Chapter 4

Spectrum Decision Framework to Support Cognitive Radio Based IoT in 5G

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Additional information is available at the end of the chapter

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Abstract

RF Spectrum Decision in Cognitive Radio enables unlicensed users of wireless communication systems to occupy the vacant spectrum slots as a solution to scarce spectrum. Internet of Things (IoT) is a wide-reaching network of unified entities. IoT capable things will be interconnected through wireless communication technologies offering cost-effectiveness and accessibility to remote users making quality life style. IoT implementation suffers from challenges of vulnerabilities to dynamic environmental conditions, ease of access, bandwidth allocation and utilization, and cost to purchase RF spectrum. As RF spectrum is a precious commodity and there is a dearth of RF spectrum, hence IoT connections are drifting towards Cognitive Radio Networks (CRNs). Permeating things with cognitive abilities will be able to make RF spectrum decisions to achieve interference-free and wireless connectivity as per their QoS requirements. The wireless systems are rapidly advancing. The leap from packet switching along with circuit switching with 144 kbps data rate (2G and 2.5G) to Long Term Evolution Advanced (LTE-A), i.e., 4G occurred in one decade time frame. As the current wireless connectivity is aimed at higher capacity, higher data rate, low end-to-end latency, massive device connectivity, reduced cost and consistent Quality of Experience (QoE) provision, therefore, 4G is being replaced with 5G. Presently the Radio Frequency (RF) spectrum band is fully sold out and allocated to various wireless operators and applications. On the other hand, new wireless applications are emerging and there is a serious dearth of frequency spectrum to be allocated to emerging wireless services. The efficient utilization of assigned RF spectrum which is otherwise underutilized due to the typical usage by the licensed users known as Primary Users (PUs) is the one of the best possible way to implement IoT in 5G. Thus the Spectrum Decision by unlicensed users of CR holds a significance in CR-based IoT in 5G and beyond network. This chapter describes a scientific supported spectrum decision support framework for CR Network. The main goal of this chapter is to discuss how CR technology can be helpful for the IoT paradigm.

Keywords: cognitive radio, internet of things, 5G/B5G, Spectrum decision framework, primary user, IoT-User

1. Introduction

4G provides voice, data and multimedia imparting to the wireless subscribers on every time and everywhere basis at higher data rates in Multimedia Messaging Service, Digital Video Chat Broadcasting (DVB), video chat, High Definitive TV content and mobile TV. As an application of 5G, the wireless systems are deployed to make All the people and things to be connected Any time with Anyone while being Anywhere via Any Path or Network and Any service (A6 connection). This A6 connection is known as Internet of Things (IoT). Internet of Things (IoT) is the environment where all over smart interconnected objects are connected with each other through unique addressing schemes based on specific telecommunication standards and protocols [1]. IoT based devices are to be interconnected through Base Transceiver Stations (BTSs) in wireless operations and the BTSs are linked with backhaul connectivity through Optical Fiber Transmission systems achieving higher bandwidths supplemented by Terrestrial Microwave links. The wireless Radio Frequency spectrum (WRFS) is almost completely assigned to existing wireless applications. At the same time, WRFS is underutilized due to the typical usage of mobile and other wireless services. To address this problem, Cognitive Radio (CR) has emerged as an enabling technology which offers a solution to spectrum scarcity problem. Hence, the CR-based IoT system has by default becomes a focus for researchers in wireless communication systems. CRN systems have emerged as a capable solution to the spectrum scarcity and as an enabling technology for the optimum utilization of otherwise underutilized RF spectrum, humanizing the synchronicity and interoperability in various wireless and mobile communications systems transforming into telecommunication devices and systems autonomous and self-reconfigurable. With swift shift to smart communication technologies and infrastructure, the Internet of Things (IoT) has emerged as a modern challenge in international Telecommunication industry and wireless applications. SUs access RF spectrum bands in heterogeneous manners in CRN and IoT supported smart area consists of heterogeneous devices, which are mobile as well as static in nature [1]. At the same time, the next generation mobile communication network referred to as the Fifth Generation (5G) is almost realized in the advanced telecommunication era [2]. 5G and beyond is expected to integrate the contemporary wireless technologies into an all Internet Protocol (IP) based networks which offer high performance worldwide network [3]. As the bandwidth for 5G and beyond is very large and the WRFS offers a large number of non-continuous idle spectrum slots in 5G communication as well [4], there is a requirement to identify the unused spectrum slots not being used by respective licensed users called primary users (PUs). This process is known as Spectrum Sensing (SS) in Cognitive Radio systems. Accurate SS allows the secondary users (SUs) to opportunistically use the vacant spectrum slots as per their wireless applications and vacate when the PU arrives in the network. This process is termed as spectrum decision. When optimally done, the SU along with PU will be enabled users using IoT paradigm in 5G/B5G networks. Therefore, spectrum decision is an important parameter for the deployment of CR-based IoT in 5G/B5G network.

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All previously mentioned research contributions are more concept oriented for IoT in 5G network. The RF spectrum accessibility as per the wireless application for the user in IoT environment remains an open research area. Motivated by this, a comprehensive survey on 5G networks embedded with IoT applications based on CR ensuring A6 connectivity by accessing across the entire RF spectrum has been carried out in this chapter. A case study based on this survey for CR-based IoT in 5G networks has also been proposed to validate the concept.

2. Structure of the chapter

Introduction, related work and the motivation of the work is given in the first section. Evolution to 5G is given in Section 3. IoT in 5G network is described in Section 4. Section 5 gives an account for 5G with CRN based IoT and the need for RF spectrum management is given in Section 6. Section 7 concludes the chapter. **Table 1** given below lists the abbreviations used in this chapter.

