Cognitive Radio Technology: A Viable Means to Support 5G Network

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***Abstract*— Radio spectrum is facing a significant demand from the emergence of new wireless technologies, to complement applications such as Bluetooth, UWB, IEEE 802.11b/g, EGDE, UMTS, WiMAX and LTE. Poor allocations and extremely low usage of the allocated spectrum have become impediment to the exploitation and development of new wireless modernizations. This motive necessitates for application of cognitive radio for liable interaction with these levels of radio access technology for the improvement of global spectrum consumption within the heterogeneous radio environment. Implementation of cognitive radio will not only advance the usage but also respite some assigned effectively idle state spectrum resources. This makes the spectrum regulatory bodies to review policies in order to search for new inventive communication technology that can scrutinize and forward the spectrum in a more flexible and intelligent manner. The concept of cognitive radio is proposed to sort out the outstanding issues of unused radio spectrum and spectrum efficiency within the wireless communication service. This paper surveys and discusses the characteristics of cognitive radio and the challenges of RF front-end components, the impairments and the use of VFDM technique for interference cancellation.**

Keywords*— *Cognitive radio; spectrum sensing; spectrum management; software defined radio; RF front-end

I. INTRODUCTION

Nowadays, there is need for a mobile device that can dynamically change it parameters such as frequency, bandwidth, and modulation for higher data transport, to respond in accordance to the user prerequisite [1]. Second generation modulation technique, high data rate was not considered for multi-media communication, but invented merely for voice and text messages [2]. Present and future high demand of multimedia communication applications, where services providers are willing to place more priority to data communication than the voice due to the arising needs from many users that aspire, for instance, to watch football match on their mobile phone and at the same time engage on their businesses, shop online, pay bills online, make video calls with their families and many more applications [3].

However, due to the demand of users, several radio access technologies invention is in the increase, such as WLAN, W-CDMA, mobile WiMAX, Bluetooth and even LTE amongst many applications [2, 4]. The advent of frequency spectrum limitation causes the inefficient spectrum allocation and usage. The inefficient usage of assigned spectrum by the primary user makes it necessary to pursuit for a cognitive radio resolution [5]. Cognitive radio (CR) is a new emerging technology that holds the key to make efficient use of the underutilized radio frequency spectrum band in the presence of wireless communication environment [6]. It is considered as one of the forefront candidate technologies for the next generation wireless system and beyond. Joseph Mitola III and Gerald Maquire officially presented the idea of cognitive radio and system that is conscious of it radio frequency environment and exploit the means of perceptive by building to learn from the environment and familiarize its internal states to statistical variation in the environment by making changes to adjustable parameters such as transmit power, carrier frequency and modulation strategy, all in real time. Cognitive radio as technology with intelligence of dynamic sensing in a specific frequency band, the unused spectrum can be used by secondary user without inflicting interference in the operation of primary user. However, a large portion of the assigned spectrum remains underutilized [5, 7] as illustrated in fig. 1.

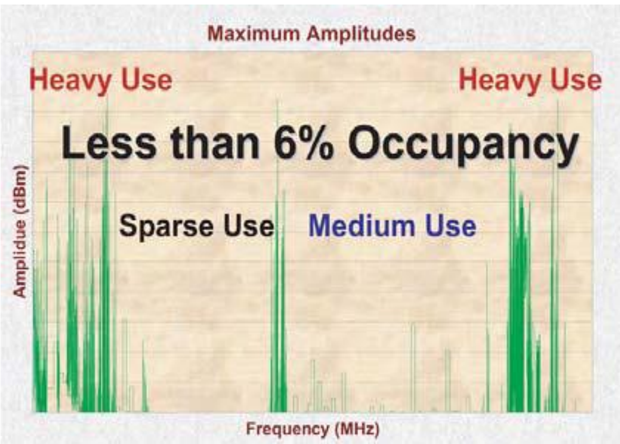

Figure 1: Spectrum usage [5].

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Intensive research has increasingly been carried out on cognitive radio, lots of writings have been put forward to address it fundamental circumstances, but still not implementable in the near foreseeable future. The veracity point of view is there has been slightly reduction of cognitive radio system research and publication in the past year, due to the stringent spectrum allocation regulations and challenges of implementation. This paper discusses main functionalities which cognitive radio has to implement to avoid interference with primary users such as spectrum sensing, spectrum management spectrum sharing and spectrum mobility. Some of the challenges of implementing cognitive radio such as the requirements for RF front-end, components versus the impairments are presented in section III

II. Cognitive Radio Network Functionalities

Cognitive radio functionalities are the features of next generation enabling technology with competence to share the primary user idle resource in a dynamic way [8]. Cognitive radio is an opportunistic system that operates in the unsurpassed obtainable channel by allowing the cognitive user to sense which potion of the spectrum is accessible, making finest decision for finest available channel, organize channel access among users, and evacuate the channel for primary user usage [9]. This section will take and discuss in detail the four main features of cognitive radio next generation network.

