Original Research Article

Effectiveness of Spectrum Sensing in Cognitive Radio toward 5G Technology

Devasis Pradhan[*], IEEE Member, Priyanka K C

Assistant Professor, Department of Electronics & Communication Engineering, Acharya Institute of Technology, Soladevnahalli, Bangalore-107, India

Abstract

Cognitive radio is an intelligent network which addresses the availability of radio spectrum in order to enable dynamic spectrum access. This paper is based on engineering model for electromagnetic spectrum, which deals with current scarcity-based regulatory model. It is an intelligent platform through which static frequency allocations can done to dynamic, intelligent, and instantaneous frequency negotiations and assignment. Various detection models were discussed to make the radio spectrum abundance model possible, and a brief discussion on the architecture of mobile network. It was identified as a promising solution to the limit less need of spectrum and the main idea behind is for dynamic access of unused spectrum for communication. Its play a vital role for dynamic utilization of idle spectrum without affecting the rights of primary users, so that the services can be available for different or for other services. In this unused spectrum can be share in order to achieve a prominent goal for avoiding the cost of usage of spectrum. It also helps in improving the utilization of spectrum resources. In order to meet the critical requirements of the fifth generation (5G) mobile network, especially the Wider-Coverage, Massive-Capacity, Massive-Connectivity, and Low-Latency four application scenarios, the spectrum range used in 5G will be further expanded into the full spectrum era, possibly from 3 GHz to 300 GHz.

Keywords: Cognitive Radio; Spectrum Sensing; Narrowband Sensing; Wideband Sensing; Compressive Sensing; Spectrum Sharing; FD-Spectrum Sensing; SDB-Spectrum Sensing; DSA; Spectrum Management.

INTRODUCTION

In order to overcome the problem which people use to face due to explosive growth of data transmission and reception with dense traffic, massive device connection with continuous emergence of new business and application scenarios more effectively in the future, the fifth generation (5G) mobile communication system comes into being. Cellular network through which Internet of Things (IoT) will be the major driving force for 5G development as well as for device to device connection. The 5G network will give a platform for people of various regions not only to exchange information but also provide interconnectedness of all things begins from home utilization to industrial applications [1].

Due to rapid growth in development of broadband access as well as in mobile technology demand of people increasing day by day with respect to information accessibility and different services from internet at any moment, from anywhere as well as while moving from one place to another as their point of interest. Basically it is intended toward human centric communication which focused on to provide better user experience. In the nearest future, the demand for communication will be more and higher in various applications, such as remote areas, urban area, and high-speed rail. With a rapid growth in the number of wireless devices with respect to static management of the radio spectrum which has created a shortage of available radio spectrum.

It was expected that by 2020 over 50 billion wireless devices will be connected, all of which are likely going to demand access to the Internet. Due to the static management of the radio spectrum it is not enough to grant the access all IoT devices. Not sharing the radio spectrum among users can result in the creation of unwanted denial of service events. The limit less need of the radio spectrum is thus one of the most urgent issues at the forefront of future network research that has yet to be addressed. One solution to these and other challenges is to use cognitive radio technology,

which has undergone extensive investigation by the research community for almost two decades [2-4].

Cognitive radio technology allows IoT devices to sense the radio spectrum, decide about the state of frequency either used or unused, and reconfigure their communication parameters in order to meet QoS for minimization of energy consumption. These devices can use unlicensed spectrum as well as licensed bands when their licensed primary users are not active, preventing adverse interference.

Basically the sensing techniques has been be classified into two categories: narrowband and wideband. Narrowband sensing analyzes one frequency channel at a time while wideband sensing analyzes a number of frequencies at a time. Sequential-sensing approaches are ineffective because they require longer times and higher energy due to the use of ADC, which is both costly and impractical for timely communications. It involves three main processes: sparse representation, coding with the sensing matrix/measurement, and decoding, also called sparse recovery [5, 6].

IoT integrates the physical world and the virtual world, and affects people's behavior and lifestyle through better connectivity and functionality. With rapid development of mobile Internet and IoT, 5G system will face new requirements and challenges in Coverage, Capacity, Connectivity, and Low-latency. The network will radically change, such as new spectrum exploration, dynamic spectrum usage, and higher energy efficiency [7].

Spectrum

Electromagnetic spectrum is a range of possible frequencies for electromagnetic radiation. With the effectiveness of radio frequency through which we are capable of sending information without wire as a free space propagation. Using radio frequency voice and telegraph it was already tested but now evolved into digital communication capable of transmitting nay data represented in digital form, from documents to sound to video. The radio spectrum has a frequency range of 3 KHz to 300 GHz (premium frequencies being below 3 GHz) which can be used for wireless communication. Common problem faced in wireless communication is fading of signal or degradation strength of signal or interference [8].

Interference between signals is basically an alteration or modification, or disrupts or radio wave while travelling in channel between transmitting end to receiving end. Most important thing about spectrum is that the entire wireless spectrum is not equally distributed. In electromagnetic spectrum frequency at the lower end of spectrum, tends to have better propagation characteristics that higher band of frequency. The lower frequency bands are capable of

travelling through solid objects with less signal degradation and signal loss. Other aspect of lower band of frequency has better range and more throughput or capacity is more.

As per current scenario, the spectrum resources are basically limited to 6GHz. Basically the spectrum are categorize into licensed and unlicensed spectrum, especially frequency band below the 3GHz. The licensed and unlicensed bands are much less than ISM band and 5GHz WLAN band.[9] The ISM band is basically used by three major areas such as industry, science and medicine, it can be used without license, as long as each user follows certain protocols and does not interfere with other frequency spectrum and also depend upon transmitted power. The wireless technologies such as WLAN, Bluetooth, Zig-Bee and others can work on this spectrum band. As compared to 4G, 5G will face higher data transfer rates, wider business platform, more rigorous in user experience, and highly dense network architecture. The demand of spectrum supply and contradictions will become more prominent in future. Below 6GHz of frequency band are very crowded and difficult to find the abundant spectrum to meet the increasing requirement. Usage of spectrum above 6GHz is relatively simple which can provide larger band width and data accessibility is more. The full spectrum involves low frequency band below 6GHz and high bands are core band in 5G, and the high-frequency bands are mainly used for local compensation due to limitation of propagation of wave characteristics. Most of the licensed spectrum has not been fully utilized.