Abbreviation	Definition	Abbreviation	Definition
AWGN	Additive White Gaussian Noise	MF	Membership function
AMPS	Advanced Mobile Phone Service	MIMO	O Multiple input multiple output
B3G, B4G, B5G	Beyond third, fourth and fifth generations	MISO	Multiple input single output
BTS	Base Transceiver Station	MHz	Mega hertz
CCC	Common control channel	MVR	Majority vote rule
CDMA	Code Division Multiplexing Access	NB Narrow band	Narrow band
CR	Cognitive Radio	NI	National instrument
CRN	Cognitive Radio Networks	OFDM	Orthogonal frequency division multiplexing
DSA	Dynamic Spectrum Access	PC	Personal Computer
		PDP	Poisson distribution process
DSMF	Dynamic Spectrum Management Framework	PSD	Power spectral density
DVB	Digital Video Chat Broadcasting	PU	Primary user
D2D	Device to Device	QoE	Quality of experience
IoT	Internet of Things	QoS	Quality of service
ED	Energy Detection	QPSK	Quadrature phase shift keying
EV-DO	Evolution Data Only/Evolution Data Optimized	RASC	Random channel assignment with single channel
ETACS	European Total Access Communication System	RFID	Radio frequency identification
FSDM	Frequency Spectrum Decision Mechanism	ROC	Receiver operating characteristics
HART	Highway Addressable Remote Transducer Protocol	SDR	Software define radio
RFID	Radio frequency identification	SDSF	Spectrum decision support framework

Abbreviation	Definition	Abbreviation	Definition
ROC	Receiver operating characteristics	SG	Smart grid
6TiSCH	IP (IPv6 settings) integrated with Time synchronized channel hopping		
SNR	Signal to noise ratio		
SU	Secondary user		
TDMA	Time division multiple access		
UE	User equipment		
URLLC	Ultra-reliable low latency communication		
UWB	Ultra-wideband		
WCDMA	Wide-band code division multiple access		
WiFi	Wider Fidelity		
WiMAX	Worldwide interoperability for microwave access		
WLAN	Wireless local area networks		
WWRF	Wireless world research forum		

Table 1. Abbreviations used.

3. Advancement of wireless technologies from 1G to 5G

Since the inception of the first generation (1G) cellular systems in telecommunication system, the entire pattern of living environment including the people's work, lifestyle and the agricultural and industrial development trends has been effected. Evolution to the fifth generation (5G) is the progressive advancement in the telecommunication industry to keep with the growing pace of mobile data traffic, huge volume of device connections and continuous emergence of latest commercial scenarios. Over the last one decade or so, the wireless communications have the capability to connect all the existing mobile technologies, to build a terminal that is to support the voice, video and data applications with respective QoS requirements guaranteed i.e., at very high data rates and users speeds making it a 5G/B5G environment. The chronological evolution to 5G/B5G [5] is listed here in the **Table 2**.

Device to device (D2D) communications in 3GPP and LTE standards offers transfer of data directly to each other without the involvement of BSs [6]. This reduces the workload and energy consumption of BS thereby offering a good platform for 5G. Emerging 5G wireless communications envision very high data rates (typically of Gbps order), extremely low latency, significant increase in BTS capacity and improvement in PUs' and SUs' perceived Quality of Experience (QoE), compared to existing 4G/3G wireless networks. The 5G/B5G implies the whole wireless world interconnection (WISDOM; Wireless Innovative System for Dynamic

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Wireless technology generation	Applications	Standards	Data rates	Mobility offered	Time span
1G (Analog)	1st Generation of the mobile telecommunication technology standardized by the voice service.	NMT, AMPS, TACS, ETACS and JTACS	14.4 kbps	Low Speed	1995–1997
2G (Digital)	2nd Generation of wireless telephone technology introducing a data service; SMS (short message service)	TDMA, GSM, CDMA, 2.4 GHz narrowband WLAN	144 kbps	Low and medium speeds	1997–2000
3G (IMT 2000)	3rd Generation of mobile telecommunications (International Mobile Telecommunications-2000)	CDMA2000, EV-DO, W-CDMA, 802.11 PAN, Bluetooth.	384 kbps	Medium and High Speed	2000–2005
B3G	Beyond 3rd Generation	WiBro802.16e, WiMax, 3GPP, LTE	<50 Mbps	High Speed	2005–2010
4G	4Th Generation of mobile telecommunications	DAB/DVB, cellular GSM, IMT-2000, WLAN, IR, UWB, DSL, LTE-A, IEEE802.16e	<100 Mbps	Very High Speed	2010 onwards
5G/B5G	5th Generation and beyond.	4G + WISDOM			2015 onwards

Table 2. Progressive evolution of Mobile services from 1G to 5G [5].

Operation Megacommunications concept), with guaranteed QoS requirements of wireless services [7]. Spectrum decision in CR would ensure spectrum scarcity problems and IoT complies wireless A6 connections for users, making CR-based IoT in 5G networks with a focus on spectrum decision framework in CR for IoT in 5G networks, an interesting study for researchers.

4. IoT in 5G/B5G networks

Mobile data and IoT are the future internet for everything and will be the key and motivating force in the advancement of 5G/B5G networks. In the time to come, likely by 2021–2025, 5G/B5G will not only meet the assorted requirements of people in various constituencies of daily life such as residence, work, leisure, and transportation, but also will infuse the IoT and light up the diverse specialized domains to the professional aspects of human life and the industry such as medical sciences and facilities and transportation to realize the true interconnectedness of all things [9]. The realization of IoT is dependent on internet application scenario based requirements which converge to 5G networks and are not guaranteed in 4G and LTE technologies. These requirements are listed in **Table 3**.

Internet application situation	**Mobile data provided internet to the subscribers**		**IoT**	
	Wide and seamless coverage	**High capacity to guarantee QoS requirements for Internet Applications**	**A6 connection**	**Low end to end latency**
Requirements	Seamless connectivity with high speed service in mobility of the subscriber	Enormously high data transmission rate	Provision connectivity to billions of devices with matching capability of power requirements for devices	Provision of service to users with less than millisecond end-to-end delays in transmission and in switching of spectrum slots.

Table 3. Modern trends and requirements in IoT [8].