A. Spectrum Sensing

One of the main features of cognitive radio network is the ability to sense the availability of spectrum holes. It has been structured to be aware and sensitive to changes in its domain [10]. Due to the sensitivity of cognitive radio, it is able to adapt to it environment by detecting specifically the spectrum holes at the link level [11]. Spectrum holes can be detected efficiently with the help of primary user detection within the communication range of the network [11]. But, it seems not easy for cognitive radio to be aware of the transmission scheme with which primary user is based on and this leads to difficulty in having access to training and synchronization signals for the primary user transmission [10, 12]. Considering that cognitive radio as an intelligent wireless communication radio device, that is very much aware of its environment and its adaptability to detect the underutilized primary user spectrum efficiently [8]. Spectrum sensing employs sensing techniques such as transmitter detection, cooperative detection and interference-based detection as shown in figure 2.

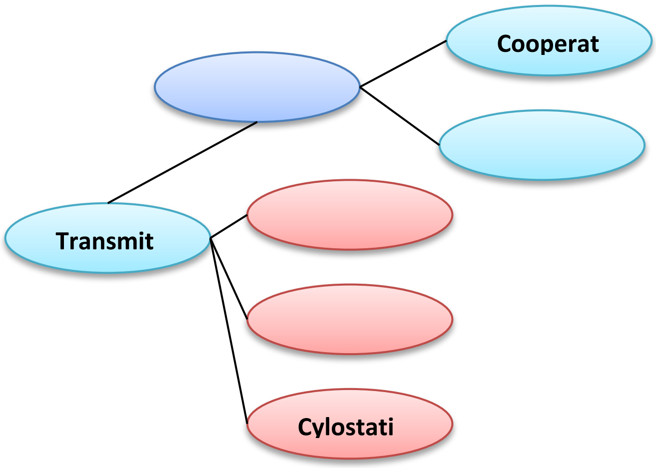

Figure 2: Classification of spectrum sensing techniques.

- *Transmitter detection*

Transmitter detection is a non-cooperative detection of spectrum sensing. In transmission detection, the responsibility of cognitive radio is to differentiate the utilized and unutilized spectrum. It is however capable of ascertaining the presence of primary user transmitter in a certain spectrum [13]. The essence of transmitter detection theory is based on detection of weak signal from a primary transmitter through observations of primary user [11]. Basic hypothesis detection for transmitter can be described as follows:

$$f[x] = \begin{cases} g[x] \\ hs[x] + j[x] \end{cases} x = 1, \dots, N \begin{matrix} H_0 \\ H_1 \end{matrix} \quad (1)$$

Where f[x] is cognitive radio primary user received signal, s[x] is primary user transmitted signal, g[x] is the additive white Gaussian noise (AWGN) added to the front-end channel, h is the amplitude or complex gain of the channel and N represents observational interval. Hand s[x] is achieved through convolution process. H0 denotes the null hypothesis which means no presence of primary user signal within a certain spectrum. H1 also represents the alternate hypothesis that certain spectrum band is occupied by primary user signal. Based on the hypothesis model, three spectrum detection techniques are realized for a single system, for the purpose of transmitter detection in the network [9, 11]. The transmitter detection techniques are matched filter detection, energy detection and cyclo-stationary detection.

- *Matched filter Detection*

Matched filter is a method for optimal detection where cognitive radio network detect primary user signal and signal to noise ratio is maximized in the additive Gaussian noise. Due to coherence, matched filter does not need much time to process high gain with the need for primary user signal (modulation type and order, the pulse shape, and the packet format). The filter performance result is not effective and un-accurate [10, 11, 13].

- *Energy Detection*

When receiver fail to gather adequate information about primary user signal, unknown zero-mean constellation signal can be detected by the energy detection method and can be applied to cognitive radios. To determine whether primary user signal is on spectrum, energy detection approach is fit to measure the energy of radio frequency or the receive signal strength indication (RSSI) [11].

- *Cyclostationary Feature Detection*

This method of detection performance exit energy detector in dealing with noise due to its strong construction in the uncertainty of noise power but demand more time to process. It main function is to characterize modulated signal to cyclostationary level only if the mean and autocorrelation of the modulated signal keep repeating itself [14].