Spectrum Reallocation

Due to good propagation characteristics the UHF band used in broadcasting and television is located in same frequency band as the band used for mobile communication. However, with the digitization of analogue TV, idle rate of frequency bands allocated to TV broadcast is higher. In order to use the idle spectrum for TV broadcast this can be used by mobile communication proposed in a conference WRC-07 [10].

It is also important to achieve high-speed internet access in rural areas and geographical blind region where the wireless network is unavailable while the TV signal is available. With rapid development of IoT devices, short distance wireless communication among terminals is more frequent, and some new business and demands continue to emerge. The uncompressed data with high quality video streaming, interactive games, massive downloads and ultra fast wireless data access in Gbps. For short distance communication spectrum has been fully occupied by 802.11, Bluetooth, microwave and other applications due to the need of low frequency wireless resources limited data rate need to be upgrade further. Though there is extremely high complexity communication

technology are used to obtain higher spectrum utilization.

With rapid development in semiconductor industry such as CMOS many countries include US and Eroupe have divided 60 GHz band into 5GHz-7GHz unlicensed continuous spectrum resources for general use. The 60GHz frequency has been widely studied in academic and industrial fields for its large bandwidth, high transmission rate, highly secure and anti-interference. The unlicensed spectrum has large bandwidth is about seven times as much as the sum of the other low frequency spectrum [11].

Consequently, the 6oGHz band has a great advantage in high speed short distance communication. The IEEE 802.11ad defines a novel MAC architecture that 60 GHz can be compatible with Wi-Fi. In 60GHz communication signals in different direction are very small which is useful for space division multiplexing. For high directional communication system the parameter such as antenna gain and beam forming has to be realizing in 60 GHz frequency spectrum.

Cognitive Radio Network toward 5G
Cognitive Radio gives an opportunity to reuse valuable spectrum resources without change in spectrum allocation policy which address a problem of low utilization rate. The core idea behind Cognitive Radio is to share the spectrum through dynamic spectrum access and implication of sharing is that SUs can use idle spectrum of Pus but only if they cannot interfere with communication of PUs. The brief diagram of spectrum sensing is shown in Figure-1.
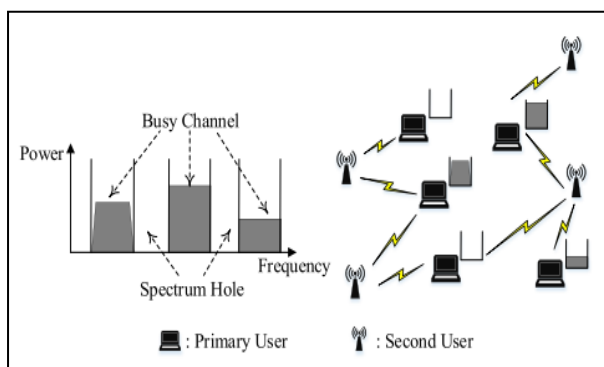

Fig-1: Spectrum Sensing

Spectrum sharing includes four basic steps as follows:
1. **Spectrum Sensing:** The goal of the sensing technique is to check for the status of the spectrum. Also, to check the activity of licensed user by sensing periodically. The CR transceiver looks for an idle band i.e., spectrum holes without causing interference to the primary network. Sensing can be of centralized and distributed. First step of sensing to complete spectrum sharing to improve spectrum utilization and can be realize for various application. SUs continuously detect frequency

band used by Pus in multidimensional space-spatial domain [12]. Basically it detects the unused spectrum as a hole is available. The main objective of spectrum sensing is to discover the status of spectrum and also the action of licensed users by sensing target band periodically. Cognitive radio transceiver will detect if there are spectrum holes and will find out a technique to accessing it without interfering the licensed users transmission or reception. The spectrum sensing is broadly divided into two types: centralized and distributed.

2. **Spectrum Allocation:** It is based on the availability of spectrum holes and distributes the unused spectrum to secondary users. The numbers of holes were not fixed and the secondary users need to compete while QoS are different for different users. Therefore spectrum holes need to be used fairly and efficiently. The basic need of spectrum allocation is to design an efficient spectrum allocation algorithms and protocols through which spectrum utilization efficiency can be increased, conflict-free and preferably close to optimal target as possible.

3. **Spectrum Management:** The licensed, unlicensed and unused spectrum bands are spread over a large number of frequencies in the cognitive radio networks. These unused spectrum bands show different properties according to the time varying radio environment. The Cognitive radio has to decide the best available spectrum band, such that it fulfills the QoS requirements. The collective information obtained from spectrum sensing is to plan and schedule the spectrum access by users which do not have licensed to access the spectrum. The basic component of spectrum management is: spectrum access and spectrum analysis.
i) Spectrum Analysis: In this the data obtained from sensing is analyzed first to collect information about the spectrum holes and the decision is made by optimizing the system performance on given desired objective and constraints.
ii) Spectrum Access: After taking decision on spectrum access which is based on spectrum analysis, the unlicensed users can access the spectrum holes. Mainly it is carried out on a cognitive access protocol call MAC protocol through which collision can be avoided between primary users and also with others secondary users. In order to access the frequency band the first priority is given to primary users where as secondary user subordinate relation to access it. It require efficient algorithm to coordinate multiple secondary users to access spectrum holes and avoid the conflicts between primary and secondary users while spectrum band.

4. **Spectrum Mobility:** The spectrum mobility is important in the communication between the nodes. If a particular part of the spectrum is required by the licensed user, communication should be continued by utilizing another free part of the

spectrum. It deals with the hand-off strategy when the PU returns. When a primary user is active or ready to use, the priority of using that band switches from unlicensed user to licensed user. The change in the allocation of the spectrum band is termed as hand-off. The corresponding protocol parameters at different layer are adjusted to the new frequency band. While the secondary user is switched for another idle band, it maintains proper communication requirements. The purpose of the spectrum mobility in CR networks is to safeguard smooth and fast transition leading to minimum degradation. The secondary users must switch to appropriate spectrum when following situation arises: **First**- if a secondary user using a spectrum hole and its appear to used by primary user then conflict occur, thus secondary users must quit the frequency band and then shift to other spectrum holes for better communication with no loss. **Second**- if secondary user change the geographical location while primary users does not change, the optimal holes for secondary users will be different and they need to switch to appropriate frequency band. **Third**- when the frequency spectrum used by secondary users cannot meet their communication requirements, they must switch to other frequency band to meet their communication needs.

