

## Energy Efficient Cognitive Radio Spectrum Sensing for 5G Networks – A Survey

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### Abstract

#### INTRODUCTION

Recently, the role of Artificial Intelligence plays a major role in the communication sector. As the revolution of spectrum and its standards is progressing towards 5G networks and beyond, there is a rapid innovation in design of 5G compatible gadgets in order to incorporate evolving wireless spectrum standards. Cognitive radio is an intelligent technology that can efficiently handle the radio spectrum usage.

#### OBJECTIVES

Researchers have been working since its inception to use this revolutionary technology in the management of the radio spectrum for both terrestrial and satellite communication. For 5G networks, research works focus on enabling efficient utilization of its features like extreme broadband, ultra-low latency communication, and ultra reliable connectivity for connected devices.

#### CONCLUSION

In this paper, energy efficient spectrum sensing schemes and challenges of 5G networks are explored and this review will assist any researcher/service provider/mobile communication sector to quickly select and apply relevant energy efficient spectrum sensing techniques using dynamic intelligent cognitive radio technology to incorporate either Co-operative, Non-Cooperative or Interference based techniques based on their application. to show how conventional energy efficient spectrum sensing techniques used in cognitive radio networks can be efficiently applied to 5G terrestrial applications.

**Keywords:** 5G radio networks, cognitive radio, energy efficient spectrum sensing

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### 1. Introduction

Next generation 5G networks are the mobile standards developed by ITU (International Telecommunication Union) established by a set of international bodies. Recently consumer demands are shaping the development of mobile broadband services. Innovative technologies will cause high traffic rate nearly 10-100 times during 2020-2030, with increased number of devices and along with demand for improved affordability and user

experience. It is expected that in 2025, the amount of devices to be connected over the Internet for communication is proposed to reach over 50 billion. This smart communication network can transport massive data much faster and connect an incredibly large number of devices efficiently. Once the IMT-2020 (International Mobile Telecommunication) specifications are finalized the first full-scale commercial deployments for 5G are expected to increase. Global stakeholders at the WRC-19 (World Radio Communication Conference 2019) reached

consensus to identify additional spectrum for IMT-2020. Compared to existing wireless 4G/3G networks 5G envisages very high data speed, low latency, and increased base station efficiency with improved quality of experience (QoE).

With the rapid explosion of smart devices, a significant burden on existing cellular networks prevails. These issues can be overcome with improved data rates, capacity, latency and QoS characteristics of 5G wireless systems. The three major distinguishing features of 5G from traditional wireless systems that ITU has outlined for IMT-2020 are outlined in Fig 1.

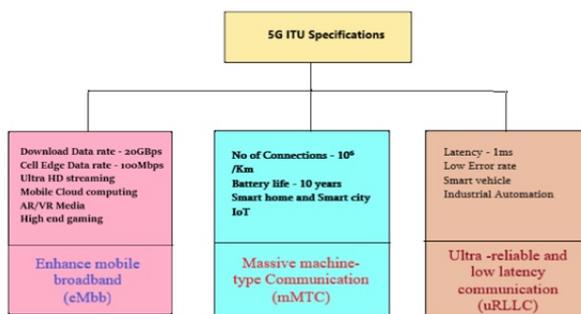


Figure 1. Specifications for the 5G Core Network

The main characteristics of 5G networks like Enhanced mobile broadband (eMbb), Massive machine-type communication(mMTC) and Ultra reliable and low latency communication (uRLLC) are depicted in Figure 1 with each of its specifications as given by IMT.

### 1.2 Spectrum and 5G

Spectrum is a non-replicable valuable and scarce phenomenon which is divided into frequency bands allocated to different radio communication services. It can coexist with each other without causing unnecessary interference to neighbouring services. 5G networks require more spectrum bandwidth, different architectures, radio access technology, and algorithms in physical layers for its applications as outlined in Table 1.