5. 5G/B5G with CRN based IoT

The Internet of Things (IoT) envisions thousands of constrained devices with sensing, actuating, processing, and communication capabilities able to observe the world with an unprecedented resolution. According to Cisco, more than 50 billion devices are expected to be connected to the internet by 2020 and 20% of which are from the industry sector [9]. These connected things will generate huge volume of data that need to be analyzed to gain insight behind this big IoT data. Moreover, in the industrial environments (industry 4.0) as well in in smart spaces (building, houses, etc.) and connected cars communications often require high reliability, low latency and scalability. Several technologies such as BLE, Zigbee, Wireless HART, 6TiSCH, LPWAN (Lora, Sigfox, etc.) have been proposed to fit these requirements. The forthcoming 5G networks are promising not only by increased data rates but also low-latency data communication for latency-critical IoT applications. 5G will enable massive IoT devices connected via a myriad of networks and critical machine type communications. While the massive IoT is more concerned about scalability deep coverage and energy efficiency, the later requires ultra-low latency and extreme reliability (URLLC). Recently, the fog-to-thing continuum [10] is proposed to mitigate the heavy burden on the network due to the centralized processing and storing of the massive IoT data. Fog-enabled IoT architectures ensure closer processing in proximity to the things, which results in small, deterministic latency that enables real time applications and enforced security. The IoT is a modern and the state of the art archetype in the technological advancement which is evolving as a future Internet. As per the principal vision of the IoT, the further requirement is the ubiquity of the Internet, after connecting people anytime and everywhere, is to connect extinct entities. By providing objects with embedded communication capabilities and a common addressing scheme, a distributed and permeating network of impeccably connected diverse electric and electronic devices is designed, which is to be indigenously cohesive into the existing Internet connections and mobile networks. Formally, IoT can be defined as, " A worldwide network on electronically interconnected devices uniquely addressable, based on standard communication protocols and allows users to be A6 connected" [11]. Thus allowing for the development of new intelligent services available anytime, anywhere, by anyone and anything. Latest research work and

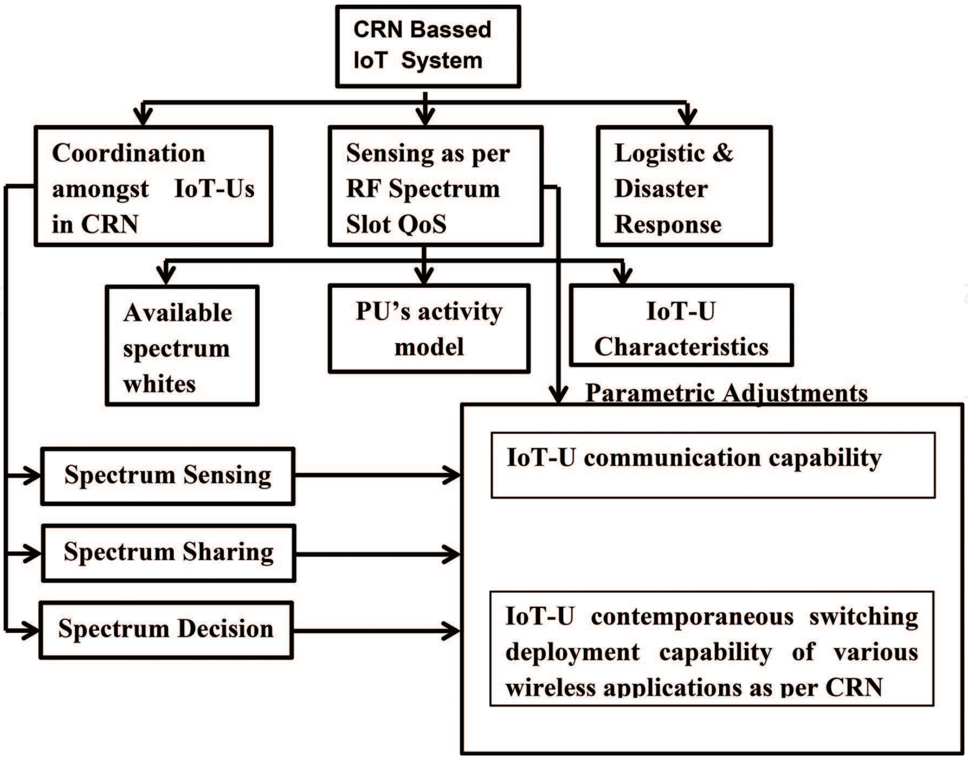

Figure 1. CRN system with its properties and research directions enabling it for IoT system for A6 connections by SUs.

technological systems are converging towards IoT and CRNs. Since the spectrum assignment policy involves expenditures for buying the RF spectrum, the assignment of spectrum for a huge number of devices and objects required for IoT connectivity will result in redundant cost effects. CRNs due to its typical spectrum utilization characteristic emerge in realization of IoT. The idea of a reserved spectrum slot as shared-to-reserve (SR) and reserved-to-share (RS) schemes in CR-HetNets proposed in [12] can enhance the system throughput and would offer a high bandwidth transmission for IoT-Us in CRN. A CRN properties enabling it for IoT applications is shown in **Figure 1**.

Usually, the SU operates in half-duplex mode (HD), i.e., it can either transmit or sense at any instant of time [13]. Due to this HD operation of SU, there is a possibility that harmful interference to PU is caused on unexpected arrival of PU and its activity during the transmission of SU. Hence the spectrum sensing should be a continuous process and SU must vacate the licensed channel on arrival of its PU and switch to another suitable channel as per its application, i.e., a befitting spectrum decision framework is essential.

6. Need for Spectrum management in IoT based 5G/B5G networks

External storage solutions offer nearly unlimited capacity, with dedicated signal processing to sort through data and find signals, interactions or events of interest. These long-duration, high-bandwidth solutions are ideal for today's crowded spectrum and advanced technologies such as cognitive radios. WRFS is characterized by PU activity modeling and accurate SS [14]. This means that the spectrum management holds a great significant in CR technologies and A6 connection. The DSA allows the users (both PUs and SUs) to optimally use the spectrum slots while guaranteeing their QoS requirements. Preserving the required QoS of the users along with their mobility requires spectrum mobility for the SUs in the network, which we now know as 5G network. Because of its mobility, an SU may change its location (cell) in a cellular network during its transmission and, therefore, will enter a new region in which the targeted RF spectrum slot is already being used by the PU [15]. The perfect SS techniques provide prior information for which SUs will work [5]. Since the primary traffic in any cell and region is always time varying and cannot be accurately predicted, therefore, the SUs must have the real time information of RF spectrum slots occupancy status to switch over to the vacant slots for resuming their transmission in case PUs arrive. Similarly, the SS errors are also required to be mitigated. The PUs use their licensed spectrum for their transmissions as per their QoS requirement and the statistical analysis says that this usage remains for a very short period of time. The decision of accessing the vacant spectrum slots would enable the SU to have A6 connections making an IoT environment. Therefore, SU is renamed here as IoT-User (IoT-U).