Requirement for Cognitive Radio Environment

Cognitive Radio is an adaptive and intelligent technology which can automatically detect available channels in wireless environment and adapting to it by changing the transmission parameters. Major requirements on cognitive radio which distinguishes it from the conventional wireless communication in order to handle the coexistence of secondary and primary users both.

It is essentially to detect and avoid the conflict where the secondary users and primary user use the spectrum at a time and other spectral opportunities for both in time and frequency domain as per the requirements in terms of QoS or maximum time delay. The main drawback is that the entire spectrum is not fully used and may prevent the transmission of secondary users even if primary users are not affected. Basically cognitive users are allowed to operate a certain frequency band; either the primary users is occupied or not, provided that the interference caused to primary users remain below threshold frequency band. Information collected by cognitive devices are used either to eliminate the interference effects produce during the transmission by primary users at cognitive receiver side or to improve the performance of primary transmission through relying the collected messages to primary receivers [13].

There must be a clear trade-off between the interference induced on primary signal and improvement in stagnant SNR by secondary users. The

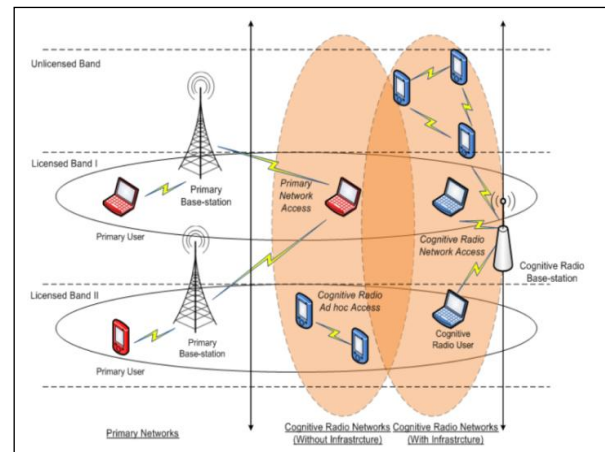architecture of cognitive radio network is shown in Figure-2.

Fig-2: Architecture of Cognitive Radio Network (CRN)

Cognitive radio/spectrum broadly divided into two types: a) Type- 1 and b) Type-2

1. **Type-1:** These devices used fixed spectral bandwidth to transmit its data exploit the holes in the spectrum by hopping on these holes for absence of primary or secondary radio systems. Example for Type-1 radio is WLAN. In this case of WLAN system may hop signal from one channel to other channel, but bandwidth of the channel has to be 20 MHz.

2. **Type -2**: Basically in this system able to expand or contract its bandwidth. For example UWB system which uses OFDM and bandwidth is between 3.1 GHz to 10.6 GHz. It is easier to tune the available holes in spectrum. If the band of 4GHz to 6GHz are occupied, then this type of radio system switch off the carrier in the range of 4-6 GHz and transmit data in the frequency band of 3-4 GHz and 6- 10 GHz.

Classification of different Sensing Techniques

The sensing technique can be broadly divided into two categories such as: narrow band spectrum sensing and wideband spectrum sensing. The classification is shown in Figure-3.

- **Narrow Band Spectrum Sensing** is technique which includes energy detection, cyclostationary detection, matched filtering detection, covariance- based detection and ML based sensing.

- **Wideband Spectrum Sensing** use two detection technique nyquist based and compressive sensing detection. Basically in Nyquist based the wideband signals get sampled by ADC at high sampling rate and low power consumption. It includes wavelet detection and filter bank based sensing. Secondly in Compressive sensing techniques

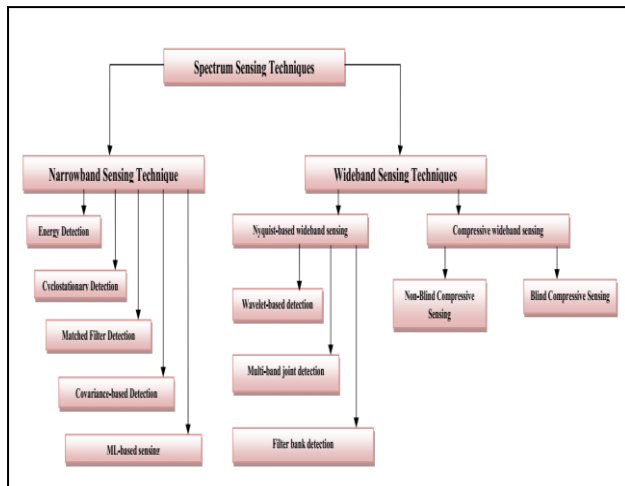signal get sampled below nyquist rate in order to reduce the high sampling rate.

Fig-3: Classification of spectrum sensing techniques

Narrowband Sensing Techniques

In this technique the secondary users allowed to decide about their presence or absence of primary users over a channel of interest. Consequently this algorithm needs to able to determine accurate spectrum hole and it can be expressed as two element hypothesis detection model:

$$\begin{cases} H_0: x(t) = \eta(t) \\ H_1: x(t) = s(t) + \eta(t) \end{cases} \dots\dots (i)$$

The above mentioned equation indicate two hypothesis of non-existence or existence of s(t). Here η(t) indicate additive white Gaussian noise and s(t) is the signal of primary user for target channel. The state H_0 corresponds primary user absence and state H_1 correspond primary user presence. Basically these techniques are often evaluated using probabilities of

detection. These two probabilities can be defined as follows:

$$p_f = p\left(\frac{H_0}{H_1}\right) \& p_d = p\left(\frac{H_0}{H_0}\right)\dots\dots (ii)$$

Energy Detection

It is also known as radiometry or periodogram whose implementation and computation is simple in which energy detection is done by comparing the output energy with some maintained threshold energy that depend upon noise floor to determine the presence of primary users signal. It is not necessary for energy detector to perform sensing to have information regarding primary users. However, there are many challenges in this technique starting from the selection of threshold energy, inability to differentiate between noise and primary user interference, degradation of performance at low SNR and difficult in detection of primary user in whole spectrum [14].