Table 1. IMT Spectrum characteristics

Parameter	Description
Latency	Over air : < 1ms end-to-end : <10ms
Channel rate	100 Mbps (for urban coverage) and 1 Gbps (for hotspot cases)
No of Connections	106 devices/km <sup>2</sup>
Area capacity	1 Tbps/km <sup>2</sup>

Spectrum range	3 times more than IMT-Advanced
Maximum throughput	Upto 20 Gbps
Energy efficiency	>90% over LTE
Mobility	500 km/h

ITU plays a vital role in management of radio spectrum and the global development of IMT-2020 standards as outlined in Fig 2. The figure depicts the frequency standards given by mobile industry and its corresponding allocated spectrum by IMT.

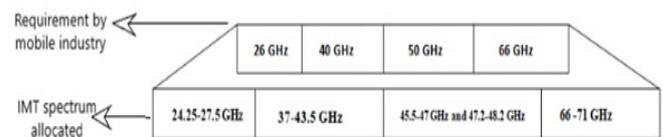


Figure 2. New IMT Spectrum allocations

ITU-R also examines the compatibility of terrestrial 5G services with other radio communication services like satellite communication, weather forecasting, Earth resource monitoring, climate change and radio astronomy. Global spectrum harmonization policies need to be framed at reduced cost which is a challenge. It ensures that 5G networks are secure, interoperable, and operate without causing harmful interference to adjacent services [1]. Harmonization benefits with ease of equipment design, optimal battery life, global roaming, efficient spectrum and minimal interference. As indicated in Fig 3, the available frequency band is divided into High-band (>6GHz), Mid-band (<6GHz) and Low-band (< 1GHz) for 5G services. The spectrum required for 5G access ranges below 1 GHz to 100 GHz. Nowadays all countries use IMT systems with spectrum below 6 GHz, which forms a significant part of the 5G spectrum allocation [2].

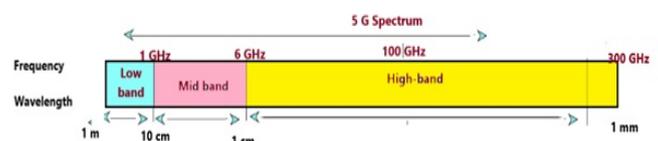


Figure 3. FCC Frequency band allocation

Existing Long Term Evolution (4G) bands have been harmonized, in particular the 700 and 800 MHz bands provides universal coverage for 5G networks. High frequency wireless communication above 10 GHz causes high network power and wide transmission bandwidth in

dense deployments. The spectrum allocation processes at low frequency bands remains the backbone for 5G networks and provide ubiquitous wide area connectivity.

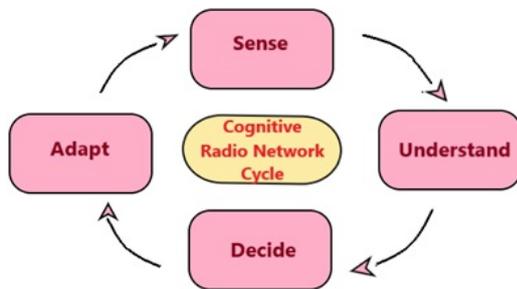
The remaining part of the manuscript is organized as follows. In section 2, Cognitive Radio spectrum sensing and its types are elaborated. Section 3 covers a detailed review of existing research contributions on spectrum sensing towards 5G problems. In section 4, few applications are discussed followed by conclusion in section 5.

## 2. Cognitive Radio Spectrum Sensing

Cognitive radio technology overcomes the issue of spectrum scarcity due to increased utilization of wireless services. It is based on the dynamic software defined radio technology which can modify its parameters by adding a cognitive mechanism [3].

CR actions are implemented as a cognitive cycle and represented in Fig 4 that includes:

- Sensing the neighbouring environment
- Understand the probable strategy for action
- Decide on an optimal operational strategy and
- Adapt for any environment from knowledge gained.



