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A Review of Cognitive Wireless Network Technology

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***Abstract*— *Cognitive Radio Networks Technology is a technology that can be employed in radio contexts to make better use of idle or underutilized spectrum. A cognitive radio (CR) is a radio that may be dynamically designed and adjusted to use the best nearby wireless channels to reduce user interference and congestion. Such a radio modifies its transmission or reception settings in accordance with available channels in the wireless spectrum to enable more wireless communications to take place simultaneously in a specific spectrum band at one location. This work highlights the functionalities of a Cognitive Wireless Network, mentioned how unlicensed secondary user devices can opportunistically access spectrum holes, Interference Modeling and Cognitive Radio Technology Standards that have been developed, Upper Layer Issues like Medium Access Control Strategies, Common Control Channel, Routing, Error Control, Security and finally, Cognitive Radio Applications.*

***Keywords*— *Cognitive Radio (CR), Primary User, Secondary User, Spectrum Sensing, Spectrum Decision, Dynamic Spectrum Management Framework (DSMF).*

I. INTRODUCTION

Applications including digital video broadcasting (DVB), wireless local area networks (WiFi), wireless sensor networks (ZigBee), mobile telephony, and the Internet of things require a vast amount of radio spectrum, which is still expanding (1,2). It is anticipated that this exponential increase will continue (3). Wireless coverage, connectivity, capacity, and services will therefore always be required. However, a significant obstacle is the radio spectrum, a finite resource that is challenging to expand. Therefore, 1-4 GHz may be the main spectrum for current wireless standards. This is due to the fact that the spectrum over 5 GHz has significant attenuation and air absorption, while the band below 1 GHz has already been set aside for uses like radar, military communications, and terrestrial radio and terrestrial television. As a result, the restricted spectrum creates a barrier to the quick expansion of wireless networks and users. The question of how effectively spectrum is now being used is evident given this actual, physical spectrum constraint. The data rate that can be sent over a unit bandwidth is known as bits-per-second-per-Hertz, or bps/Hz, and this is how spectral efficiency is quantitatively quantified. Technical advancements like the application of higher order modulation and adaptive approaches have led to a steady increase in this efficiency; nevertheless, the rate of growth has recently gone down. Owing to this saturation, alternative methods of increasing spectral efficiency are crucial for the expansion of wireless networks. What steps can we take to increase the overall spectral efficiency of radio networks? We need to examine the shortcomings of the current spectrum usage before we can respond to this question. First, national regulatory authorities assign spectrum in a fixed way. By allocating bands (such as frequency division) to one or more services, they achieve their main objective of preventing radio interference. These include amateur radio, GPS, satellite, mobile, and other radio services. A license gives you the sole authority to operate (send and receive wireless signals) in a specific frequency band, at a specific location, or within a specific geographic area. However, in reality, a great portion of the licensed spectrum is left unutilized at various times and/or places. As much as 15–85% of the licensed spectrum (5) may be made up of those transient spectrum slots, often known as spectrum gaps or white spaces (4). To improve overall spectral efficiency, unlicensed users can undoubtedly be allowed to take advantage of such gaps in the spectrum. This fact implies that opportunistic spectrum access is necessary without unduly interfering with licensed users' use of the spectrum (7,8). This is the distinguishing feature of cognitive radio (CR) nodes. CR is a powerful tool for enhancing spectrum quality and possibly mitigating spectral scarcity issues (8), which call for algorithms and protocols for quick spectrum sensing, collaboration, and coordination. Put another way, CR nodes have the ability to identify underutilized spectrum and modify their communications to make the most of it while causing the least amount of interference to authorized users. Therefore, CR improves overall spectrum utilization by moving away from static assignments and toward more dynamic types of spectrum access. As a result, CR networks have already been incorporated into IEEE 802.22 WRAN (Wireless Regional Area Network) and its modifications, IEEE 802.11af for wireless local area networks, IEEE 1900.x series, and have been instrumental in the development of LTE mobile operators' licensed shared access (LSA) (9). This has made idle or unused spectrum accessible. Moreover, test beds have been constructed to confirm that CR is feasible in LTE systems (10). In the context of CR, licensed spectrum users are called primary users (PUs), whereas unlicensed users are called secondary users (SUs) or CR nodes. SUs must therefore exploit spectrum gaps while keeping interference on PU receivers at zero or below a predetermined threshold. There would be more improvements to spectral efficiency from the interaction between PUs and SUs. Cooperative Cognitive Radio Networks (CCRNs) also characterize such mutual networks. The spectral efficacy of CRNs is increased by SUs acting as relays for PUs due to their higher likelihood of using the spectrum (11). The cognitive radio network, in which the designated principal user (PU) and the unlicensed secondary consumer (SU) share a frequency range, is another well-liked method for optimizing spectral

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performance (12). Figure 1 depicts the cohabitation of a primary network and a collection of subsidiary CR networks.