The allocated frequency spectrum for wireless applications is under-utilized due to the emblematic customs of wireless applications [16]. The conventional approach to spectrum management is very inflexible in the sense that each wireless service provider is assigned an exclusive license to operate in a certain frequency spectrum band. It has become very difficult to find vacant spectrum bands (to either deploy new services or to enhance existing ones) [17]. Therefore, for efficient utilization of the spectrum creating opportunities, Cognitive Radio (CR) technology allows its users called Secondary Users (SUs) to occupy the available spectrum slot for their communication (model is shown in **Figure 2**) and vacate it on arrival of the licensed user (called Primary User (PU)) [18]. The process of spectrum utilization using CR systems requires a Dynamic Spectrum Management Framework (DSMF) [19] which consists of four main components (naming Spectrum Sensing (SS), Spectrum Decision Framework, spectrum sharing and spectrum mobility). Spectrum sharing refers to coordinated access to the selected channel by the SUs. Spectrum mobility enables SU to switch over to another channel when a PU is arrived. SS involves identification of spectrum holes and the ability to quickly detect the onset of PU communications in the channels occupied by the SUs. Spectrum decision enables SUs in CR Network (CRN) to select the best available spectrum slots to satisfy SUs' Quality of Service (QoS) requirements without causing harmful interference to PUs [20]. On appearance of PU in the spectrum slot in which SU was carrying out its transmission, the SU looks for (which requires an efficient SS) and selects (which requires a suitable Spectrum Decision Framework) another QoS complying spectrum slot which is available/vacant. This implies that there are two steps (SS and spectrum decision framework) of efficient utilization of spectrum in CR-based IoT in 5G/B5G.

There are two scenarios as an overlay and underlay for spectrum sharing [21, 22]. In spectrum overlay scenario, a SU accesses a RF spectrum slot only when it is not being used by the PU [23]. This scenario is also known as opportunistic spectrum access. In other scenario the SU coexists with the PU and transmits with power constraints to guarantee the quality of service (QoS) of the PU. This scenario is known as underlay spectrum sharing [24]. The overlay mode operation is focused in this chapter.

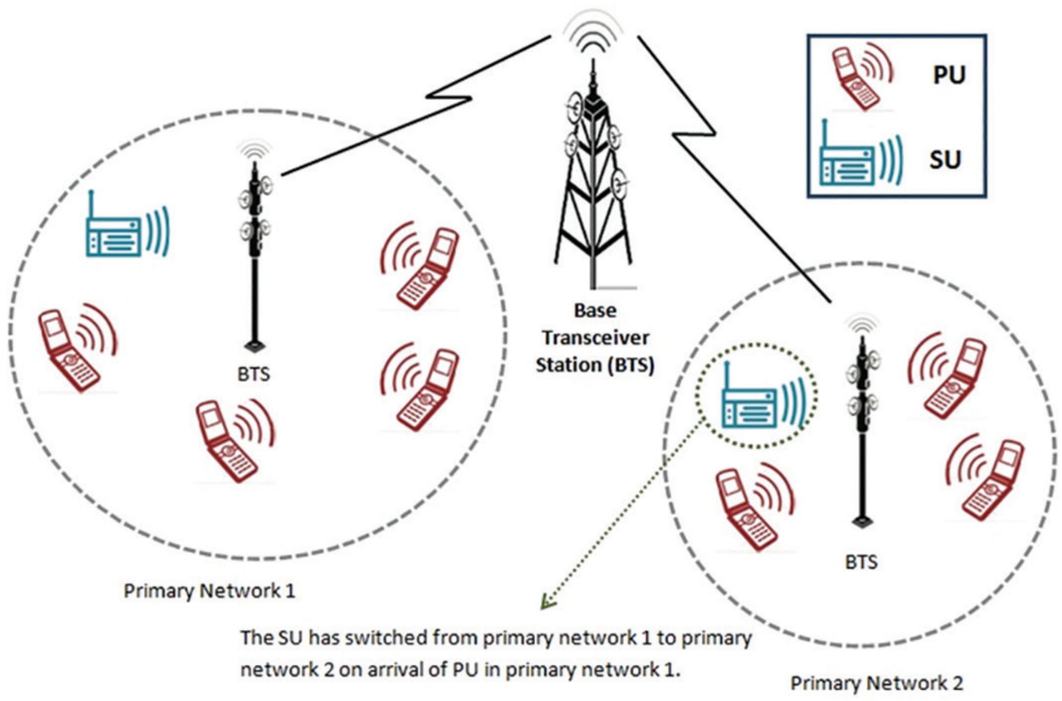

Figure 2. Working of a CRN model in which SU switched to another network on arrival of PU in primary network 1.

6.1. Spectrum sensing

CR systems offer the capability of IoT-Us to improve the spectrum utilization under the existing fixed spectrum assignment policy. IoT-Us cannot only sense the spectrum environment around and access vacant spectrum slots in the opportunity way, but also require to sense the presence of PU's signal continuously to keep the SS data updated. Hence, SS is the fundamental requirement in CR and the foundation for Spectrum Decision. The SS techniques are categorized into non cooperative (Energy Detection (ED), Matched Filter Detection (MFD) and cyclostationary detection), interference detection and cooperative (centralized SS (CSS) and non-centralized detection) [25, 26]. ED is the widely used scheme for SS due to its simplicity, easy implementation and it corresponds to the general purpose of SS for heterogeneous wireless communication systems [27]. The improved ED and CRs with multiple antennas can increase the SS performance [28]. MFD requires the exact synchronization and prior knowledge of PU signal, moreover implementation complexity of the sensing unit is large as the SU need receivers for all types of signal [29]. ED and MFD perform non coherent (by calculating the energy of the received signal samples) and coherent (comparing with the known PU signal) detection respectively [30]. Cyclostationary detection suffers from high complexity as all the cycle frequencies are required to be calculated [31]. CSS and non-centralized detection have exhibited SS errors due to time lag involved between sensing and its results [32]. Although the vacant spectrum slots are identified in SS but unless these are not simultaneously occupied through a well-defined decision process, the concept of CR cannot be realized. Therefore, it is imperative to mitigate the SS errors (false alarm and miss detection) before taking the decision to occupy the sensed vacant spectrum slot. A brief analysis of existing SS techniques [33] is given in **Table 4**.