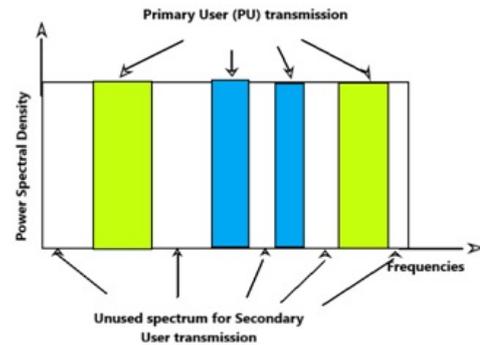
**Figure 3.** Cognitive Radio Network cycle

When the incumbent spectrum users also called primary users (PUs), vacate the spectrum, it may be accessed by non-incumbent users called secondary users (SUs). The interference of SUs can cause limitations to PU.

Cognitive radio spectrum sensing (CR-SS) will be performed at the physical layer to detect radio frequency (RF) signals. Depending on the situation, sensing technique can be either implemented via centralized or distributed manner. Spectrum sensing information will be transmitted to the decision component, which queries about PUs spectrum usage.

Dynamic Spectrum Sharing (DSS) is a mechanism for reducing the shortage of spectrum capital to ensure a robust and effective sharing of the spectrum. DSS allows SUs to identify and occupy unused spectrum regions called “spectrum holes”, as well as ensure that they do not

interfere with the PU [4]. The idle state of primary users causes spectrum holes. This results in detection of absence of primary signals by secondary users in a given frequency slot to locate spectrum holes. Frequency spectrum sharing makes efficient utilization of spectrum hence enable other users to use the spectrum when the PU does not use it, as seen in Fig 5.



**Figure 4.** Used and Unused Spectrum bands

This function can be interpreted as a binary hypothesis. Assume that  $r(\eta)$  is the received signal at detector input, here  $\rho(\eta)$  is the amount of noise signal and  $\tau(\eta)$  is the transmitted signal.

Equ (1) states the two hypotheses:

$$\begin{aligned} H_0: r(n) &= \rho(n) \\ H_1: r(n) &= \tau(n) + \rho(n) \end{aligned} \quad (1)$$

Where,

$H_0$  - means that primary signal is absent and channel is idle

$H_1$  - means that primary signal is present and channel is occupied

$\eta$  - is a sample index

When  $H_1$  is true the signal is detected and when  $H_0$  is true it is not detected. Decisions regarding frequency channel allocation to idle spectrum holes are made based on the spectrum sensing information. DSA significantly increases the overall efficiency of the spectrum by maximizing coexistence among different devices and technologies. Access to the dynamic spectrum includes sensing, spectrum management, sharing of spectrum and spectrum mobility.

The 5G architecture incorporates huge number of different network entities mainly sharing the resources under same spectrum through dynamic access spectrum. Cognitive radio plays a vital role for alleviating the problem of scarce spectrum in 5G communication network which allows better use of unused licensed

spectrum. The challenge relies in implementing a spectrum sensing that maximizes device efficiency against the 5G cognitive radio network under different scenarios as follows:

- Measurement of interference temperature - SUs are aware of their location and transmission power but unaware about PUs location. There is no mechanism for CR to calculate the temperature of interference in neighbouring PUs.
- Multiple-user based spectrum sensing - PU sensing is harder in such scenario, hence cooperative detection applied in this situation.
- Detection capability - secondary users based on OFDM are best suited in cases where PU needs to be detected quickly.

### 2.1 Types of Spectrum Sensing

The task of sensing the spectrum is categorised as transmitter based detection and interference based detection and is outlined in Fig 6.

The transmitter-based detection is classified into non-cooperative and co-operative detection. Further non-cooperative detection can be classified into energy detection, matched filter detection, cyclostationary feature detection, and eigen value based detection [5].

#### Transmitter Detection

When using this technique, the cognitive radio will focus on local signal observation from a primary user, i.e. transmitter. Transmitter detection can be achieved either by one cognitive radio or by a co-operative group of cognitive radios sensing a specified band of spectra. In this method the primary receiver location is not known and weak signal detection is done using primary transmitter via local SU observations.