Non-coherent detection method has been adopted by energy detection and does not require any complex processing as matched filtering detection method. Figure-4 represents the structure of energy detection. First step is to select a centre frequency to receive signal from interested bandwidth and then the received signal is measured by a magnitude squaring device. Secondly the integrator control the observation time, sum up all receive signal after squaring it. Then the receiver compares the sum with predefined threshold level in order to estimate primary user activity. The energy detection can be performed without any prior information of primary user signal, which require low implementation complexity and perform poorly under low SNR and cannot be distinguish between signals of primary user from signal of other secondary user. It also require knowledge of noise power through which performance get degraded
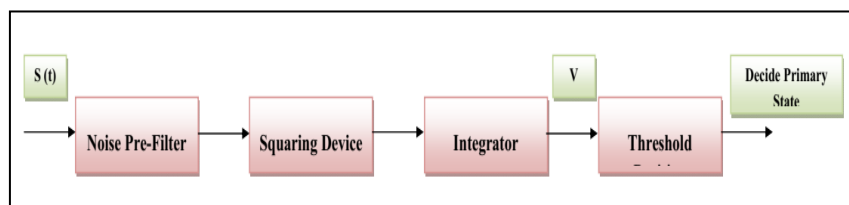

Fig-4: Spectrum Sensing of Energy Detection

Mathematical approach for Energy Detection

In order to calculate the energy of the samples as the squared magnitude of the FFT averaged over the number of samples N. This is given by:

$$\boldsymbol{F_{ED} = \frac{1}{N}\sum_{n=1}^{N}\big(Y(n)\big)^2 \dots\dots\dots (iii)}$$

Where N indicate the total number of received samples, and Y(n) denote the nth integrated sample. The output of the integrator is provided to comparator where it was compared with predefined sensing

decision. If the energy is above the threshold level then primary user is considered to be present whereas it was considered as absent. λ_{ED} indicate denotes the threshold that depends on the noise variance. The selection of the threshold, which can be static or dynamic, dramatically affects the detection performance.

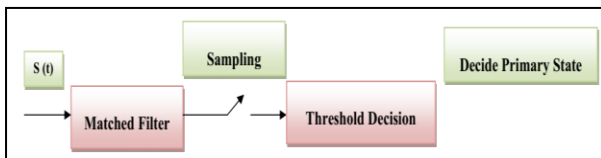$$F_{ED} < \lambda_{ED} \text{ Primary User \textbf{Absent}}$$
$$and$$
$$F_{ED} > \lambda_{ED} \text{ Primary User \textbf{Present}}$$

Table-1: Advantage & Disadvantage of Energy Detection Method of Sensing

Advantage	Disadvantage
Implementation is easy.	False alarm rate is high.
No requirement of prior knowledge of signal characteristics.	At Low SNR value it is unreliable.
	It is noise sensitive in nature.

Matched Filter Detection

In this detection additive noise status is matched and the decision made if primary user signal information helps to maximize the SNR. It also reduces the observation time with the help of coherent detection. The basic structure of matched filter detection is shown in Figure-5. In coherent detection require prior information about the primary user signal and it needs carrier synchronization through which signal can be processed. Thus matched filter detection is more complex as compared with other detection scheme and performance is also poor.

Fig-5: Spectrum Sensing of Matched Filter

Mathematical approach for Matched Filter Detection

In this sensing technique the received signal was compared with predefined and pilot carrier samples captured from transmitter. These pilot carrier is use to compare test and compared with threshold. If higher than threshold signal is present otherwise absent.

For test statistic function matched filter technique use a relation given by:

$$F_{MFD} = \frac{1}{N}\sum_{n=1}^{N} y(n)x_p^*(n) ..... \text{ (iv)}$$

N denotes number of samples, y is the vector of samples and x_p are the pilot samples. The statics sample is then compared to a threshold to determine the sensing decision such as:

$$F_{MFD} < \lambda_{MFD} \text{ Primary User } \textbf{Absent}$$
$$and$$
$$F_{MFD} > \lambda_{MFD} \text{ Primary User } \textbf{Present}$$

Where λ_{MFD} denotes the threshold, which depends on the noise level present in the received signal. As for the previously mentioned techniques, the use of a static threshold can lead to less accurate results because of the noise uncertainty. Matched filter techniques are optimal in the sense that they require only a few samples to achieve good performance detection, but they are not very practical.
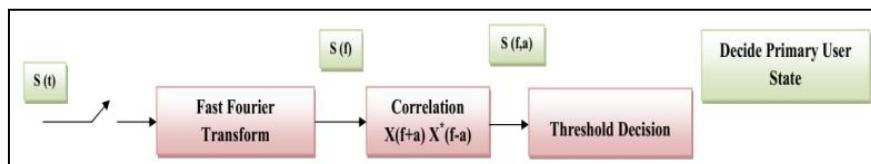
Table-2: Advantage & Disadvantage of Matched Filter Detection Method of Sensing

Advantage	Disadvantage
Better detection at low SNR region.	It requires prior information regarding primary user signal.
Optimal sensing	It is impractical because it requires prior information of signal which is not always possible.

Cyclostationary Feature Detection

This detection technique depends on certain features of received signals. The feature includes such as modulation rate, carrier frequency, and periodic/a-periodic. Since the noise is stationary with no correlation so the feature detection can distinguish the signal by analyzing spectral correlation function of the signal. The performance of this detection technique is better than energy detection technique. Moreover, it has the ability to differentiate between signals and noise and allow this methodology to be lesser probability of false alarm. The performance of the cyclostationary detection can be further enhanced by increasing number of samples through which time of sensing increased and complexity also. A block diagram of cyclostationary feature detection is present in Figure-6. Mostly Primary User transmitted signals are modulated signals, which are modulated by pulse train, cyclic prefixes, or repeating spreading.