6.2. PUs and IoT-Us activity model

In CRNs, there are two types of users to use the WRFS, one is PU and the other is SU, which we have renamed as IoT-U in this chapter. Since FCC has approved the access of unlicensed users (IoT-Us) to the already sold RF spectrum provided the unlicensed users do not cause harmful interference to PUs. The performance of CRNs is largely dependent on PU arrival and departure from the spectrum slots, the license of which it holds [34]. Hence, it is very important to model the PU activity for CRNs to enable IoT-Us to decide for occupation idle spectrum slots. PUs in the wide range (kHz to GHz as UWB and 5G networks operate in 3.6–39 GHz) of WRFS operate in any spectrum depending upon the specific wireless applications. **Table 5** shows the operating radio frequency bands for various wireless technologies.

As the RF spectrum band is wide range for various wireless applications, therefore, one PU activity cannot reflect the activity pattern of PU of all wireless applications as these varies from application to application. As the FCC has approved to use secondary users on licensed RF spectrum only with the condition that PU transmission will not be interfered. This implies that the licensed spectrum will only be occupied when PU is not using it, the underlay occupancy. Moreover, it is very important to ensure that PU is not harmfully interfered. That is why, the CRNs' performance is dependent on PU activity. Stochastic geometry provides a natural way of defining and computing macroscopic properties of mobile users' networks, by averaging over all potential geometrical patterns for the nodes, in the same way as queuing theory offers mobbing and the reliability, i.e., low end-to-end latency in wireless communication, average out the overall possible arrival patterns of the PUs within the networks on assigned RF spectrum. Thus PU activity modeling in wireless communication networks in terms of stochastic geometry is particularly relevant for spectrum decision framework. The PU activity, as a simplest case, in CRN can be represented as a print of a stationary random model in a probabilistic way. In particular the locations of the CRNs nodes are seen as the realizations of some point processes. When the underlying random model is ergodic, the probabilistic analysis also provides a way of estimating spatial averages which often capture the key dependencies of the CRN performance characteristics (connectivity, stability, capacity, etc.) as functions of a relatively small number of parameters [35]. Hence, the PU activity should be modeled with some stochastic arrival and departures probability expression. Poisson distribution process (PDP) provides a near to realistic probability of arrival and departure of the (primary) user in the network. PDP offers spatio-temporal representation of PU activity model. Moreover, Poisson distribution process is simple and adapts well in wireless communication scenario. The PU's arrival and departure follow the poison distribution process:

$$P(k\ events\ in\ interval) = \frac{\lambda_p^k e^{-\lambda_p}}{k!} \qquad (1)$$

where k is occurrence of PU arriving and takes values $0,1,2,3, \ldots, N$ and λ_p is the arrival rate of PU in the spectrum slot in the CRN. The existing spectrum decision techniques model PU activities without taking into account for SU (IoT-U) behavior and characterization. This is desirable in this CRN growth era as well as in CRN based IoT-U to have its model defined. This will help in ensuring no interference and will provide basics for mechanism of switching

SS Techniques	Method Used	Main Feature
ED, MFD and Cyclostationary detection based SS	Based on PU's transmitter	ED does not require the prior information of the PU
		MFD is related to prior knowledge of PU's signal
		Cyclostationary detection relies on distinguish between the PU's signal and the noise
Cooperative SS	Combining the sensing results of multiple SUs to improve the detection reliability	The fusion mechanisms including reliability based cooperative decision fusion. One is described in section of this chapter
		Using directional antenna
		Quashing interferences
		Integrates quickest detection and belief propagation framework
		Guaranteeing the high sensing accuracy in vehicular networks or industrial wireless networks
Spectrum-database SS	Enables to find all available spectrum slots by comparing the historical information of spectrum usage pattern with the received by a base station from each SU in the network	Exploiting spectrum table for SS
		A framework for determining the topology of vehicular network
		An iteratively developed history processing database
		A mobile crowd sensing-driven geolocation spectrum database for D2D communication
Compressive SS	Each SU detects and extracts the wide band signal directly to achieve efficient wide band sensing with much lower sampling rate than the Nyquist Criterion	Wideband SS scheme
		Based on real time PU's signal
		Analyze the sparsity of the wideband spectrum
		Reducing SS errors
		Spectrum occupancy status measurement
Full duplex SS	Each SU in the network can access the vacant spectrum slots while sensing the spectrum continuously	Listen and talk protocol
		Joint mode/rate adaptation policy for WiFi/LTE-U
		At low SNR values
		Optimal detection thresholds
		Canceling the self-interference of transceiver

Table 4. List of SS techniques available in literature [33].

Wireless applications	Frequency spectrum bands	Bandwidth
IEEE 802.11 g to n/WiFi	2.4 GHz	10 KHz
IEEE 802.16/LAN/2	5 GHz	100 KHz
IEEE 802.22	54–862 MHz	5–20 MHz
GSM	890–915 MHz (uplink) 935–960 MHz (downlink)	200 KHz
CDMA	800 and 1.9 GHz	125 MHz
W-CDMA	850–2100 MHz	125 MHz, 250 MHz
LTE	1710 –1770 MHz (uplink) 2110–2170 MHz (downlink)	20 MHz
UWB	3.1–10.6 GHz	500 MHz
5G Cellular	26.5–40 GHz and 30–50 GHz	All ranges of bandwidths i.e., narrow, wide, ultra wide and super ultra wide bands communication systems

Table 5. Frequency spectrum ranges for various wireless applications.

to other available slot, if PU arrives. The study of opportunistic spectrum access in CRNs with SU's transmission performance reveals that the interference caused to PU can be avoided by evaluating the SU's transmission blocking [34]. When PUs appear in the multiple spectrum slots in a WRFS band denoted by '*S*', IoT-Us need to vacate the spectrum slot and switch to another suitable spectrum slot (to complete their transmission) without interfering the PUs. This transmission process for PU and IoT-U is shown in **Figure 3**. This causes IoT-Us a temporary break in transmission, which is mitigated by simultaneous access in multiple noncontiguous spectrum bands by IoT-Us for their transmission. Even if a PU appears in one of the channels, the rest of the channels will continue to allow SUs to transmit while maintaining their QoS requirements.