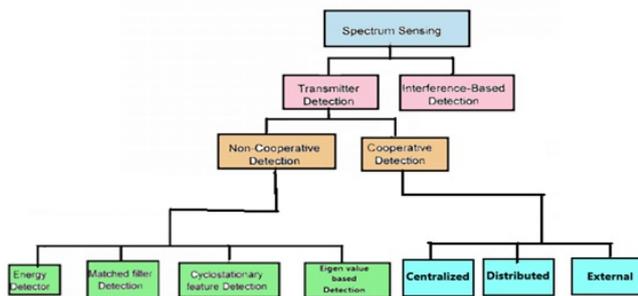


Figure 6. Types of classical spectrum sensing

#### Energy detection

Energy detection sensing technique will compute the energy of samples and compare it to a threshold value to determine if the primary user is present or absent. Using

this approach, the obtained signal energy is measured within the predefined bandwidth and time span. The energy of the samples is calculated as given in Equ (2).

$$T_E = \frac{1}{N} \sum_{n=1}^N (Y[n])^2 \tag{2}$$

Where,

N – no. of samples received

Y[n] - n<sup>th</sup> received sample

Let  $\lambda_{et}$  denote threshold, then:

$T_E < \lambda_{et} \rightarrow$  Indicates PU is absent

And if

$T_E > \lambda_{et} \rightarrow$  Indicates PU is present

#### Advantage

- No prior information about signal is required
- Requires low implementation cost, without requiring channel gains and other parameter estimates.

#### Disadvantage

- Difficult to differentiate between noise and signal
- The detection performance for low SNR is minimum

#### Matched filter detection

This method compares the obtained signal to pilot samples that are captured from same transmitter device. Hence these pilot samples are used to calculate the test statistics, which is again compared to a threshold value. If the resulting signal samples are greater that threshold, then the signal is present. The energy of the samples is calculated as given in Equ (3).

$$T_M = \frac{1}{N} \sum_{n=1}^N y(n) * \rho * (n) \tag{3}$$

Where,

N – no. of samples received

Y[n] - n<sup>th</sup> sample received

$\rho$  - Pilot samples

$T_M$  is then compared with a predefined threshold value -  $\lambda_{mt}$ .

If

$T_h < \lambda_{mt} \rightarrow$  Indicates PU is absent

and if

$T_h > \lambda_{mt} \rightarrow$  Indicates PU is present

#### Advantage

- Improved sensing performance via dynamic threshold selection
- Minimum samples sufficient to achieve optimal performance

#### Disadvantage

- Prior signal information is required since coherent operations are performed
- Increased computational complexity due to synchronization on both physical and medium access control layers
- Reduced efficiency due to varying channel response

### Cyclostationary feature detection

The unique features in the PU signal are detected to check if the mean value and auto-correlation value are periodic with time then the signal is said to be cyclostationary. These features can also be artificially induced within communication signals since information is modulated over cyclostationary carriers that are periodic in nature to aid the process of signal detection. The cyclic spectral density is based on the detection process which separates PU signal from noise and is weak since it has little correlation [27].

For a received signal the cyclic spectral density is denoted as in Equ (4).

$$S(f, \alpha) = \sum_{\tau=-\infty}^{\infty} R_y^{\infty}(\tau) e^{-j^2 \pi \alpha \tau} \quad (4)$$

Where,

$\alpha$  - denotes the cyclic frequency and  
 $R_y^{\infty}$  - denotes the cyclic autocorrelation function

And  $R_y^{\infty}$  as in Equ (5)

$$R_y^{\infty}(\tau) = \mathbf{E}[y(\mathbf{n} + \tau) * (\mathbf{n} - \tau) e^{-j^2 \pi \alpha \tau}] \quad (5)$$

Equ (5) reaches the peak value when  $\alpha$  reaches frequency of transmitted signal ( $n$ ).