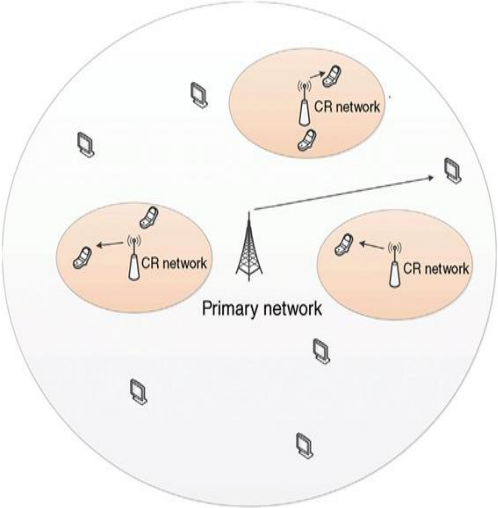

Fig. 1. Cognitive radio (CR) networks existing within a primary network (7).

CR networks can be divided into the following three paradigms (13):

• *Interweave networks*. These function without interference and adhere to the original concept of using spectrum holes, which are unoccupied or underutilized spectrum slots or chunks within a specific geographic area. As soon as a spectrum hole opens, interweave devices can begin sending data; however, they must stop when the sensing algorithms indicate that PU devices are restarting. These methods include beacon detection, waveform sensing, cylostationary, matching filter, and detection based on signal energy or eigenvalues (14). Geolocation databases or out-of-band beacon emissions are used in other techniques (14, 15). These will be explained in more depth later.

• *Underlay networks*. Under this, devices from both PU and SU simultaneously broadcast across the same frequency slots (16). Spectral hole detection is therefore not required. However, interference temperatures below a specific threshold must be tolerated by a PU receiver. The SU gadgets have the ability to reduce their broadcast power, eliminate interference, and create non-transmitting areas (guard regions) around the principal receivers (6) in order to lower the interference temperature. Sensing pi-lot signals from the PU nodes, GPS (Global Positioning System) data, or historical location data from a centralized controller using a geolocation database can all be used to enforce these areas.

• *Overlay networks*. They permit simultaneous PU and SU transmissions as well. But unlike the underlay mode, SU devices need to be aware of the PU sent data sequence (message, for example) and its encoding techniques (code book) (17, 19). There are two possible uses for this information. First, it can be used to cancel PU interference on SU receivers by precoding transmitted data to counteract the effects of interference, like dirty paper coding (DPC) (17). Second, by forwarding PU messages, SU nodes can utilize it to collaborate with the main network.

1.2 Concept Cognitive Radio

CR is a powerful tool for enhancing spectrum quality and possibly lowering issues related to spectral scarcity (non 18). By detecting the radio environment, cognitive users are able to adjust the transmitters and secure incoming users. The first two stages of the spectrum are usually sensory and cognitive transmission. Cognitive users detect the radio environment and collect spectrum data (such as channel gain, occupancy status, traffic, and electricity) at the spectrum sensing level. Cognitive users select the optimal spectrum bands and modify transmissions based on the spectrum data collected during cognitive transmission.

The cognitive radio has the ability to sense and modify its settings to efficiently utilize bandwidth. With 90% of accessible frequency channels effectively protected, this technology concentrates on optimizing and augmenting spectrum use. When there is unutilized spectrum, CR finds and transmits a group of frequencies at a specific time and place. With the exception of primarily authorized custom strip intervention, this employs empty strip for secondary use. Consequently, the CR technique may distinguish between a principal user and a secondary user. Approved users receive higher priority, and important users are identified. It offers sufficient bandwidth to boost data rate services and increase content (19).

II. FUNCTIONS COGNITIVE WIRELESS NETWORK

In order to enable opportunistic spectrum access, CR networks' main functions include spectrum sensing, spectrum sharing, spectrum mobility, and spectrum management and decision-making. They are briefly mentioned here.

2.1. Spectrum Sensing

This is the precise detection of spectral holes. Moreover, it needs to be continuous and ongoing so that the PU alerts the CR nodes to stop transmitting as soon as it re-accesses the spectrum. Geolocation databases, off-band sensing, and in-band sensing can all be used to achieve it. To reduce unwanted interference, it also helps to modify other parameters including power levels, codes, and frequencies.

2.2. Spectrum Management and Decision

- when a large frequency range is covered by several scattered spectrum holes. The process of spectrum management entails choosing the optimum option. Transmit power, bandwidth, coding schemes, modulation schemes, and scheduling are noted when making the decision. The decision is also influenced by Quality of Service (QoS) needed for packet error rate, latency, and throughput, which are necessary for CR communication. These requirements can be placed on what is best for a one pair of communicating nodes or on the needs of the entire set of CR devices. In the latter scenario, decisions are made centrally and then distributed to the participating nodes. Prior to making a spectrum decision, the following criteria must be used to define the available spectrum holes (5):
- *Interference on the primary network:* When employing a spectrum hole, there are a number of variables that could cause interference on the main network. There might be nearby PUs for a certain spectrum hole inside a given

geographic area, and they could potentially be affected by interference. Underlay nodes can also communicate in the presence of PU activity. Furthermore, a neighboring PU transmitter may reaccess the spectrum hole at any time, even if it is silent. The least probable source of interference between the PUs must be selected when there are numerous spectrum holes that are otherwise equivalent.