In the transmission process of SUs when accessing the channel in a heterogeneous manner, the transmission level measure for PU is given by the PTB as,

$$P_{TB} = P(i,j) = \frac{\lambda_p\left(P_{i-i,j}\right)\varphi(i+1.j) + (j+1)\,\mu_s\,P(i,j+1)\varphi(i.j+1)}{i\,\mu_p + j\,\mu_{s+}\,\lambda_p + \lambda_s} \tag{2}$$

where PUs and IoT-Us arrive and depart from each spectrum slot in *s* at the rate λ_p and λ_s respectively. Similarly, the μ_p and μ_s are the mean values of the respective transmission durations of PU and SU in the network. The number of spectrum slots in *s* by PU and IoT_U at some specific time are represented by *i* and *j* respectively, such that $i + j \leq N$. P (i,j) is the stationary probability of two dimensional Markov state which is P_{TB}.

The state space ϖ for PUs and IoT-Us occupying spectrum slot in *S* is given as under;

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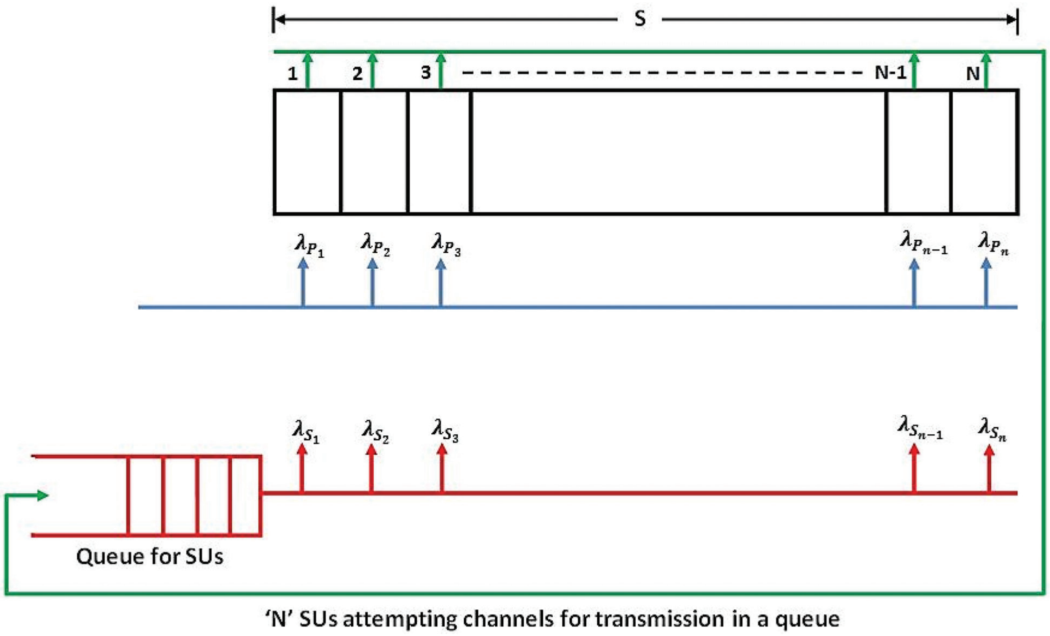

Figure 3. Transmission process for PUs and SUs (IoT-Us) to mitigate interference.

$$\varpi = \{(i, j) \mid 0 \le i \le N; 0 \le j \le N\} \tag{3}$$

and

$$\varphi(i, j) = \begin{cases} 1, (i, j) \in \varpi \\ 0, \text{otherwise} \end{cases} \tag{4}$$

7. Spectrum decision framework

CR Technology is characterize by PUs and SUs, a coordination among the IoT-Us to use the licensed bands when PUs are not using spectrum slots in the targeted spectrum slot. Although, in the recent 5 years, the researchers have carried out work in the area of Spectrum Decision, however, still this area is not yet fully explored. A survey of spectrum decision in CRNs based on RF spectrum characterization, spectrum selection and CR reconfiguration has been presented in [20]. Since then (2013) in one of spectrum decision research works, the authors have proposed a fuzzy inference-based decision strategy which is based on three key parameters, spectrum slot idle time, spectrum slot occupancy status and spectrum slot QoS [36] which provides an accurate and robust spectrum decision framework for SUs. The same and can be equally effective for IoT-Us in CR-based IOT in 5G/B5G networks as it encompasses all signal processing matrices such as Massive MIMO Antennas, varying bandwidths characteristics and wireless propagation channel models for all wireless applications (through spectrum slot QoS), required for wireless communications. Likewise, a spectrum decision scheme is

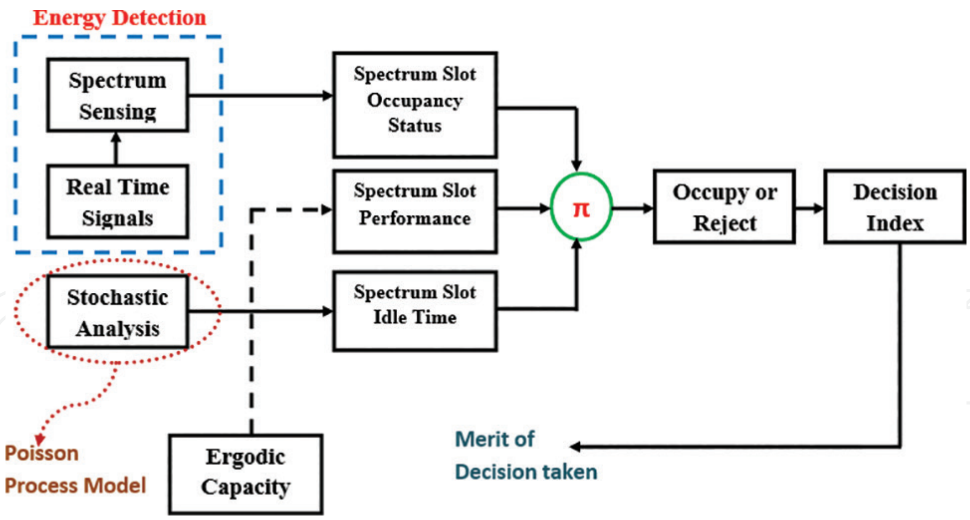

Figure 4. Proposed Spectrum decision framework for CRN based IoT in 5G/B5G networks.

proposed here with an analysis through Radio Operating characteristics (ROC) curves at various SNR values. This scheme is based on fusion of three separate decision of three key parameters, spectrum slot idle time, spectrum slot occupancy status and the spectrum slot performance. The spectrum decision framework first finds the idle time of the spectrum slot, spectrum slot occupancy status through SS using ED scheme and spectrum lot performance based on its ergodic capacity as shown in **Figure 4**.