#### Advantage

- Better performance than energy detection
- Minimum false alarm probability, as its less susceptible to noise

#### Disadvantage

- Sensing time and complexity increases with increase in length

### Eigen value-based spectrum sensing

In communication models, the noise in receiver is called Additive White Gaussian Noise (AWGN). This approach uses the function of the sample covariance matrix eigen value. The key concept behind Eigen value-based spectrum sensing is to operate over the similarity in the obtained signal when there is a PU. It is assumed that the noise in various receivers is uncorrelated. Hence the correlations between different SUs can be observed over time using covariance matrix.

### Co-operative spectrum sensing

In this type of sensing, the efficiency of detection is improved when the secondary users collaborate to find spectrum holes. It is utilized by secondary users to confirm channel status whether it is idle or busy by interacting with other SUs or a fusion centre. The sensing results of multiple users are exchanged with a central agency to enhance decision reliability. The process of spectrum sensing can be affected with multi-path fading

which is minimized by improving the signal-to-noise ratio (SNR). Further improvement in SNR cannot be made by higher transmit power or additional bandwidth due to the challenges of next generation systems [28].

Cognitive radio thus calculates the power spectral density of the radio spectrum to check which bands are in use and not utilized.

Before transmitting any signal, the primary users of a band are ensured to be safe from intrusion. Cooperative spectrum sensing technique overcomes the "hidden terminal issue" in the following manner:

**Step 1:** Cognitive radio makes a binary decision by measuring the local spectrum.

**Step 2:** Then it forwards its decisions to a specific receiver like wireless LAN access point (AP) or a cellular base station (BS).

**Step 3:** The receiver finally makes the decision to ensure if PU is present or absent.

Following two metrics are used for effective spectrum sensing:

- Probability of detection ( $P_d$ ) indicates how correctly the spectrum is detected when its being occupied
- Probability of false alarm ( $P_{fa}$ ) indicates the misdetection of idle spectrum

An effective system must have high  $P_d$  and low likelihood of  $P_{fa}$ . The received cognitive signal can be unreliable due to the effects of shadowing, multi-path fading and noise disruption which degrade the precision of spectrum sensing. Cooperative sensing of the spectrum among multiple- users is utilized to improve accuracy.

Further, Cooperative Sensing is divided into centralized, distributed and external sensing:

#### Centralized sensing

The sensing information is collected by a cognitive device as a central unit which transmits the information to other cognitive radios. This form of sensing reduces the risk of information being lost. When the users are more, the reporting bandwidth also increases. In this case, the centralized sensing optimizes the local observation of CR to single bit thus reducing the bandwidth size.

#### Distributed sensing

In distributed sensing, each cognitive node exchange information about frequency bands and make individual decision over band usage. In order to reduce the overhead of network, only final decisions are exchanged. This type of sensing technique have potentially improved compared to centralized sensing as it does not require specific infrastructure and has minimum cost.

**External sensing**

In this method, sensing is performed via an external agent and information about channel occupancy is transmitted to cognitive radio. Major issues like hidden primary user, shadowing and fading are overcome by this method.

**Interference Based Detection**

This type of detection measures the tolerable quantity of signal interference by the primary receiver. Growing primary consumer has a temperature limit for interference that determines toleration to ensure certain service quality. Cognitive radio will measure the environment of interference and adjust its transmission to ensure that interference with PU does not exceed regulatory limits. Measuring interference is the big drawback of the interference model [29].

**3. Existing Research Contributions**

For over a decade various research works are in progress to overcome the problem of spectrum under-utilization using cognitive radio technology. The telecommunication sector is moving towards incorporating the next generation 5G networks and its services by enhancing spectrum standards. A brief survey on research works for cognitive radio spectrum sensing technology to support 5G Networks and its application are reviewed and outlined in Table 2.