- *Cooperative Detection*

This method is used for detection of primary user by incorporating multiple cognitive users. This method of spectrum sensing can be executed using centralized or distributed method. The centralized method refers to the role cognitive radio play in collecting information from cognitive users to detect spectrum holes. Distributed method also refers to the situation where cognitive users exchange observation for spectrum detection. This reduces the uncertainty in single user's detection by increasing the accuracy in spectrum holes detection [11, 15].

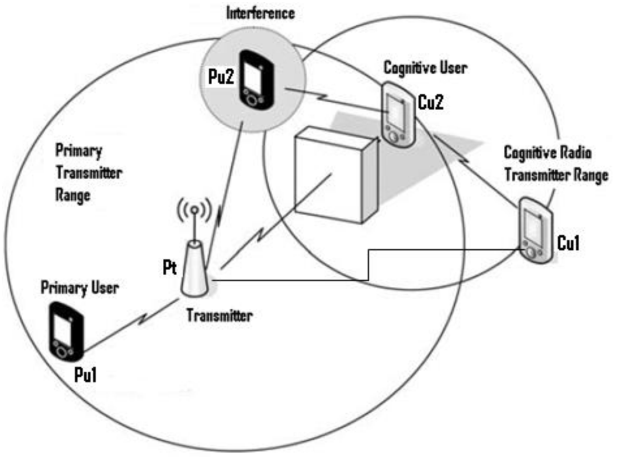

Figure 3: Corporative spectrum sensing for two CR users [11].

- *Interference-Based Detection*

In this method, radiated power, out-of-bound emissions and location of individual transmitter contributed to controlling the interference at the receiver. For effective interference measurement, interference temperature model needs to be employed to compliment the interference-based-detection method [16].

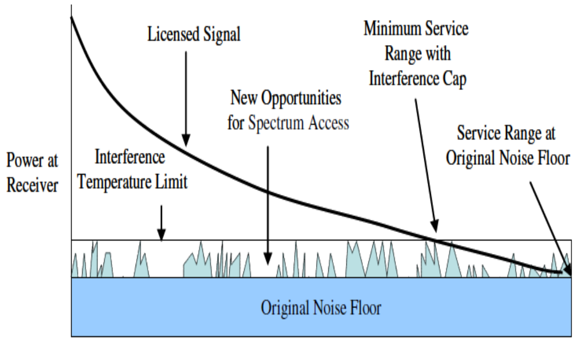

Figure 4: Interference temperature model [11]

Fig. 5 is an interference temperature model developed by Federal Communication Commission (FCC) to determine the presence of interference. The model used one cognitive user and shows how the interference disrupted the service of a primary user. However, cognitive user could not detect the location of the primary user. In connection to that point of view, the method relates factors such as power control, antennas, unlicensed signal modulation, ability to detect active licensed channels, and active levels of the licensed and unlicensed users [11, 17].

B. *Spectrum Management*

Spectrum sensing is component of spectrum management major challenge. Spectrum management is but discussed separately, because it is many features that require detailed explanation and is primarily on the physical layer. Spectrum management discusses decisions that cognitive radio network is expected to be made for the best frequency band, with QoS requirements over all available frequency bands. Spectrum management is a way of managing the usage of radio frequency for optimum efficiency. So, spectrum management functions apart from spectrum sensing include spectrum analysis and spectrum decision which are assumed to be related to upper layer [5, 15].

1) *Spectrum Analysis*

Cognitive radio network takes advantage of spectrum analysis to study the characteristics of all available spectrum holes which their status changes overtime. Analysis helps to obtain the best spectrum band to satisfy cognitive user requirement. Spectrum band information such as bandwidth and operating frequency are obtainable. It is however significant that cognitive radio network recognizes the effect of spectrum parameters such as interference, path-loss, and channel error rate, holding time and link layer delay [18]. These parameters are what determine the quality of spectrum band, explained in summary as follows:

- Interference:

The level in which some spectrum bands are crowded than others base on their priority. Only spectrum band on use can ascertain the channel interference characteristics. Estimation of primary user channel capacity can be done by the power of the cognitive user depending on the amount of interference of the primary user receiver.

- Path loss:

Path loss must be low for the interference to also be low. The cognitive user must maintain its transmitter power to avoid increase in frequency.

- Channel error rate:

Error rate of the channel majorly depends on the type of modulation scheme applied and the intensity of interference.

- Holding time:

This is the period of time in which cognitive user hold spectrum band before interruption.

- Link layer delay:

Addition of many headers of different link layer protocols for different spectrum bands result to transmission delay.