Fig-6: Spectrum sensing of cyclostationary feature detection

This detection adopts cyclic correlation function for detecting Primary User signal with a certain modulation type with additive noise. After obtaining partial information of the PUs signal, cyclic correlation function can distinguish certain modulated Primary User signals from other modulated signals and noise because different types of modulated signals exploit different cyclic characteristics and wide-sense

stationary additive noise has no correlation. However, there are two disadvantages in this detection technique. In this first of all partial information of PUs is required. Secondly there is a high cost of computation introduced for cyclic correlation.

Mathematical approach for CFD

Let s(t) is received signal also called cyclostationary if it satisfy the mean and correlation of signals to be periodic.

$$m_s(t) = E[s(t)] = m_s(T_0 + t) \ldots\ldots (v)$$

$$R_s(t, \tau) = R_s(t + T_0, \tau) \ldots\ldots\ldots (vi)$$

Where, T_0 denotes the period of the signal s(t), E denotes the expectation operator, R_s denotes the autocorrelation function of s(t), and τ denotes the time

offset. The autocorrelation R_s of the received signal s(t) is given by

$$R_s(\tau) = E[s(t + \tau)s^*(t - \tau)e^{j2\pi\alpha t}] \ldots (vii)$$

Where, $E[\cdot]$ denotes the expectation operator, and α denotes a cyclic frequency. In order to determine the degree of correlation which consists of the auto correlated values of the received signal samples, The correlation distance is computed as the difference between ACF_S, which consists of the auto correlated values of the received signal samples, and the reference vector ACF_{REF}, given by:

$$d_c = \sqrt{\sum ACF_{REF} - ACF_S} \ldots\ldots (viii)$$

The correlation distance d_c is compared with threshold level parameter γ to decide whether signal is present or absent.
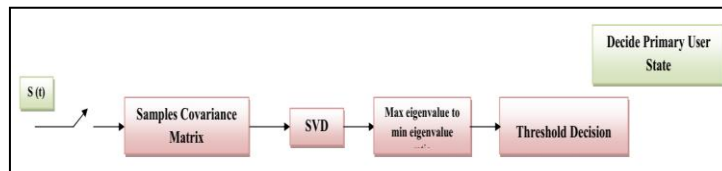
Table-3: Advantage & Disadvantage of Cyclostationary Detection Method of Sensing

Advantage	Disadvantage
• Immune to effect of noise. • Probability of false alarm toward SNR is low.	• For good performance it require large sensing time. • For computation of large data it require large amount of energy.

Covariance-Based Detection

In this detection process presence of Pus signal SVD technique has been used. It also use covariance matrix of received signal and determine the effect of noise. The signal from primary users are correlated and differentiated from noise. With the help of SVD method

eigen values of the covariance matrix can be found and in order to decide about threshold value a ratio has been taken between maximum eigen value to minimum eigen value. This helps to decide between the two states H_0 and H_1. The basic steps of covariance detection are as shown in Figure-7.

Fig-7: Spectrum sensing of Covariance based detection

Mathematical approach for CBD

In order to compute the sample covariance matrix of the received signal, the following expression is used

$$R_S(N) = \frac{1}{N} \sum_{n=L-1}^{L-2+Ns} s(n)s^*(n) \ldots\ldots (ix)$$

Where N is the number of collected samples. The singular value decomposition operation applied on the matrix R_S(N) gives the maximum and minimum eigenvalues of R_S(N), that is λ_{max} and λ_{min}. The test

statistic, which is calculated as the ratio of maximum to the minimum eigenvalue, $\lambda_{max} / \lambda_{min}$, is then compared to a threshold to determine the sensing decision. Such that if the test statistic is below a threshold, the primary user is declared absent; otherwise the primary user is declared present. This can be expressed as:

$$\lambda_{max} \ or \ \lambda_{min} < \gamma_c \ \text{Primary User } \textbf{Absent}$$
$$F_{CBD} > \gamma_c \ \text{Primary User } \textbf{Present}$$

Where γ_c is a pre-defined threshold.

Table-4: Advantage & Disadvantage of Covariance Based Detection Method of Sensing

Advantage	Disadvantage
• No prior knowledge of the primary user signal and noise is required. • Blindly detection	• Good computational complexity coming

Machine Learning Based Spectrum Sensing

Machine learning has received increasing interest and has found application in many fields due to its ability to apply complex mathematical calculations to analyze and interpret patterns and structures in data,

enabling learning, reasoning, and decision making. In the context of cognitive radio networks, several research papers related to machine learning for spectrum sensing have been published.

This machine learning-based sensing techniques aim at detecting the availability of frequency channels by formulating the process as a classification problem in which the classifier, supervised or unsupervised, has to decide between two states of each frequency channel: free or occupied. These classifiers use features, such as the energy statistic or probability vector, to determine the availability of channels [15, 16].

The technique in the first category uses two steps. In the first step, unsupervised machine learning techniques are used to analyze data and discover the primary user's patterns. In the second step, supervised machine learning techniques are used to train the model with the data labeled in the first step. Two-step machine learning model for spectrum sensing. In the first step, the K-means algorithm is used to identify the state of the primary user's presence. In the second step, support vector machine or other types of classifiers are used to attribute the new input data into one of the classes specified by the K-means method used in the first step. Techniques of the second category assume that the classes are known, and they are based on supervised machine learning to train models.

Table-5: Advantage & Disadvantage of Covariance Based Detection Method of Sensing

Advantage	Disadvantage
• Machine learning can detect if trained correctly can be a good approach • Minimize the delay of the detection • Use complex model in an easy manner	• Complex techniques • Has to be adapted in learning in very fast changing environments • Features selection affects detection rate and adds complexity • High dataset has to be build

Wideband Spectrum Sensing

The next generation of communication systems requires high data rates and therefore high bandwidth. From this perspective, secondary users need to sense wide frequency ranges of the radio spectrum to find the best available channels.

As a result, several types of approaches have been proposed to perform wideband spectrum sensing. Most approaches divide the wideband spectrum into several narrow bands and perform sensing sequentially, a process that increases sensing time as they scan one band at a time. Another solution is to sense the narrow bands in parallel by using multiple sensors and performing joint detection [17].