- *Mutual CR interference:* When several CR nodes access the same spectrum hole, this happens. As a result, selecting the spectrum hole takes into account the degree of their mutual interference. Lower order QPSK (quadrature phase shift keying) may be replaced with higher order constellations, such as 256 QAM (quadrature amplitude modulation). due to low possible interference levels that allow the use of greater transmit voltages.
- *Holding time:* Is the amount of time a CR node can stay in a spectrum hole before PUs start to re-enter it and force it to be released. Long holding periods allow for continuous connection with CR.
- *Frequency band:* There are numerous reasons why the frequency range of available spectrum holes matters. First, higher frequencies result in greater loss in the free space channel, necessitating higher transmit power levels. However, this results in a decrease in energy efficiency and battery life. Increasing power might not be practical, particularly for handheld mobile phones, and as a result, The range of CR communication steadily diminishes. Second, higher frequency bands, such as the millimeter wave frequency band (30–300 GHz), experience additional channel impairments such blockages due to the lower scattering properties of signals at higher frequencies. Third, some frequencies are significantly attenuated by the absorption of water vapor at 24 GHz and oxygen at 60 GHz. In these types of bands, spectrum gaps are frequently undesirable.
- *Channel capacity:* This is the highest possible data rate that a certain channel may theoretically support. The well-known Shannon formula provides the channel capacity C in bits per second as follows:

$$C = B \log 2(1+ SN + I) \tag{1}$$

where A is received signal power, B is bandwidth (Hertz), C is receiver noise power, and D is receiver interference power. Watts serve as the units for v, y, and u. One of the primary factors considered while allocating spectrum is the channel capacity.

There are three methods for making judgments on spectrum access after accounting for all of these factors: (1) cluster based, (2) centralized, and (3) distributed (5,20).

• *Centralized decision-making.* A fusion center (FC), which can be a central controller, sink node, base station, or access point, is involved in this. The FC gathers independent spectrum sensing data from many SUs as well as its own. It might also make use of a geolocation database that displays the spectrum activity of PUs across various regions of the world. Ultimately, it determines whether or not PU signals are present by suitably combining all of these findings, which allows it to pinpoint spectrum gaps. The key benefit is that a centralized mechanism may prioritize essential devices with additional resources, reduce intranetwork and intranetwork interference, optimize the overall throughput of the network, and ensure fairness among SU devices (20). Because of SU nodes transmitting their position and sensing results in formation and receiving from the FC information on power levels, scheduling, spectrum access, and other topics, the centralization process necessitates a significant overhead. As the network becomes denser and more congested, this overhead increases. Moreover, the total spectral and energy efficiency of this process is decreased because it requires a dedicated control channel with energy and spectrum slots allotted.

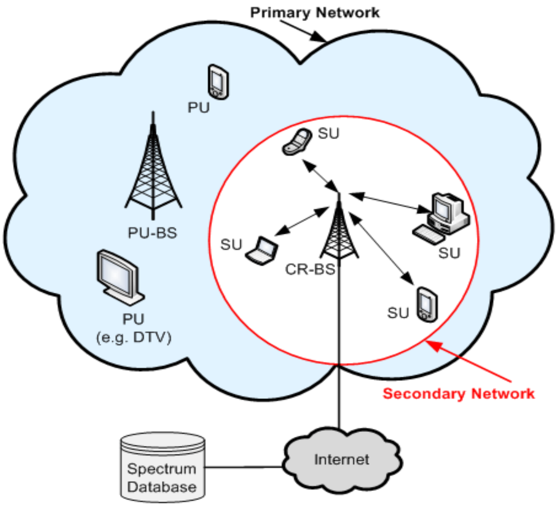

Fig. 2: Centralized CRN Topology(21)

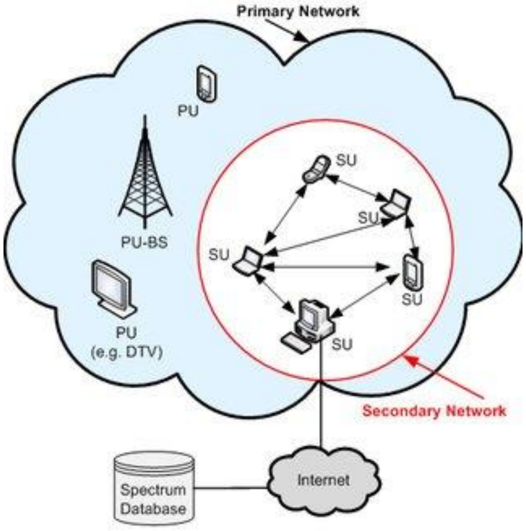

Fig. 3: Distributed CRN Topology (21).

• *Distributed decision-making.* This means that every SU will choose its own spectrum access Nodes in ad hoc networks without a centralized management body or base station this might be the ideal method. With this method, every SU node has total control over the choices it makes, which can be made to optimize an appropriate performance metric. Furthermore, there is less delay in decisions. The node can react instantly to abrupt changes in spectrum activity without waiting for the FC. Nevertheless, the network as a whole may not benefit from those locally optimal choices. Erroneous choices also run the danger of interfering with the primary and SU networks. With centralized decision-making, the likelihood of this happening is reduced.

• *Cluster-based decision-making*. It is possible for a cluster of adjacent CR nodes to form, and decisions about the spectrum are made by the cluster leader (20). This method minimizes drawbacks while having the benefits of both distributed and centralized solutions. It is possible to maintain the cluster size large enough to enable optimal decision-making for a given area, while yet minimizing control information transfers. Clustering, as a result, lowers the power needed to transmit control signals.