Table 2. Survey on Spectrum Sensing techniques for 5G

S . No	Existing work	Type of spectrum sensing	Support to 5G Networks
1	L. Zhang et.al [7]	CR-Based Spectrum Sharing, D2D-based spectrum sharing, full-duplex spectrum sensing, non-orthogonal multiple access (NOMA) spectrum sensing, LTE-U-based spectrum Sharing	Ultra-high-frequency bands, support multiple users via multiple spectrum sharing
2	W. S. H.M.W. Ahmad et.al [8]	Full Duplex spectrum sensing, spectrum database based spectrum sensing, compressive spectrum sensing and carrier aggregation based	Increased bandwidth capacity, High data rate and ultra-low latency

		spectrum allocation	
3	L. Wang et.al [9]	Massive MIMO in spectrum sharing	massive antenna arrays, optimized downlink and multi-user MIMO transmission in PU network
4	M. Shikh-Bahaei et.al [10]	Cognitive and Full Duplex networking	Spectral efficiency and multi-user interference
5	B. Li et.al [11]	Deep spectrum sensing, Primary user location tracking	Location awareness for 5G networks
6	Giuseppe Caso et.al [12]	Energy efficient cooperative spectrum sensing	D2D communications, full-duplex and massive MIMO, Wi-Fi coexistence
7	Y. Arjouni et.al [13]	Narrowband, Wideband and Machine learning based spectrum sensing.	Secure spectrum sensing and sharing for 5G applications
8	Jessica Moysen et.al [14]	Machine Learning for Self-Organized Networks	5G Network Management
9	Lu Lv et.al [15]	Non-orthogonal multiple access (NOMA) and cognitive radio (CR) with underlay NOMA networks, overlay NOMA networks, and CR-inspired NOMA networks	High spectrum efficiency, Massive connectivity, low latency, and better fairness
10	Noura A. El-Alfi et.al [16]	Cyclostationary sensing for 5G generalized frequency division multiplexing (GFDM)	Address 5G Physical layer to support broadband challenges
11	Yang Liu et.al [17]	Cyclostationary spectrum sensing	multiple-input multiple-output (MIMO)
12	Tianheng Xu et.al [18]	Reinforcement learning based spectrum sensing	Throughput and Energy optimization of 5G networks
13	Małgorzata Wasilewska et.al [19]	Machine learning based spectrum sensing algorithms (KNN and Random forest)	Increasing the quality of spectrum sensing of LTE downlink signal transmission

14	Devasis Pradhan et.al [6]	Intelligent Spectrum sensing techniques such as full-duplex spectrum sensing, spectrum-database based spectrum sensing, compressive spectrum sensing	Wider-Coverage, Massive-Capacity, Massive-connectivity and Low-Latency
15	Weidong Mei et.al [20]	UAV sensing-assisted ICIC(Inter Cell Interference Coordination)	Avoid interference with co-channel terrestrial communication for 5G cellular assisted UAV communication
16	Petros S. Bithas et.al [21]	Study of various Machine learning techniques for UAV communication	Channel estimation, resource management, trajectory, and security for 5G-UAV communication
17	Long Zhang et.al [22]	Study on channel modelling, estimation and blockage detection	mmwave communication for UAV-assisted Wireless Networks
18	Wenbo Xu et.al [23]	Compressive spectrum sensing	Reliable and timely communication for UAV networks
19	Modar Shbat et.al [24]	Blind, non-blind, and fine spectrum sensing	Address the Spectrum sensing ability of IoT in 5G networks
20	Sivasankari Jothiraj et.al [25]	Machine learning(SVM) based spectrum sensing	Reduced the energy consumption and increased spectrum utilization
21	Waleed Ejaz et.al [26]	Multiband cooperative spectrum sensing	Reduced energy consumption
22	Haldorai A.[3]	IEEE 802.16g network selection model	Energy efficient network selection

#### 4. Case study

5G will become dynamic and permits feasible new applications especially in urban. 5G use cases cover various domains and are depicted in Fig 7as ‘5G triangle’.