A compressive sensing technique has been used to reduce the number of samples, reducing the sensing delay. The most relevant sensing techniques from types, Nyquist and sub-Nyquist based, present their advantages and disadvantages, and discuss the efficiency of each type.

Nyquist Wideband Spectrum Sensing

Conventional wideband spectrum sensing techniques use standard ADC converters operating at the Nyquist rate to sample the wideband signal. Examples include wavelet, multi- and joint detection, and filter bank sensing.

Wavelet-Based Sensing

Wavelet-based sensing uses the Wavelet transform to get time and frequency information simultaneously about the wideband signal. Unlike the traditional Fourier transform that provides only spectral information and works for a stationary signal. Short Time Fourier Transform (STFT) is also used for time-frequency analysis, however, the main problem with the STFT is the inability to obtain both high time and frequency resolutions simultaneously due to the constant window length used in STFT analysis.

Wavelet transform can be used to analyze signals with different frequencies at different resolutions and obtain high time resolutions and low frequency resolutions at high frequencies and vice versa at low frequencies. The main idea in wavelet-based sensing is using the wavelet transform to detect the edges in the Power Spectral Density (PSD) function of the wideband signal. These edges carry important information about transitions from an occupied sub-band to an empty sub-band. Locating these edges and estimating the power between every two edges helps to represent the wideband signal in a binary fashion and classify the sub-bands into occupied and vacant [18].

Waveform-Based Sensing

This sensing technique takes advantage of the special patterns sent with the PU signal such as preamble, mid-ambles, pilot patterns and spreading sequences. A preamble is a pattern transmitted at the beginning of the data sequence, while midamble is transmitted in the middle of the data sequence. These patterns are added to the signal intentionally for synchronization and detection purposes. Sensing is performed by correlating the received signal with these known patterns, and comparing the output of the correlator with a certain threshold. This method is also known as coherent sensing and can be applied on systems with known signal patterns. It was found that waveform-based sensing outperforms energy detector with higher reliability and shorter sensing time. However, this sensing technique is Secondary Users to synchronization errors, and it decreases spectrum efficiency since longer signal patterns are required for a more accurate sensing performance [19].

Sub-Nyquist Wideband Sensing

Each of the Nyquist-based sensing techniques has limitations, such as a high sampling rate and power consumption, are not acceptable for the next generation of communication systems. Therefore, several compressive-based techniques have been proposed to mitigate the sampling rate issues. The application these methods in the context of wideband spectrum sensing is motivated by the scarcity of the spectrum and the sparsity of the wideband signal in the frequency domain.

Compressive Sensing-based Wideband Spectrum Sensing

With the development of smart city, smart agriculture, smart medical and other IoT applications targeting sensing and data collection, this kind of Massive-Connectivity application scenario which requires a wide range of terminals, large quantity, small data packet, low power consumption and mass connection has put forward higher requirements for the speed and power dissipation of spectrum sensing. Most existing spectrum sensing techniques only focus on the single channel and narrowband signal detection. However, with the mushroom of innovative services, traditional narrowband spectrum sensing can no longer meet the fast growing spectrum requirements.

The high sampling rate and the large amount of sampled data bring great challenges to the existing analog to digital converters (ADC), processors and storage devices in terms of the wideband spectrum sensing. Based on the compressed sensing theory, which can extract and detect the wideband signal directly to achieve efficient wideband sensing with a much lower sampling rate than the Nyquist criterion.

At present, most research on compressive wideband spectrum sensing is based on the assumption that the sparsity of wideband spectrum is known. However, due to the limited information interaction between Primary Users and Secondary Users and the dynamically changing spectrum environment, the sparsity of wideband spectrum becomes unknown. Furthermore, there may be many active PUs who occupy wireless resources at the same time in some hot areas. The sparsity of the spectrum will be reduced or even disappeared. Therefore it is necessary to analyze the sparsity of the wideband spectrum before using the compressive spectrum sensing method [20].

In the current wideband spectrum sensing model, the continuous frequency band is represented by the discrete frequency. Nevertheless, this model is out of practice and cannot reflect the reality of spectrum occupation. The heterogeneous characteristic of wideband spectrum, where different spectrum bands could have different Primary User occupancy patterns, and modeled this heterogeneous wideband spectrum as an inherent, block-like structure.

Non-Blind Compressive Wideband Sensing

Non-blind compressive wideband sensing techniques determine the parameters of the wideband signal such as its sparsity, or its occupancy, the number of measurements required before performing the measurement process. The sparsity level of the wideband signal can be determined by estimating the number of occupied frequency channels within a band of interest. Then, the number of measurements that can be determined, which is a function of the sparsity level, measurement matrix, and the recovery algorithm.

Blind Compressive Wideband Spectrum-Sensing

An estimation of the parameters of compressive sensing, such as sparsity level and the number of measurements, is often required to minimize the recovery error and enhance detection performance or consult an external entity to exchange information about the occupancy of the wideband spectrum. However, estimation of sparsity adds more complexity to the sensing process because doing so often requires more traffic exchanges between the sensing nodes and an external database or the use of one additional block to estimate that sparsity.

Spectrum Sensing toward 5G
Full Duplex Spectrum Sensing

Most existing Secondary Users deploy half-duplex (HD) mode to receive and transmit signals as shown in Figure-8, in which Secondary Users sense the spectrum before transmission. It will not only sacrifice transmission time for spectrum sensing, but also lead to a collision when Primary Users arrive and spectrum waste when PUs leave owing to Secondary Users cannot detect the change of Primary Users status (active or inactive) during data transmission. between If the Primary User re-accesses the channel again during the time of Secondary User transmission, it can cause conflicts them, and if the Primary User is in active state during the sensing period while is in inactive state during the transmission period, Secondary User will not be able to detect the activity of Primary User in time.
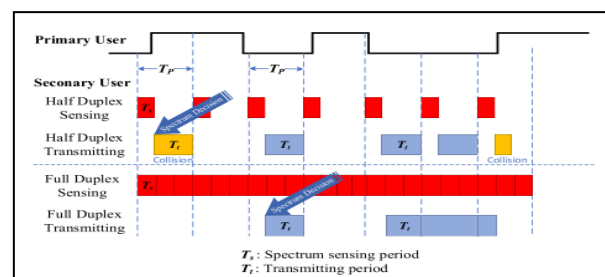