2.3. Spectrum Sharing

The fair distribution of available spectrum across different CR devices is known as spectrum sharing. Code, time, frequency, and even space can all be used to carry out this scheduling-based activity. It is also designed to avoid unwanted intranetwork interference (5). It may be dispersed or centralized. In the former, access and allocation are managed by a central body that makes use of the sensing data that it gathers from dispersed nodes. The spectrum decisions are computed by this entity. In the latter, each node determines what spectrum to use based on local knowledge and regulations in the absence of a central authority. More broadly, PU nodes as well as CR devices may be involved in spectrum sharing. This usually applies to the underlay CR mode, which is when simultaneous transmissions take place. In such cases, priority should always be given to the PU.

2.4. Spectrum Mobility

This refers to CR nodes' ability to seamlessly switch between different spectrum holes depending on the situation. Unfavorable channel conditions in the current frequency band, PUs reentering the spectrum hole, and increasing bandwidth to satisfy growing demands for data rates are a few examples. When data is transferred across different spectrum holes, this is known as a spectrum handoff. These are similar to traditional cellular handoffs, where a mobile device moves to a separate service-providing base station.

2.5 Dynamic Spectrum Management Framework (DSMF)

Effective spectrum use using CR technology requires a dynamic spectrum management framework (DSMF). This DSMF includes spectrum sensing, spectrum decision, spectrum sharing, and spectrum mobility, as shown in Fig. 4. Spectrum sharing is the coordinated access to the selected channel by CR users or secondary users (SUs). (Although "SU" and "CR user" are synonymous concepts). The capacity of a CR to leave the channel upon detecting the presence of a licensed user is known as spectrum mobility. Identifying spectrum gaps and having the capacity to promptly identify the beginning of licensed or primary user transmissions in the spectrum hole occupied by the Secondary Users.

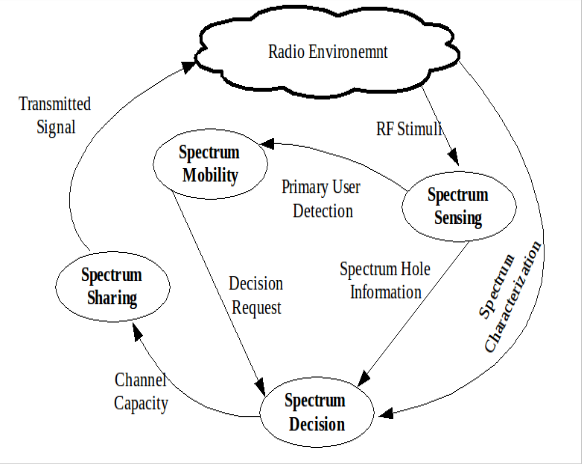

Fig. 4: Dynamic Spectrum Management Framework (21).

The ability of the Secondary Users to choose the optimal spectrum band to meet users' quality of service (QoS) demands is referred to as "spectrum decision." We shall concentrate on the DSMF's spectrum decision component in this work. Three primary processes are involved in spectrum decision (21): CR reconfiguration, spectrum selection, and spectrum characterization. Each unoccupied spectrum band is then described based on local observations and statistical data from the principal networks (often referred to as PU activities) when they have been located (using spectrum sensing, geo-location databases, or other ways). The ability of the Secondary Users (Sus) to choose the optimal spectrum band to meet users' quality of service (QoS) demands is referred to as "spectrum decision." We shall concentrate on the DSMF's spectrum decision component in this work. Three primary processes are involved in spectrum decision (21): CR reconfiguration, spectrum selection, and spectrum characterization. Each unoccupied spectrum band is then described based on local observations and statistical data from the principal networks (often referred to as PU activities) when they have been located (using spectrum sensing, geo-location databases, or otherways). The most suitable spectrum band is chosen in the second phase using the spectrum band characterisation as a guide. Thirdly, in order to facilitate communication within the designated spectrum band, a CR ought to have the ability to modify the parameters of its transceiver. Fig. 5 summarizes the necessary functions for the spectrum choice framework. To carry out these tasks, the following inquiries must be addressed:

- In what way may one characterize the available spectrum?
- How can the optimal spectrum band be chosen to meet the QoS needs of the SU?
- Which method of reconfiguring the CR for the chosen spectrum band is the best one? (However?)

Due to its significance and centrality in the DSMF in CRNs, as well as the fact that it has gotten less attention than other CR DSMF components like spectrum sensing, mobility, and sharing, we have decided to concentrate on spectrum decision. In many ways, spectrum decision represents the culmination of the DSMF in CRNs. concentrate on this particular DSMF component, which is founded on the widely recognized communications engineering concepts of modularity and abstraction—possibly best and most forcefully demonstrated in Shannon's seminal 1948 article (21).