7.1. System model

A CRN operating in a spectrum band '*S*' with frequency ranging from 54 MHz–50 GHz covering most of the wireless applications given in **Table 5**, is considered. The other specifications to be considered (like uplink and downlink frequencies, modulation techniques used in transmission and bandwidth) are as given in [37]. Channel bandwidth is the frequency range over which a IoT-U's transceiver transmits and receives its signals in CRN. An IoT-U can carry out its transmission on either narrow, wide and ultra wide band (UWB) ranges depending on the RF environment and wireless applications. The CRN has a centralized network operator, for instance a BTS which functions as "serve to provide". A region comprising of 5 BTSs, unlimited number of mobile devices, all buildings in the neighborhood are under the coverage of all the wireless services as shown in **Figure 5**. A wide range wireless based applications, i.e., GSM, bluetooth, UWB, NB, video conferencing, IP based communication, office automation systems, building security management systems, 5G and RFID, connected through IP based communication radios. 3GPP channel model has been used owing to its typical characteristics for wireless systems, i.e., it has properties that impact on system performance by reflecting the important properties of propagation channels. Moreover, wireless networks are optimized in the region of system model. Let there be '*J*' SUs (using ED for SS) in the CRN each having its own Software Defined Radio (SDR) to exploit the multiple spectrum bands over wide spectrum ranges by adjusting the operating frequency through software operations. The BTSs exercises control over all *J* IoT-Us within its transmission range as shown in **Figure 2**. The

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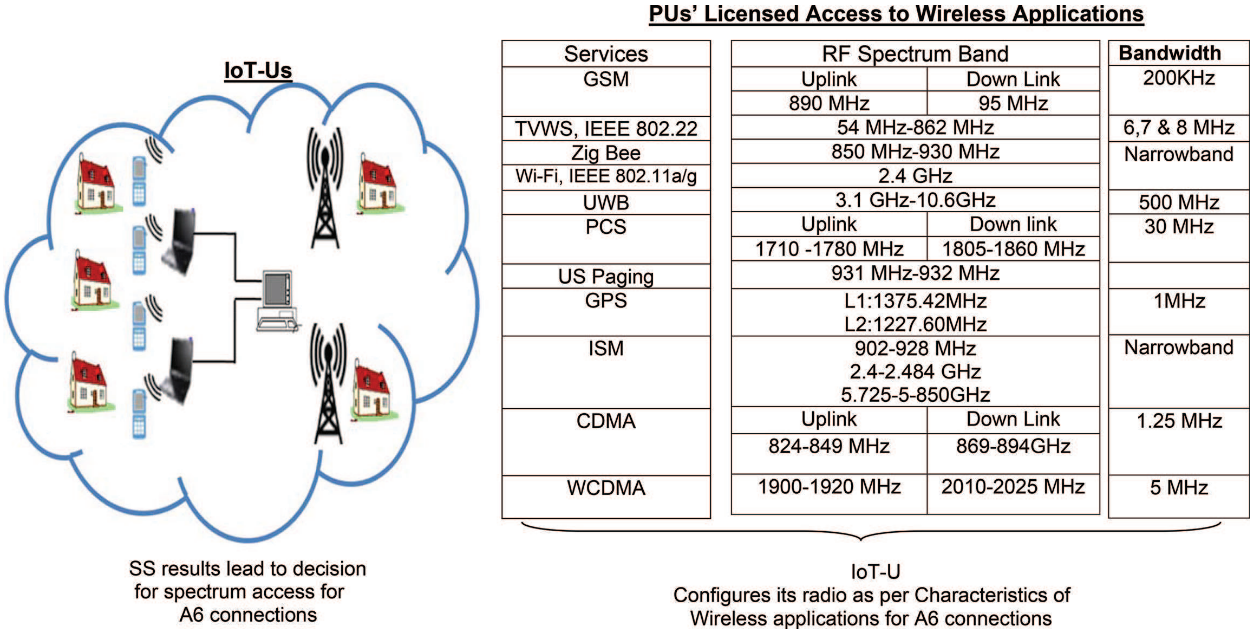

Figure 5. System model for proposed Spectrum decision framework.

RF spectrum slots in CRN are considered to have varying bandwidth. There are *N* PUs having rights to access same number of corresponding spectrum slots. *J* IoT-Us are attempting to access these slots for their transmission. Wireless services employ a combined FDMA/TDMA approach for air interface.

7.2. Performance evaluation and numerical analysis

The simulation parameters are given in **Table 6**. In finding the idle spectrum slot through the PU activity time, there can occur two types of errors. One is, false alarm and the other is the miss detection. Later is due to sensing an idle spectrum slot as occupied, and the following is due to assuming an occupied slot as idle. The performance of the proposed spectrum decision framework is assessed here through ROC curves between probability of false alarm and miss detection. These two are the inter-related parameters in the proposed decision process. To

No. of BTSs	5
No of IoT-Us in CRN	*J*
No of PUs	5
RF spectrum range	890–915 MHz (GSM Band)
Wireless channel model	3 GPP
Bandwidth	200 KHz

Table 6. Simulation parameters.

have accurate data of PU(s) activity time and occupancy status, there should be low values of both the probabilities, which cannot be achieved as both are inter related to each other. Therefore, an optimal set of range must be obtained. Transmission at different values of SNR give different ROC curves for the PU's activity time and its occupancy in the spectrum slot. The lower the probability of miss detection (or higher the probability of detection) for a given probability of false alarm, the more reliable and accurate the detection would be, which is desirable for taking the decision by the SU(s) to occupy that particular spectrum slot in CRN.