Fig-8: Frame structure between half-duplex (HD) mode and full-duplex (FD) mode

Furthermore, in order to offer higher data transmission rate for users to meet the network extremely high flow density requirements in the *Massive-Capacity* application scenario, Secondary Users need to detect the available spectrum holes quickly and accurately. Consequently, it is hoped that

the Secondary Users can use the spectrum holes uninterruptedly and meanwhile sense spectrum continuously, i.e., the full-duplex (FD) mode and Secondary User can simultaneously perform spectrum sensing and data transmission by using the full duplex spectrum sensing algorithm, which can not only reduce the probability of collision with Primary Users, but also improve the efficiency of spectrum usage. The realization of the zero interference of receiving antenna is based on the theory that when the distance between the two transmitting antennas and the receiving antenna is an odd number of half wavelengths, the phase of the two transmit signals is opposite and it was achieved by OFDM FD communication system [21, 22].

For a FD-CR network, optimal detection thresholds for single-user and cooperative spectrum sensing considered the low signal to noise ratio (SNR) situation and designed a power function based weighting scheme for energy detection to improve the sensing performance. FD enabled WiFi station can transmit and receive data simultaneously to improve the throughput, or transmit and sense simultaneously to monitor the LTE-U activity.

Spectrum-Database Based Spectrum Sensing
Continuous wider area coverage will be the inevitable trend to meet the needs of users in the future, which need to ensure the mobility of users and provide seamless high-speed service experience. Although many research works have concentrated on the development of effective spectrum sensing approach, the sensing overhead is large and the performance is limited in some existing sensing algorithms. Moreover, in order to protect the communication of PUs, the complexity of sensing algorithm will be obviously increased and the transmission power will be restricted. Recent years, the spectrum-database based spectrum sensing algorithm was proposed by some spectrum regulators such as FCC and Ofcom, which is suitable for the Wider-Coverage application scenario well. The spectrum database is utilized to store the historical spectrum information and to generate a new available spectrum table based on the current spectrum state information [23].

Figure-9 shows the spectrum-database based spectrum sensing model. Each SU uploads the spectrum sensing result (including the false alarm and missing detection probability, the sensing period, the sensing time, and the PUs' exit time, etc.) to Base Station (BS), and then the sensing result will be compared with historical information in spectrum database to find all available spectrum holes. Finally, BS controls SUs' sensing and access operation according to the available spectrum list. A spectrum sensing scheme with geolocation database is proposed to improve the sensing accurate.
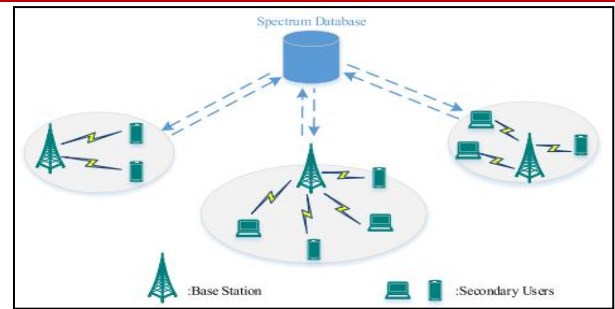

Fig-9: Spectrum-Database Based Spectrum Sensing Model

Based on the spectrum database, a framework for determining the topology of vehicular network including the spectrum data, multiple BSs and moving vehicles in different traffic conditions. The spectrum database minimizes the cost of analyzing the vehicular environmental parameters such as vehicular density and BS road coverage effectively, and reduces the resulting error in spectrum sensing. A mobile crowd sensing-driven geolocation spectrum database for device-to-device (D2D) communication used the TV white space is built in which mobile devices detect lots of spectrum usage information, and then the cellular base station performs data mining algorithms to build the geolocation database [23].

5G System Vision
The spectral resources will indeed be required for traditional links between Base Stations and Mobile Devices. Moreover, as outlined in the 5G system vision illustration given by Figure-10, new services such as Deviceto-Device and Multi-Hop communication, Wireless Backhauling, etc. will consume additional resources. Furthermore, the identified need for further spectral resources drives current discussions on the introduction of mmWave communication as a novel ingredient to the cellular wireless broadband infrastructure landscape. Utilizing mmWaves, the cell densification can be driven much further than with frequencies below 6 GHz due to reduced coverage range. Among the multitude of challenges to be addressed in the design of future 5G systems, this White Paper focuses on the spectrum challenges. In particular, new spectrum usage paradigms will be addressed which are considered to be a key enabler for making more spectrum resources available to 5G systems and services.
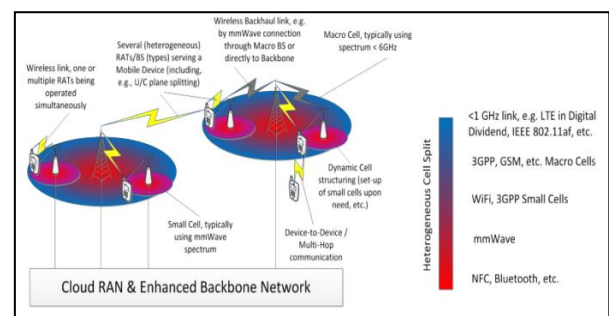

Fig-10: A 5th Generation Mobile Wireless Communications System Vision

Spectrum Scarcity

Spectrum scarcity has emerged as a primary problem encountered when trying to launch new wireless services like IoT wireless sensors, M2M communication, Wireless Surveillance, etc. The effects of this scarcity is most noticeable in the spectrum auctions where the operators often need to invest billions of dollars to secure access to specified bands in the available spectrum. In spite of this scarcity problem, recent spectrum utilization measurements have shown that the available spectrum are severely underutilized i.e. left unused This artificial access limitation based scarcity is often considered to result from the static and rigid nature of the command and control governance regime. Interested parties and stake holders have now started to consider possible improvements in the governance regime by relaxing the constraints on spectrum access by making use of the latest technological capabilities [24-26].

