efficiently over the network. • Increasing spectrum efficiency.

14.	**Vlacheas [14]**	Cognitive management system for smart cities.	• Application of IoT devices in smart cities.
15.	**Alhussein [15]**	EEG sensors, IoT in healthcare.	• Application of IoT in healthcare. • Monitoring patients with the help of IoT devices.
16.	**Haykin [16]**	Risk management in cognitive IoT.	• Managing the risks in the cognitive IoT like security, efficiency and energy consumption.
17.	**Zhang [17]**	Cognitive capabilities like spectrum sharing, spectrum sensing, and self-learning.	• Embedding IoT objects with cognitive radios. • Providing spectrum sensing capabilities to IoT devices.
18.	**Gai [18]**	Cost-saving in IoT. The efficiency of the spectrum, cognitive wireless communications.	• Saving the cost in IoT. • Efficiently using the spectrum and communication using wireless networks.
19.	**Dhevi [19]**	Multiple input multiple outputs, cognitive capabilities.	• Using multiple inputs multiple out. • Using cognitive capabilities like spectrum sensing.
20.	**Pranaya [20]**	Application of IoT in smart cities using smart grids.	• Using IoT devices in the cities to make it a smart city. • Using smart gird to achieve this goal.
21.	**Samanta [21]**	Lope holes in dynamic spectrum access, security in cognitive IoT.	• Methods to increase the security of cognitive IoT. • Advantages of dynamic spectrum access.
22.	**Deng [22]**	Complex spectrum exchange, neural networks.	• Introduction of AI in IoT. • Providing learning capabilities to IoT objects.
23.	**Liu [23]**	Security concerns related to cognitive IoT.	• Security concerns like data theft, and privacy breaches.
24.	**Khalid [24]**	Spectrum sensing, fusion with heterogeneous networks.	• Spectrum sharing capabilities in IoT. • Fusion of different types of networks.
25.	**Khan [25]**	Cognitive capabilities of cognitive IoT.	• Cognitive capabilities like spectrum sharing, spectrum sensing and self-learning.

Conclusion:

In the report, we have discussed the potential of cognitive radios in the IoT. Its spectrum sensing and sharing capabilities. The different challenges which will appear when implementing this and opportunities. With extensive research, the cognitive IoT will surely have a lasting impact on IoT. The growing technology, advances in artificial intelligence and the introduction of the 5G network had opened the door for the bright future of the Cognitive Internet of Things and it will most likely become the standard in the future.

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