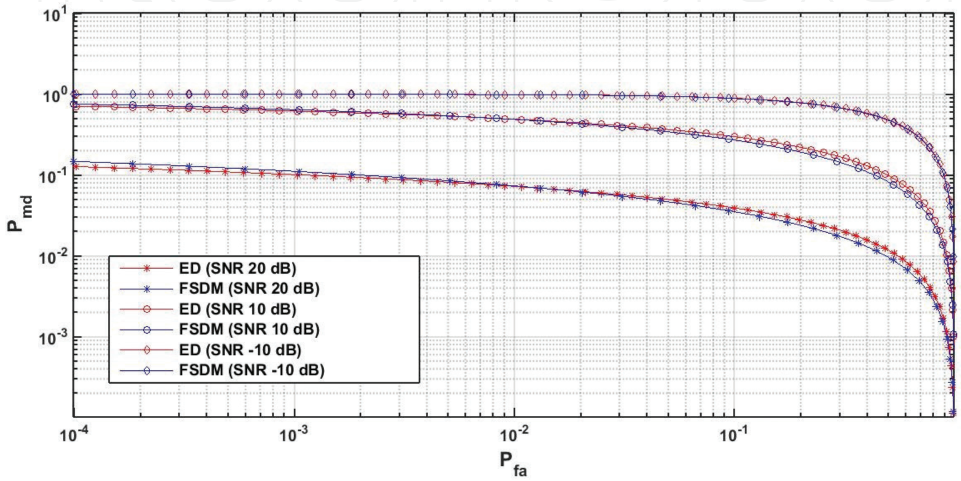

Figure 6. ROC curves for various values of SNR compared with ED SS results and on occupying the spectrum slots by 5 IoT-Us under proposed frequency Spectrum decision mechanism (FSDM).

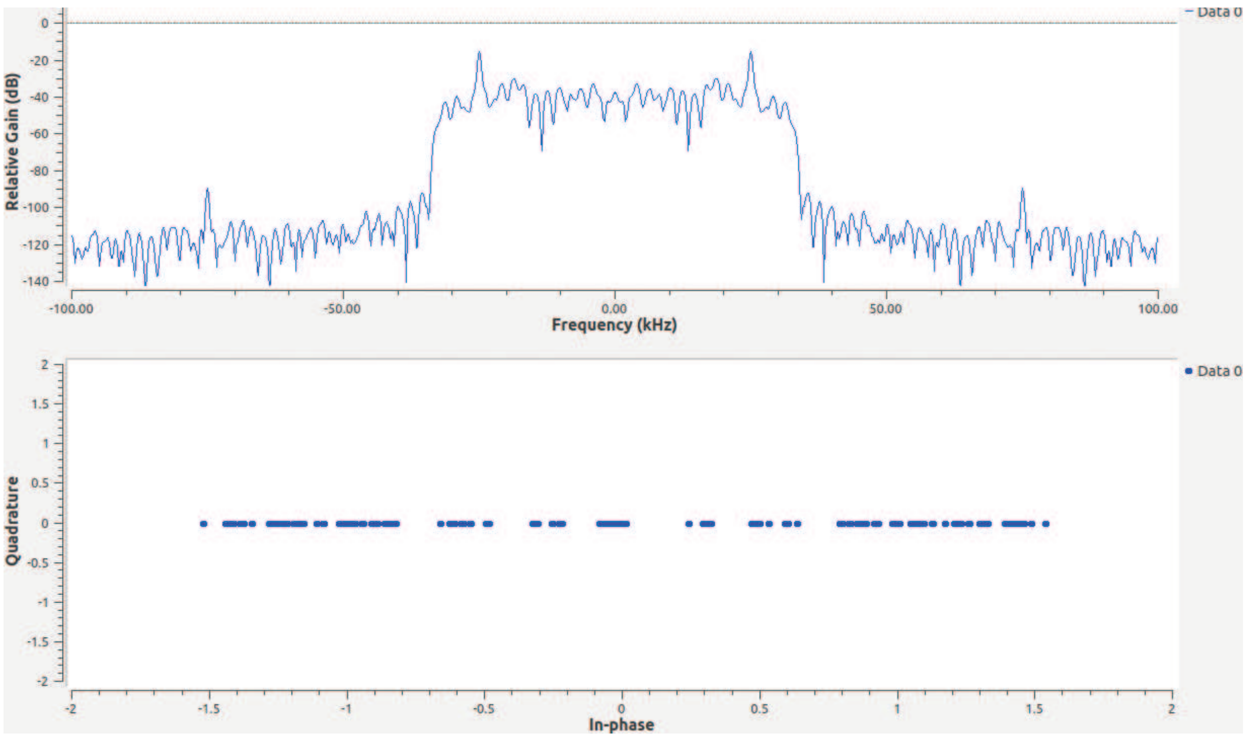

Figure 7. SU's transmitter transmitting low power signal around center frequency in their side lobs.

Energy Detection (ED) in SS offers a fast and reliable detection method for SUs in CRN. The detection performance of ED depends on effects of multipath fading [38]. Accordingly, the proposed decision framework has been validated by ROC curves compared with those of SS through ED method at various SNR values. ROC curves for 5 IoT-Us are shown in **Figure 6**. For the communication overhead as an outcome of information exchange required by the statistical approach, has been significantly reduced by using existing common control channels (CCC) by IoT-Us. This complexity cost is fully justified given the significant performance improvement that the proposed framework offers in terms of latency, throughput, energy efficiency, delay, and the reliability for realization of IoT in terms of A6 connections.

To ensure there is no harmful interference caused to PU by the SU, the SU's transmitter transmits less energy in the side lobs of the transmission signal as shown in **Figure 7**.

8. Conclusion

CR is an important measure to spectrum scarcity problem. To optimally utilize the already allocated spectrum, spectrum decision holds significance in CR. Spectrum decision enables CR users to access the spectrum slots as per their wireless application over a wide RF spectrum range. In this chapter a spectrum decision framework has been proposed which weighs the spectrum band on its idle time, occupancy status and performance and ensures A6 connection thereby providing an enable technology for IoT to support 5G/B5G networks with higher data rates.

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