A Review of Dynamic Spectrum Networks Using Cognitive Radio

Elesa Ntuli, Fisseha Mekuria, Seleman Ngwira and Tranos Zuva

Abstract— **Future wireless networks are expected to be spectrum agile and use cognitive radio technologies. The spectrum regulatory committees have been taking measurable steps with regards to laying down the rules and implementing them, which will open the doors to dynamic spectrum network technologies based on cognitive radio. The usage of free spectrum sharing between primary users (licensed) and secondary users, being license-exempted and has been demonstrated in the recent experimental trails based on TV whitespace networks. The technique of dynamically accessing unused spectrum using Dynamic Spectrum Access (DSA) is gaining momentum. Several experimental trails on dynamic spectrum networks is being carried out in the TV-band spectrum to test the technology and enact regulations. In this paper, an overview of cognitive radio i.e. spectrum sensing, spectrum sharing, spectrum management and spectrum mobility are discussed. This paper will explore the dynamic spectrum technologies as a precursor to full-fledged cognitive radio networks.**

***Index Terms*—dynamic spectrum access, cognitive radio, Primary Users, spectrum management, wireless communication**

I. Introduction

COGNITIVE Radio technology is expected to enable dynamic spectrum networks such as TV white space networks which are being tested intensively in several countries. Software Defined Radio (SDR) lies at the heart of cognitive radio technology starting from simple function device to a radio that senses, reacts to its radio frequency operating environment and geo-location [13]. Intensive research and innovation is directed around the topic of cognitive radio and dynamic spectrum networks.

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The topic covers a range of different subject areas like Dynamic Channel Allocation (DCA), frequency assignment, spectrum coexistence together with spectrum access both to the licensed and unlicensed frequency bands though timeously spectrum remains unused, free and difficult to find. Licenses are needed to operate on a specific frequency band, up to date the spectrum allocated has not been utilized properly. Each country governs the use of radio spectrum by corresponding with government agencies. [22] have implemented real-time Dynamic Spectrum Management (DSM) algorithms, already published papers discussing triggers of DSM algorithms, management of the traffic on the used carriers radio or system that senses surrounding environment and dynamically adjust its radio parameters to communicate efficiently.

Efficient utilization can be improvised by allowing secondary user to use these licenced bands when the primary user is absent. These unlicensed Industrial Scientific and Medical (ISM) bands are a low power transmitters they severely limits the range of their services and makes them unstable for broadband connectivity in spacey populated rural areas. Whereas cognitive radio technology promises intelligent and efficient use of Radio Frequency (RF) spectrum, the TV spectrum provides a characteristic that ensures lager coverage areas for wireless access than the current Wi-Fi system.

The ITU Report of 2009 [18] mentions that, cognitive radio system employs the technology that allows the system to obtain the information of its operational RF and geographical environment, established policies and its internal state to dynamically and autonomously adjust its operational parameters and protocols according to its obtained knowledge. This will help future wireless networks, to efficiently utilize scarce spectrum resources and achieve predefined objectives, to learn from the results obtained. When considering the concept of dynamic spectrum access where a radio identifies unused, free portions of licenced spectrum and utilises the spectrum without opposing the impact on the primary licensees. This paper is arranged as follows: Section I: Introduction, Section II: Dynamic spectrum access, Section III Dynamic Spectrum Access Technology, section IV Cognitive Radio (CR), Section V Cognitive Radio Software VI Cognitive capacity Section VII TV whitespace networks and finally Section IX Concludes the paper.