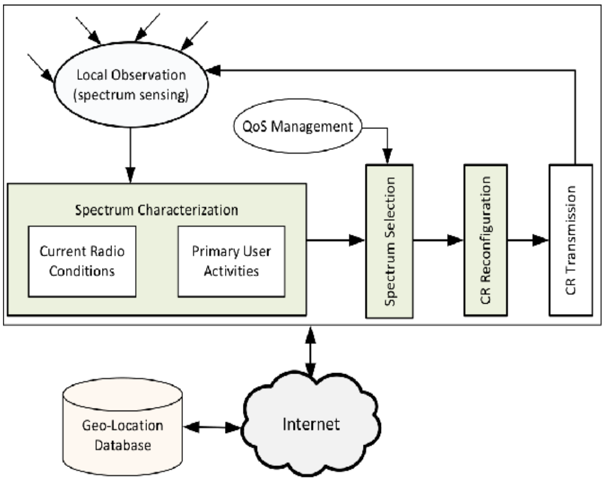

Fig. 5: Spectrum Decision Framework (21)

III. SPECTRUM OPPORTUNITIES IDENTIFICATION

Unlicensed SU equipment’s can, as previously indicated, by opportunistically access spectrum holes. There can be holes in the spectrum that is occupied, underutilized, or unoccupied. When there is no PU activity within a specific geographic area, it is known as vacant spectrum. This might happen, for instance, if the licensee doesn't make use the spectrum in a particular place or region. Underutilized spectrum is the result of PU activity being absent during some periods of time but present at others.

Techniques for identifying spectrum include co-operative sensing, in-band and out-of-band sensing, interference temperature-based detection, and geolocation databases (22). Next, we will discuss these plans in more detail.

3.1. Geolocation Databases

An SU initially determines its position before requesting a list of frequencies that are available at this place from a geolocation database. The database might also include other details, like the maximum allowable transmit power levels that correspond with each of the frequencies that are available and the duration of validity for the parameters that are supplied (13, 22). To easily discover spectrum holes, these centralized databases store current data regarding spectrum consumption across many geographic locations (13, 22). The authorities may be in charge of managing these databases and will ultimately decide whether or not a certain CR device is permitted to use restricted spectrum. In these centralized schemes, every CR device is connected to the base station or access-point, which is the decision-making entity. The database is then contacted by this entity over a backhaul connection.

3.2. In-Band Sensing

When an SU device that is attempting to access or is currently using the principal band measures it directly, it is referred to as "in-band sensing." Although it can be modified for centralized judgments, in-band sensing works best when used in conjunction with distributed decision-making. Its primary transmitter detection method has a significant drawback in that it is unable to detect the presence of primary receivers, which are silent, non-transmitting nodes and are the entities that are genuinely impacted by interference. This includes frequency division duplexing and broadcast-based systems like digital terrestrial television. As a result, primary receiver location cannot be determined by in-band sensing; it can only detect the existence of a transmitter within a specific range. Hence, when SU broadcasts in the spectrum and no primary transmitter is found, there may be interference on adjacent primary receivers. The term "hidden terminal problem" (22) refers to this. In-band spectrum sensing techniques include energy detection, cylostationary feature identification, eigenvalue-based detection, matching filter detection, p-norm detection, and Anderson–Darling sensing (23). Filter-based sensing, fast sensing, learning-based sensing, measurement-based sensing, and diffusion-based detection techniques are among the additional systems that have been suggested (23). A number of these proposals will be discussed in greater detail below.

Energy Detection: compares a signal's energy level throughout a target frequency band to a threshold by computing the signal's energy level (23, 24).

Cyclostationary Feature Detection: This detector exploits the periodicity of the statistics, such as the mean and autocorrelation of the PU signals. The periodicity is caused by a variety of causes, including cyclic prefixes, codes, hop-ping sequences, PU modulation properties, and upconversion to passband signals.

Eigenvalue-Based Detection: This method does not require prior knowledge of the signal, channel, or noise power in order to recognize principal signals in the presence of noise. It accomplishes this by calculating the ratio of the highest and lowest eigenvalues in the received signal's covariance matrix.

Wideband Spectrum Sensing: These methods allow the sensing of spectrum blocks bigger than the channel's coherence bandwidth, even though narrowband sensing usually yields a binary decision on spectrum occupancy for a narrow band (25). These techniques are especially crucial in the UHF (ultra high frequency) band between 300 MHz and 3 GHz and the upcoming millimeter wave frequency range over 3 GHz.

3.3. Out-of-Band Sensing

This does not entail directly detecting the frequency range for which spectrum access is necessary, in contrast to in-band sensing. Rather, a specific out-of-band control channel determines whether or not PU devices are using the frequency band. In order to do this, PU transmitters or receivers send beacon signals across the control channel. These beacons, for instance, are best suited for CR implementation in a cellular system and have been suggested for IEEE 802.22.1 (22). By comparing the received signal power in the control channel with a threshold level, the SU devices are able to identify beacon signals.

Beacon signaling is easy to use and effective (26, 27). All that the beacon signals are narrowband electromagnetic waves that have been switched on and off.