2) Spectrum Decision

Spectrum decision can be taken as soon as spectrum management requirements are met. This requirement can be described as mentioned in the previous paragraphs [18]. Best operating spectrum band is decided after characterizing all the available spectrum bands and in selection, user QoS requirements must be put into consideration for transmission such as the data rate, the bandwidth, transmission mode and the delay bound. When all the mentioned user requirements are satisfying the decision will be set accurately without having interference with the primary user [19].

C. Spectrum Sharing

Spectrum sharing is one of the challenging functionalities of cognitive radio network in using licensed spectrum band. Sharing of spectrum between primary user and secondary user can substantially help to solve the problem of spectrum scarcity [11]. According to many existing research works, secondary user can transmit when primary user transmission strength is weak, and the spectrum is presumably considered as unused. But this can only apply to TV broadcasting [15]. However, in the case of bidirectional scenario a secondary user transmit while primary transmission is strong that existence of secondary user transmission will not cause harmful interference [18].

Primary-secondary spectrum sharing can be based on two conditions which are cooperative sharing and coexistent spectrum sharing. This has indicated the extent in which primary users share with unlicensed secondary spectrum bands.

1) *Cooperative spectrum sharing*: Cooperative spectrum sharing can also be called collaborative spectrum sharing. It is where the secondary user measure how much interference it can share among other users through communication. The spectrum communication allocation solution uses this information to consider the effect of the two different users sharing the spectrum resource with negligible interference. In this effect a protocol is needed that is supported by the two networks to achieve cooperation [6].

2) *Coexistent spectrum sharing:* Coexistent spectrum sharing is a non cooperative spectrum sharing. Describing the communication between primary and secondary is not obvious and hence protocol is not supported by both systems. The effect of coexistent sharing is less the usage of spectrum sharing and to search for solution the users introduced a trade-off for minimal communication. Cooperative and coexistent spectrum sharing have been investigated through their throughput, spectrum utilization and fairness. Based on the investigation in [16], illustrated that cooperative spectrum sharing performance outcome coexistent spectrum sharing.

D. Spectrum Mobility

Spectrum mobility is another main functionality in cognitive radio network providing awareness to cognitive radio nodes. The key function of spectrum mobility is to maintain and provide seamless communication requirements during the transition to better spectrum. The cognitive radio network allows the cognitive radio to use or operate in the best available frequency band. This has however justified how the spectrum is targeted to be dynamically and efficiently utilized by the cognitive radio network. According to [11] ‘get the best available channel’ has been a concept for communication principle, which defined spectrum mobility as the method when the cognitive user changes its frequency of operation.

Spectrum mobility allows the cognitive user perform spectrum handoff by vacating ongoing communication to a not in use channel. In this topic, spectrum mobility is discussed based on spectrum handoff effect [20].

1) Spectrum Handoff

Spectrum handoff effect or process occurs usually take place in the cognitive network to shift ongoing data transmission from current channel and sought for a new free channel. This is as a result of primary user appears to take over the current channel. This eventually affect the performance of the cognitive user due to additional latency to the cognitive user communication. There are protocols for different layers of the network stack which can only be a possible compensator to the unavoidable handoff delay [14].

III. RF FRONT END CHALLENGES IN COGNITIVE RADI

A. Softtware Defined Radio (SDR) RF System

One of the most significant challenges of cognitive radio is the high-performance reconfigurable RF front-end device called software defined radio (SDR). Cognitive radio can be achieved essentially in some ways, by reconfiguration of RF front-end [21]. RF front-end reconfiguration can support several radio access technology (RAT) systems and to change its frequency and modulation in accordance with the user need. Hence, there is need for holistic approach on how efficient, tuning speed and size can the RF front-end such as antennas, filters, power amplifiers, low noise amplifiers be when designing to work as reconfigurable system [7, 22].

However, the general idea of software defined radio is to shift as much very close antenna as possible. That is the analogue domain to digital domain which is called analogue to digital converter (ADC). It is not possible in the context of cognitive radio. Cognitive radio deals with several radio access technology system and the performance of these systems is too demanding and the circuit space area will be too large [23]. Each radio access consists of a power amplifier, filter, mixer, local oscillator, and low noise amplifier, consecutively [4]. Several access radios called several nonlinear components obviously lead to excessive power consumption, dynamic range, and large circuit board size. Therefore, cognitive radio design requirements dictate the needs for reconfigurable devices. Both mobile phones and base stations must be reconfigured to the duplication of components reduce the size of the circuit board, and hence reduces the power consumptions.