II. Dynamic spectrum access

Dynamic Spectrum Access (DSA) has the goal of coexistence between primary (licensed users) and secondary (unlicensed users. The challenge is to make sure that there is sharing of the license spectrum without interference between the two users. DSA algorithms allocate unutilized frequency channels efficiently and effectively to the secondary user. Assigning different fixed bandwidth to different systems is not producing a full benefit of having dynamically shared bandwidth. [17] mentions that DSA can help to minimize unused spectrum band referred to as spectrum hole or white spaces. Cognitive Radio (CR) has one important function that the utilization of the white space must not interfere with licensed band. When the primary user wants to utilize the licensed band, the CR enabled device must make sure that the licensed band is used without interference from the secondary user who takes advantage of the white space. These CR enabled devices uses the DSA strategies shown in fig. 1

Dynamic Spectrum Access strategies can be broadly categorized under three models; *Dynamic Exclusive Use Model, Open Sharing Model and Hierarchical Access Model* as shown in fig. 1[21] discuss the DSA as:

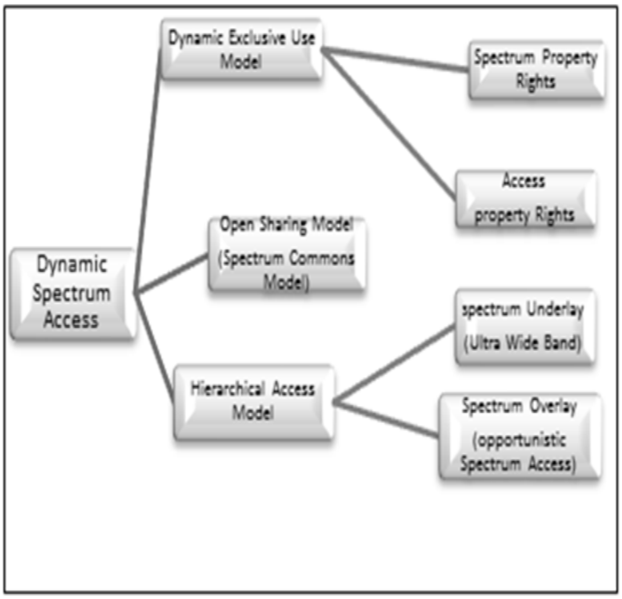

Fig. 1 Taxonomy of Dynamic Spectrum Access

A. *DYNAMIC EXCLUSIVE USE MODEL*

The basic structure of the current spectrum regulation policy is maintained in this model, the spectrum bands are licensed to services for exclusive use. The main idea is to introduce flexibility to improve spectrum efficiency. There are other two approaches under this model: Spectrum Property Rights and Dynamic Spectrum Allocation.

The first approach allows licensees to sell and trade spectrum, to freely choose technology. Licensees have the right to lease or share the spectrum for profit, such behavior is not authorized by the regulation policy. The second approach improves spectrum efficiency through dynamic spectrum assignment by exploiting the spatial and temporal traffic statistics of different services.

B. *OPEN SHARING MODEL*

Also known as spectrum commons, this model employs open sharing among peer users as the basis for managing a spectral region. Promoters of this model draw support from the remarkable success of wireless services functioning in the unlicensed Industrial Scientific and Medical (ISM) radio band.

C. *HIERARCHICAL ACCESS MODEL*

This model adopts a Hierarchical Access Structure with primary and secondary users. This model opens licensed spectrum to Secondary Users (SUs) while limiting interference perceived by primary users (licensees). The other two models under this one the spectrum underlay and the spectrum overlay. The underlay approach executes severe limitations on the transmission power of secondary users so that they operate below the noise floor of primary users by spreading transmitted signals over Ultra Wide Band (UWB). Secondary Users (SUs) can potentially achieve short-range high rate with extremely low transmission power. Based on a worst-case assumption that primary users transmit all the time, this approach does not rely on detection and exploitation of spectrum white space. This model restrict on where and when spectrum can transmit.

III. DYNAMIC SPECTRUM ACCESS TECHNOLOGY

The main enabling technology of Dynamic Spectrum Access (DSA) is the cognitive radio (CR). This cognitive radio technology provides the capability to use or share the spectrum in a dynamic or opportunistic manner. The DSA involve independent observation of radio spectrum by a secondary device, which then select and continually adapts the selected frequency band to avoid interference. This high-speed data network of the DSA type is covered by the IEEE 802.22 standard which utilizes TV white space as permitted by the FCC.