3.4. Interference Temperature

The idea is to depict the ways in which primary and secondary users interact with interference. It allows for the quantification of both the feasible capacity for the underlying network and the interference impact on licensed users. It is particularly crucial that this idea is receiver-centric as primary receivers, not primary transmitters, are the ones that are impacted by interference. Furthermore, what matters is the overall interference from different CR devices, extra cochannel primary transmitters, and unknown third-party transmitters. Interference temperature-based spectrum identification is especially attractive for underlying CR devices that do not actively perceive the spectrum. Therefore, the Federal Communications Commission's (FCC) Spectrum Policy Task Force developed the interference temperature, which is the temperature equivalent of radio frequency power available at a receiver antenna per unit bandwidth. The interference temperature can be expressed in Kelvin as follows:

$$T = \frac{P_i(f_c,\mathrm{B})}{\mathrm{kB}} \tag{2}$$

where k =1 .38 × 10−23 J/K is the Boltzmann constant, B is the bandwidth of the channel, and $P\mathrm{i}(f\mathrm{c},B)$ is the interference power centered around $f\mathrm{c}$ over a bandwidth of B. The interference temperature model's primary goal is to characterize noise and interference simultaneously (28, 29). Depending on certain receiver characteristics, It is possible for a main receiver's interference temperature level to be unaffected by the comparable levels of other receivers (30). Under such circumstances, the CR network needs to know beforehand the interference temperature levels of each receiver, or the level of the device with the lowest threshold.

3.4 Cooperative Sensing

This means that multiple SUs share their local spectrum sensing data in order to make a collective decision. As a result, it improves sensing performance by taking use of wireless networks' multiuser and geographical diversity (31). Moreover, it is feasible to minimize detection error and shorten individual sensing times (32). Wireless channel impairments including multi-path fading, shadowing, and path loss may prevent a CR node from detecting a spectrum hole using in-band or out-of-band sensing. which could lead to the hidden terminal issue. (22).

IV. INTERFERENCE MODELLING IN COGNITIVE RADIO NETWORKS

Primary devices are quite vulnerable to undesired SU interference, as was previously indicated. For interweave networks, interference should ideally be zero, while for underlay networks, it should be less than a tolerable threshold. Interference is caused by a variety of causes, such as spectrum sensing techniques, activity factors of CR devices, power control and receiver association procedures, spatial distribution of SU and PU devices, and wireless propagation characteristics. Here are some quick descriptions of some of these subjects.

4.1. Wireless Channel

Numerous impairments affect the wireless channel, such as doppler changes, route loss, shadowing, and small-scale fading (3,76). It is essential to model these limitations in order to study and describe wireless networks. Small-scale fading is the fast fluctuation of the received signal caused by the superposition of several replicas of the transmit signal with varying phases and time delays resulting from multipath propagation from random scatterers. The power delay pro-file represents the powers of several multi-path components, and key parameters include average delay and root mean square (r.m.s) delay ($\sigma\tau$). Signals with frequencies lower than Bcoh are said to experience frequency flat fading, while signals with frequencies higher than Bcoh are said to experience frequency selective fading. The coherence bandwidth is defined as Bcoh = $1/\sigma\tau$. Several models, including Rayleigh, Nakagami-m, and Rician fading, are used to characterize small scale fading.

4.2. Spatial Modelling

Base stations and user terminals are typically not arranged according to a predefined plan. Although base station placement is not entirely random, it is becoming more and more erratic as tiny and pico cells are added. On the other hand, the locations of the user terminals are frequently and almost entirely arbitrary. Because of this, traditional fixed models—like the hexagonal grid model—do not accurately depict the network. As a result, stochastic geometry-based modeling has become more popular among researchers. (33,34).

4.3. Power Control and Receiver Association

Depending on factors including channel conditions, other transmissions, and distance from the receiver, the transmitter adjusts its power. Benefits include lower interference and transmitter power consumption. Techniques for power regulation include measurement-based schemes, distance-based systems with channel inversion, and fixed power (96). For example, both open-loop and closed-loop techniques are used in Wideband Code Division Multiple Access (WCDMA) and Long-Term Evolution (LTE) networks (3). Power control techniques for CR networks and noncognitive contexts have been thoroughly researched (35).

4.4. Interference Analysis

The sum of the interference from every active CR device is what a primary receiver experiences as total interference (36, 37). Consequently, the total interference I can be expressed as

$$I = \sum_{I=1}^{n} I_1 \tag{3}$$

where d is the number of interferers and y is the interference produced by the ith interferer. N may be infinite or have a finite value. The interference of each unique Ii is written as

$$I_i = \beta_i P_i X_i / h_i /^2 r_i^{-\propto} \tag{4}$$

where Pi is the transmit power of the ith CR device and βi is a Bernoulli random variable that depends on the activity level and spectrum identification errors of the ith CR device. The shadowing gain, small-scale fading gain, and distance between the ith CR device and the primary receiver are represented by the variables $X_i/h_i/^2$, and r_i, respectively. The environment's route loss exponent is represented by α. An MGF (moment generating function)-based technique is typically employed for analysis since the PDF of the aggregate interference is typically unmanageable (38,39, 40). Because the overall MGF is the product of the individual MGFs for a sum of independent interferers, the MGF may be determined quite readily (39). One way to express the MGF $M_1^I(s)$ of interference from a single node is as

$$M_1^I(s) = E[e^{-sI_i}] \quad (5)$$

where $E[\cdot]$ denotes the expectation and s is the Laplace variable. If the individual interferers are independent and identically distributed, the MGF of the aggregate interference becomes

$$M_I(s) = (M_1^I(s))^N \quad (6)$$

Other valuable parameters of the aggregate interference include the mean and higher moments and cumulants. The nth moment ($\mu_n = E[I^n]$) can be obtained from the MGF $M_I(s)$ as

$$\mu_n = (-1)^n [\frac{d^n}{ds^n} M_I(s)]_{s=0} \quad (7)$$

Modeling aggregate interference to fit well-known distributions has gained popularity because exact analysis is unachievable. Frequently, these distributions are tailed α-stable, gamma, Gaussian, log-normal, and sums of log-normal and normal (41). This is usually achieved by matching the moments of the aggregate interference with the corresponding moments of the known distribution.