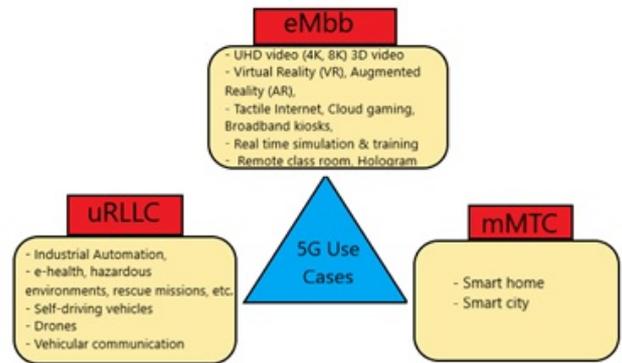


Figure 7. 5G Use Cases and Applications

#### Healthcare

Globally, the healthcare sector is all set for a shift in paradigm with growing proliferation in devices and evolution of sensing tools, technology and telemedicine. It is a rapidly growing sector with increasing number of applications with distinct data type and formats, which affects the bandwidth, data rate, and latency demands on the network among other factors. With the increasing growth in this sector, the communication demands growth of Massive-Machine Type Communication of devices and machines with sensor-based applications in larger hospitals. Following technological requirements need to be undertaken for efficient implementation of 5G in healthcare:

- Manage huge data generated by IoMT devices.
- Enable Smart wearable devices to measure heart rate, basic blood pressure and respiration rate.
- Use of tactile internet for remote healthcare with latency of milliseconds.
- Support critical communication like remote blood sugar safety tracking, ECG, etc., with essential QoS capability.
- Enable timely emergency care services such as high definition scan images
- Ensure privacy and security of patient data  
Analyze and maintain patient information in form of big data for processing

#### Smart Cities

It is anticipated that the increasing growth in urban population smart city environment require resource conservation, economic and technology initiatives. 5G enabled smart cities will pose both challenges and opportunities to meet the growing urban demands. The recent growth in application of connected devices in the domain of IoT has contributed in the development

of 5G enabled communications and has made current systems operationally effective.

Technological requirements for efficient implementation of 5G in smart city are:

- Support Massive Machine Type Communications (MTC) like IoT applications.
- Provide minimum latency, reliability, and availability for mission critical communications like drones and data.
- Provide high data rates and coverage for enhanced mobile broadband applications like Augmented Reality (AR) and Virtual Reality (VR).
- Support network operations such as network slicing, connectivity and routing.
- Support vehicle-to-everything communication like autonomous driving.

### Automation Industry

The recent development in 5G supports the automotive sector by linking vehicles, pedestrians, roadside infrastructure, or application servers by supporting several innovative and dynamic technologies.

Various 5G application in automation industry includes the following:

- Vehicle platooning where vehicles form a dynamic group.
- Support advanced driving 5G network architecture for emergency services to handle virtual access.
- Remote cloud based driving to controls a remote vehicle in dangerous condition.

Technological requirements for efficient implementation of 5G in automation industry are:

- Network slicing like virtual feature graphs
- Multi-access edge computing with high resilience and low end-to-end delay, bandwidth and energy consumption
- Support necessary mmWave communications

## 5. Conclusion

As the mobile communication standards are often updated by standards framing bodies like ITU and FCC with respect to 5G/Beyond 5G applications, it is important for any researcher to keep track of these corresponding spectrum standards and apply corresponding spectrum sensing techniques. Many researchers are working on developing new technologies to face the challenges of 5G developments. There are some major issues in optimizing spectrum sensing that should be considered for implementing 5G networks. In this research survey, a detailed study was made to address the research challenges of emerging 5G spectrum requirements and the importance of cognitive radio spectrum sensing in

supporting this issue. Few important requirements of IMT-2020 are also elaborated in this work. The standard frequency bands for 5G were outlined to assist the spectrum considerations for varying 5G applications. This work contributes in detail over the IMT spectrum standards framed by ITU and briefed about Cognitive Radio Technology and types of spectrum sensing techniques that will assist in efficient utilization of available spectrum with reduced energy emission for both terrestrial and non-terrestrial 5G networks and application development thus providing a green and safe environment. From the survey it is understood that different spectrum sensing techniques are adopted for varying 5G terrestrial applications like cellular IoT and UAV communication. This survey work will assist researchers in exploring the spectrum requirements and future research directions with respect to emerging 5G spectrum allocation scenarios.

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