The first DSA technology allows the CR to function in the best available channel and allow the users to decide which portions of the spectrum are unused and detect the presence of licensed users as shown in fig. 2 when a user uses the licensed band the first process is called *spectrum sensing.*

The basic hypothesis model for transmitter detection can be used, mathematically, the detected signal maybe represented by the following signal model [16] as in.

$$a(b) = z(b) + y(b), \qquad (1)$$

Where a (b) is the received signal and y (b) denotes addictive white Gaussian noise. When assuming that channel occupancy follows a binary model for being either occupied or unoccupied, then the following binary hypothesis may be formulated as in.

$$a(b) = \begin{cases} s(x) & To, \\ z(b) + y(b) & T\iota, \end{cases} \qquad (2)$$

Where z (b) is the primary user's transmitted signal, y (b) is the Addictive White Gaussian Noise and channel's amplitude gain is h. T_0 is a null hypothesis, T_1 is an alternative hypothesis. then secondly it select the best available channel this process is called the *spectrum management*, then thirdly with others coordinate the access to this channel in the process called *spectrum sharing* lastly when the licensed user is sensed it vacate the channel this process is called *spectrum mobility*.

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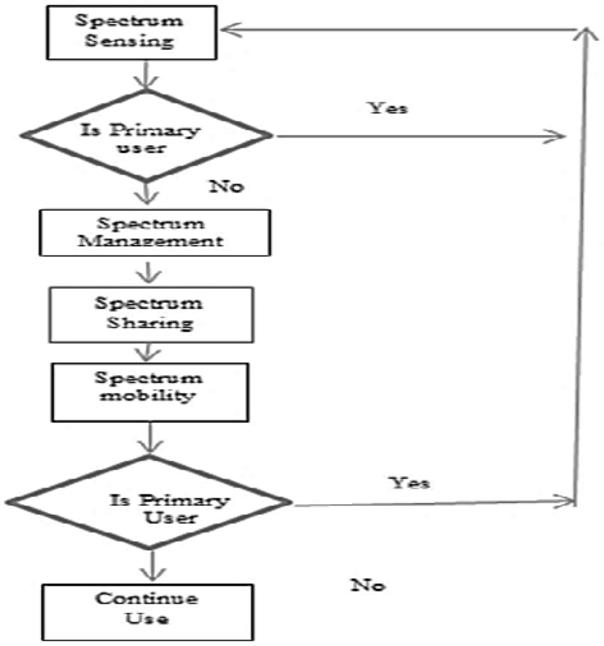

Fig. 2 Process of usage of licensed band

After the whole process the CR has a challenge to make adaptive the network protocols to the available spectrum.

IV. Cognitive Radio (CR)

In the SATRC Report, 2012 they mention one of the CR definitions as: "The CR is a radio system using technology that allows the system to obtain information about its operations and geographical environment, established policies and its internal state; to dynamically and autonomously adjust its operational parameters and protocols according to its obtained knowledge in order to achieve predefined objectives; and to learn from the results obtained."

CR is the vital technology that allows DSA to use the spectrum in a dynamic manner CR is improved by its use of spectrum resources, reduced engineering, planning time, adaptation to current operating conditions and looking at some of the features of CR includes: *sensing the current radio frequency spectrum environment, policy and configuration database, self-configuration, security, distributed collaboration, adaptive algorithms and mission-oriented configuration*. The characteristics of CR technology can be defined as;

V. Cognitive capacity

Cognitive capability enables the cognitive radio to sense the information from the radio environment in order to find out the unused radio spectrum at a specific time or location. Then the appropriate portion will be selected for the communication without coursing harmful interference to the other users.