V. UPPER LAYER ISSUES

5.1. Medium Access Control Strategies

Traditional wireless networks employ fixed access techniques such as code division multiple access (CDMA), frequency division multiple access (FDMA), and time division multiple access (FDMA). In CR networks, the accessible channels are dynamic in one or more dimensions, such as location, coding, frequency, and time. For the CR network to operate properly, dynamic media access control (MAC) techniques are therefore required.

Two essential features of a CR device are spectrum-aware sensing and spectrum-aware access control, which are managed by the MAC layer. (43).

5.2. Common Control Channel

A common control channel (CCC), a dedicated channel shared by CR devices, has been assumed by many MAC techniques for CR networks (42). Since CR devices may report and negotiate channel access thanks to the CCC, it must always be accessible. The CCC's inability to facilitate interoperability across various device kinds using various protocol stacks made by various vendors is one of its drawbacks.

5.3 Routing

Efficient routing procedures are required when CR devices relay data or packets from an originating CR to a destination. Due to the large dispersion of accessible spectrum holes, routing is a crucial problem in CR networks. Moreover, a given node's spectrum availability varies over time, and other nodes might not recognize the same frequency band for opportunistic access. Deploying outdated routing methods meant for general ad hoc networks might not be appropriate because the routing algorithms need to be able to handle the dynamics of the CR environment (43).

5.4 Error Control

The maximum power that secondary devices are permitted to transmit is severely limited in order to prevent interference on the principal network (44). The secondary network's capacity and dependability will inevitably decline as a result of this limit. Error correction coding, which includes automated repeat request (ARQ) schemes and forward error correcting codes, is one possible remedy. ARQ methods rely on the receiver's feedback to determine when data is correctly received and when timeouts occur. Retransmissions take place if the sender is not notified of an acknowledgment before the timeout.

5.5 Security

CR networks have a number of particular security issues because of their distinctive features (19). Although conventional network hazards are relevant to CR networks, extra risks to CR devices are introduced by their cognitive capabilities and reconfigurability (45). Adversaries emulating PU behaviors, transmitting false spectrum information, jamming receivers during the sensing phase, posing as CR devices, and CR devices acting selfishly out of greed are some of the specific security issues for CR networks (46). These dangers may manifest throughout both the sensing and communication phases. Transmitter verification processes, incorporating cryptographic signatures, abnormality detection methods, and trustworthy node-assisted mechanisms are a few countermeasures for security problems (46).

VI. STANDARDS

The International Telecommunications Union, IEEE, the European Telecommunications Standards Institute, and the Federal Communications Commission of the United States have all published CR technology standards (5). The intended environment and cognitive level of these criteria vary. The primary CR standards at this time are IEEE P1900.X and IEEE 802.22 Wireless Regional Area Network (WRAN), both of which were created by the IEEE Dynamic spectrum access networks (DySPAN) committee. Furthermore, some aspects of cognition have been increasingly incorporated into WiFi (IEEE 802.11), Zigbee (IEEE 802.15.4), and WiMAX (IEEE 802.16).

6.1. IEEE 802.22 (Wireless Regional Area Network)

While some channels wouldnt be used in a particular region or geographical area, spectrum is set aside for terrestrial TV broadcasts. Furthermore, a sizable portion of the UHF and VHF (very high frequency) spectrum remain unoccupied as a result of the analog to digital conversion (5). Therefore, the unlicensed use of television frequency ranges (54–862 MHz) without interfering with primary users is the aim of the IEEE 802.22 WRAN standard, which focuses on wireless broadband connectivity for rural areas. With a typical cell radius of 17–30 km and a maximum allowed range of 100 km, this standard employs a cellular architecture.

6.2. IEEE DySPAN (Dynamic Spectrum Access Networks) Standards

This set of standards for advanced spectrum management and dynamic spectrum access (DSA) supports new approaches to network management, interference management, sensing, and wireless network coordination. The IEEE DySPAN Standards Committee was formerly known as the IEEE P1900 Standards Committee and Standards Coordinating Committee 41 (SCC41) (5,47).

6.3. IEEE 802.19.1

In order to facilitate coexistence and take use of TV spectrum gaps, this standard was created (48). Coexistence describes the coexistence of systems that use different CR standards as well as self- cohabitation of CR devices that adhere to the same CR specification. Self-coexistence is almost usually covered by the CR standard, while coexistence between devices implementing different CR standards is more challenging (48). This standard attempts to accomplish this in three primary ways: Finding various CR systems that must coexist, modifying the working parameters of various CR systems to enhance performance, and offering a single interface for CR devices with various technological backgrounds are the first three steps in the process (48). The main elements of the protocol are channel categorization, coexistence set element reconfiguration, communication of coexistence set information, registration, and subscription (48).