Dynamic Spectrum Management for 5G

Spectrum is finite, a limited scarce resource, but measurements reveal that several licensed frequency bands are underutilized most of the time. The key advantage of Cognitive Radio (CR), also known as Dynamic Spectrum Access (DSA), is that it can sense an unused channel and switch to it. Cognitive radio is one technology under development that could allow spectrum to be used more efficiently. A CR transceiver scans for unused bands and changes its transmission and reception parameters to different frequencies during heavy data loads without interruption. It also can listen for interference on busy channels and calculate a way to reduce it, so the channels may be used by more people.

Dynamic spectrum management (DSM) or dynamic spectrum access (DSA) is a set of techniques based on theoretical concepts in network information theory and game theory that is being researched and developed to improve the performance of a communication network as a whole. These are techniques for cooperative optimization. The concept of DSM also draws principles from the fields of cross-layer optimization, artificial intelligence, machine learning etc. DSM covers different areas like dynamic channel allocation, frequency assignment, spectrum coexistence, and spectrum access both the licensed and unlicensed frequency bands. New generation of radio transceivers makes dynamic and opportunistic spectrum access possible.
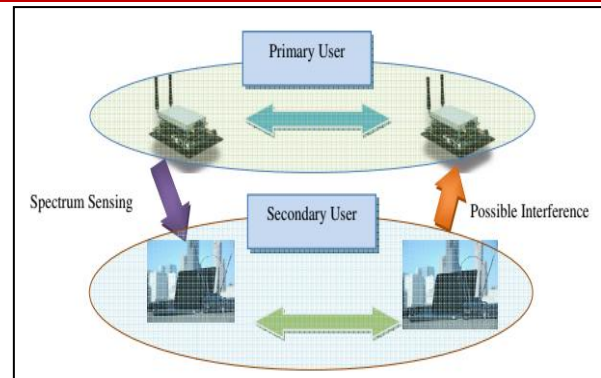

Fig-11: Illustration of DSA

Ability of a device to be aware of its environment and to adapt to enhance its performance and the performance of the network allows a transition from static manual, oversight process to an automated device-oriented process. This allows much more intensive use of the spectrum, and spectrum management policies of the regulator. Radios which are aware of their environment and makes decisions about the radio operating behavior based on that information and predefined objectives. Environmental information may or may not include location and time information. Main functions of DSM are wide band spectrum sensing, spectrum analysis, spectrum decision, spectrum sharing, and spectrum mobility shown in Figure-11.

Device Relaying and Cooperative Communications

Cooperative communications represent a new class of wireless communication techniques in which network nodes help each other in relaying information to realize spatial diversity advantages. Device terminal relaying makes it possible for devices in a network to function as transmission relays for each other and realize a massive wireless mesh network. Device relaying here refers to a fixed device or cell phone or any other portable wireless device with cellular connectivity (tablet, laptop, robots, etc) a user owns. Device relaying makes it possible for devices in a network to function as transmission relays for each other and realize a massive ad hoc mesh network. Multiple devices communicate with each other using cooperative or non-cooperative communication, and one or multiple devices can play the role of relays for the other devices. Connection setup, interference management, and resource allocation should therefore be addressed using distributed methods. Before the data transmission phase, two devices need to find each other and the adjacent relays (i.e., peer discovery and Device2Device connection setup). The devices can periodically broadcast identity information so that other devices may be aware of their existence and decide whether or not they can start a D2D direct or device relaying communication [27, 28].

In conventional cellular system, devices are not allowed to directly communicate with each other in the licensed cellular bandwidth and all communications

take place through the base stations. Mobile 5G network propose a device tier and D2D communication for fringe area coverage. This includes direct D2D communication as well as device relaying D2D. Extending this and making the network totally device centric or user centric, and a network of intelligent wireless devices where a given device transceiver has the entire spectrum available to operate through community or group co-operation. Radios involved are wideband spectrum agile, location aware radios capable of location discovery and communication with neighboring devices. These smart devices deploy a learning algorithm to find best neighbor. Neighboring nodes in the groups hold social relationship and are committed. Incorporates device relaying with device controlled link establishment where service provider nodes assist in network and session establishment [29].

The new network architecture that merges network routing into wireless link and RF design can create a dynamic "fluid wireless network" without predetermined topology and spectrum allocation. In the multi-hop wireless communications, every packet takes opportunistically available paths and spectrum on each hop of the smart wireless system. In the new wireless cooperative mesh network architecture newer smart radios are capable of 5G operation, and treats exiting base stations as just another wireless end point or node. Co-existence of existing non cognitive devices possible and they makes use of the current services as is the new intelligent devices filter out these frequencies as and when it encounters during its operation. This way new architecture acts as an overlay on top of the existing networks. Every node in the network not bothered about the type of service, and service provider need not have high power base stations. With the use of distributed cloud based service access points or service element cloud, every radio node shall be capable of acting as service provider node. In the Internet of Things (IoT) world, every wireless device is also on the internet and in the cloud [30].

CONCLUSION
CR technology is an essential measure to mitigate the contradiction between supply and demand, and it is the basic guarantee to meet the imbalance of supply and demand in the future. With the resource guarantee of spectrum sharing, the new generation of information technology can effectively accelerate the practical application and promote the healthy development of 5G. Spectrum sharing scheme in the following four key steps: spectrum sensing, spectrum allocation, spectrum access, and spectrum handoff. Furthermore, they are divided into several classes on the basis of requirements of diverse application scenarios that Wider-Coverage, Massive-Capacity, Massive-Connectivity and Low-Latency.

Better electromagnetic signal detection mechanism, which emulates the way eye detects things

needs to be in place. Radio devices then consume air waves in much the same way as human beings consume air from the atmosphere. Fully automated and independent spectrum conditioners can over see the use of spectrum in an area, and regulate the use than a static stringent manual regulation of air waves. The new network architecture that merges network routing into wireless link and RF design can create a dynamic "fluid wireless network" without predetermined topology and spectrum allocation. Cognitive radio technology has the potential to address challenges associated with spectrum access.

The key enabling technologies that may be closely related to the study of 5G in the near future are presented, particularly in terms of full-duplex spectrum sensing, spectrum-database based spectrum sensing, compressive spectrum sensing, carrier aggregation based spectrum allocation.

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