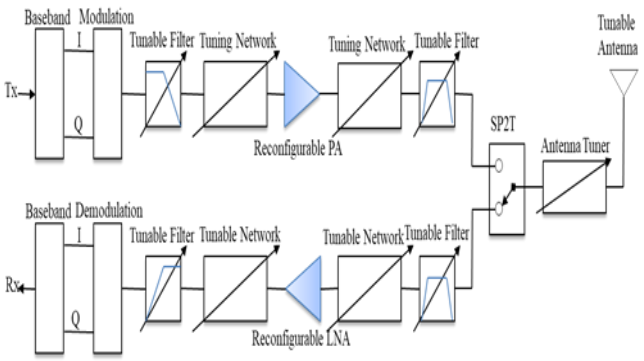

Figure 5: Block diagram of multi-standard reconfigurable wireless system

The reconfigurable RF front-end of the cognitive radio design must be efficient in high tuning speed that will change from one access radio technology to another with less power consumption and high linearity handle different modulation standard [24]. Therefore, software defined radio technology came with a solution which is efficient and reasonably inexpensive to overcome any pressing need. Software defined radio technology supports multiband, multimode and multi functional wireless systems that needs to be improved by software upgrade [25]. One of the applications of software defined radio as mentioned previously is that base station is upgradable using any standard frequency with the generic hardware system incorporated. For example, moving from system to system and new software can be uploaded and configure with no hardware upgrade [25]. Example of the system on focus can be upgraded from UMTS to HSPA or WiMAX to LTE and so on, depending on requirements.

Another interesting aspect of software defined radio (SDR) is it can be used as military venture called joint tactical radio system (JTRS) where a single hardware platform is employed by reconfiguring the software application of particular frequency for different communication purposes [11, 26, 27]. For example, during Iraq or Afghanistan war where different countries formed a coalition force to work together for one cause. Same frequency band could be reconfigured on the radio for all the military units of different countries to communicate efficiently.

B. RF Components and Impairments

The RF component for cognitive radio should be design with re-configurability to conform to any range of frequency spectrum. A block diagram of next generation transceiver system with tuning components is shown in Figure 5. The main components of the reconfigurable transceiver are the front-end and the baseband unit in the RF transmission chain. Each component of the transmitter is tunable to adjust to the time varying environment [24, 28]. The performance of most of the conventional transceiver systems get affected by the RF impairment such as power amplifier nonlinear crosstalk, in-phase/quadrature-phase imbalance, in-band and out-band distortions, inter-symbol interference (ISI), inter-block interference (IBI) and other obstacles from other components of transmitter system [29]. These problems originating from the RF components increase the symbol error rate (SER) reduce the data rate, spectral re-growth increases and resulting to channel interference. However, problems of this magnitude can cause a great deal of harm to the system performance, fast cognitive radio wideband sensing capability reduction, and challenge of accurate detection of weak signals in primary user domain [30]

C. Vandermonde – Subspace Frequency Division Multiplexing(VFDM) Scheme

VFDM is a frequency division multiplexing (FDM) technique proposed for interference cancellation in the overlay networks. The model allows cognitive radio secondary (unlicensed) network to simultaneously work with a primary (licensed) network on the same operating frequency band, and without causing any detrimental effect.

Primary networks adopt OFDM, while secondary network adopt VFDM for which both techniques are in orthogonal based frequency modulation families. It is however at large extended compatible for the overlay networks to transmit without interference, despite the absence of communication between the two systems. A special null-spaced pre-coder is used for data alignment to achieve zero interference towards a licensed system. VFDM use cyclic prefix over frequency selective channels. Frequency selectivity of the channel can provide frequency beam forming for VFDM technique. In other words, VFDM technique takes advantage of the frequency selectivity of Rayleigh fading multipath channels in tracing out transmit opportunity when channel state information

(CSI) is available at the unlicensed transmitter. By doing this, additional redundancy at the licensed transmitter eliminates the inter-symbol interference (ISI) and inter-block interference (IBI) which are caused by the multi-path behavior of the channel

IV. CONCLUSION

For years now, cognitive radio has been another area of research, since spectrum band remain a scarce resource due to poor allocation and this slows down creation of new wireless technologies. However cognitive radio was suggested to work with the existing licensed spectrum band networks to improve the global usage within the heterogeneous radio interface. The cognitive radio must adapt re-configurability to interact with all levels of radio technology. For cognitive radio to be reconfigurable, software defined radio with tunable RF front end was proposed. Different cognitive radio functionalities also investigated to mitigate the effect of transmitter interference characteristics towards the licensed spectrum band network, to increasing the accuracy in spectrum holes detection.

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