6.4. IEEE 802.15.4m (Zigbee)

This standard (49) rebands frequencies utilized by conventional IEEE 802.15.4 devices (low rate personal area networks) to fill in the TV spectrum gaps (50). For body area networking, smart utility networking, active radio frequency identification, and wireless sensor networks, IEEE 802.15.4 has gained popularity (50). The existing spectrum is restricted, thus it is essential to look into new options as fresh uses come to light. Peer-to-peer/device-to-device connections have been included in IEEE 802.15.4m in order to align with the intended sensor network applications.

6.5. IEEE 802.11af (WiFi)

To enable local area networks (LANs) to take advantage of TV spectrum holes, the IEEE 802.11af standard proposes modifications to the MAC and physical layers of 802.11 (51). The main elements are a geolocation database, a secure server for users who have registered, and geolocation database-dependent entities (GDD), such as GDD enabling and dependent stations (52). The registered location query protocol (RLQP) enables the dependent stations to select transmission characteristics such as the spectral band, bandwidth, and power to enable communication between GDD enabling stations (52).

VII. COGNITIVE RADIO APPLICATIONS

The most common usage of CR is in television networks, where white space is employed to let secondary cognitive users use the unused spectrum without conflicting with prime users (53). A further noteworthy facet of spectrum reuse for telecommunications systems involves leveraging the spectrum to support the growth of wireless networks and enhancing bandwidth competition. The CR technology uses the spectroscope spectrum opportunistically for high data requirements and anticipates the characteristics of the macro cellular traffic spectrum.

The fact that 5 G combines CR and NOMA (None-Orthogonal Multiple Access) with high performance, high availability, and low latency is another selling feature. However, in practice, both CR and NOMA are susceptible to interference, resulting in NOMA multiplexing in a controlled area and, eventually, large interferences between secondary, central, and internal interference networks (54).

The following are the benefits of a perceptive cognitive sharing of the NOMA spectrum.

- *Better utilization of spectrum:* NOMA cognitive networks will allow for the proper level of reception for both PUs and SUs.
- *Broad Connectivity:* 5G wireless networks are expected to allow a large number of smart devices. This requirement will be met by NOMA cognitive networks, which supply several PU and/or modules at different power levels simultaneously in a single source block (55).
- *Low latency:* High transmission delays in SUs can produce low latency in cognitive NOMA networks. For instance, by utilizing NOMA to support CR networks, many SU units can be connected at the same time (56).
- *Greater Justice:* NOMA Perceptual Networks will guarantee greater consumer equity. As a result, equity and secondary network efficiency are fairly balanced (55)(57).

VIII. CHALLENGES AND RECOMMENDATION

- Despite the fact that CR promises to use the RF spectrum efficiently, network switching latency remains a problem. This spectrum switching delay encompasses the time spent on the base station's spectrum decision process, channel establishment signaling, and RF front-end reconfiguration. Applications that are sensitive to delays may suffer during this switching time when the SU's transmission is momentarily severed. The solution to this delay will primarily come from computer-based technologies or suitable software.
- When working in CRNs with spectrum decision algorithms, another crucial issue to take into account is resource allocation and interference management. Therefore, future spectrum decision algorithms should provide an answer to the following query: How can the SUs and PUs transmit at the same time while allowing the SUs' interference level to remain within a reasonable bound? and the unused of specific frequencies that are designated, such as those for emergency services.
- A number of security concerns pertaining to the spectrum choice will need to be resolved. How can sensitive spectrum decision information, such as PU and SU activity models, be ensured, for example? is only accessible to authorised users and that only they are able to use secondary CRNs? The issue of security in CRNs is challenging to resolve. These days, security assaults can target wireless networks. This is a result of the features and nature of CR communication. Communication systems based on CRN are generally required to ensure, at the very least, address communication security requirements such availability,

authentication, authorization, access control, secrecy, and privacy by maintaining the same degree of security as traditional wireless systems. This results from adherence to current guidelines and standards that have previously been established for wireless communication networks.

- Sensing with limited information: CRs must use the limited information at their disposal to sense their multidimensional radio environment. Possible ways to improve sensing capability include secondary users working together to communicate.

IX. CONCLUSION

A potential remedy for the spectrum scarcity experienced by emerging wireless applications is cognitive radio, which seeks to more efficiently access unutilized or underutilized airwaves. The three most used CR paradigms are interleave, underlay, and overlay. Furthermore, one of the main challenges is identifying spectrum opportunities, which can be done in a variety of static or dynamic ways. Mutual interference in CR networks is a major impediment that can be described by statistical spatial and channel models. In addition to other considerations, a successful implementation of CR must address security, MAC, routing, and physical layer difficulties. A number of CR standards have already been created, and others that include cognitive components have been added. PUs and SUs working together would significantly increase spectral efficiency. These mutual networks fall under the general category of Cognitive Collaborative Radio Networks (CCRNs), which use a variety of spectrum-sharing strategies. Combining NOMA with CR can meet 5G requirements for high performance, strong connection, and low latency; however, there are certain integration-related problems that require further research and analysis. As a result, we advise further research in this area. In the future, NOMA and CR technologies may be able to make better use of the wireless spectrum.

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