Cognitive cycle requires adaptive operation in open spectrum access. Three major parts of the cognitive cycle are:

- ✓ Spectrum Sensing: determine which portion of spectrum is available to detect the presence of licensed users and spectrum hole. The spectrum sensing techniques are:
  - o Primary transmitter detection
  - o Primary receiver detection
  - o Interference temperature management
- ✓ Spectrum Analysis: performs estimation of spectrum hole through spectrum sensing.
- ✓ Spectrum decision: a CR determines the channel capacity, spectrum hole information along with data rate and bandwidth of the transmission. Appropriate spectrum band is chosen for transmission of the signal. Parameters to define the presentation of a particular spectrum bands are:

- o Interference – estimate permissible power of the CR.
- o Path loss - closely related to distance and frequency.
- o Wireless link errors – depending on the modulation scheme and the interference level.
- o Link layer delay – different types required at different bands.

VI. Reconfigurability

The cognitive capability provides spectrum awareness whereas Reconfigurability implies that the radio spectrum is dynamically changeable according to the surroundings of the functions.

It can transmit and receive on a variety of frequencies, use different access technologies i.e. cognitive radio can change the radio frequency, transmit mission power, modulation scheme, and communication protocol without any modification of the hardware environment. Fig. 3 explains the components of a typical cognitive radio; cognitive radio has a goal of providing adaptability to wireless transmission through dynamic spectrum so that the wireless transmission performance can be optimized, as well as the improving the utilization of the frequency spectrum.

The main function of the CR system includes the spectrum sensing, spectrum management, and spectrum mobility. After the spectrum sensing, the targeted radio spectrum information must be obtained and used by the CR user, that information is exploited by the spectrum management function to investigate the spectrum opportunities and make decisions on spectrum access. When the position of the targeted spectrum changes, the spectrum mobility function controls the change of operational frequency band for the CR users.

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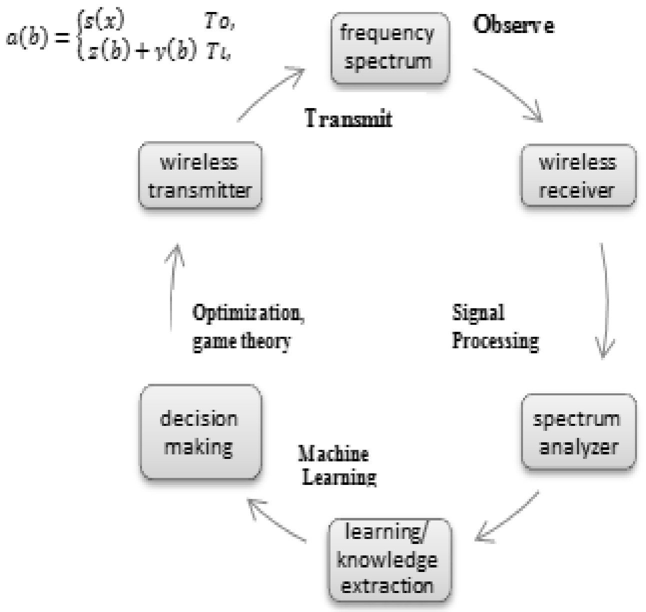

Fig. 3 Components of Cognitive Radio Node

VII. COGNITIVE RADIO SOFTWARE

The extensive software system of cognitive radio requires the basic function to perform its capabilities. A preliminary description of a possible software organisation for a cognitive radio will be discussed below, the development of cognitive radio technology is developing very fast and the function of this preliminary cognitive radio includes:

A. **The radio hardware***:* this function includes a radio frequency circuitry and signal processing device. This hardware will be able to provide a description of its capabilities to enable self-configuration.

B. **Software modules***:* Field Programmable Gate Arrays (FPGAs), Digital Signal Processors (DSPs), or embedded general purpose processors has been loaded with software modules with codes, and since these software modules, each defines its own interface to other software components. A common language to describe the interface would be very useful.

C. **Middleware***:* in this layer the middleware will attempts to reduce the details of specific devices and software modules to common abstractions. For example, setting the transmitting frequency of the radio frequency circuitry, or setting the encryption key of a software module. Creating a middleware system will require development of a common model for a wide range of hardware/software modules.

D. **Logical radio layer:** the programming will depend on the hardware and software to act like multiple radios available links. For example, the radio might support communications on several frequencies, time slots, or CDMA codes, each of which looks like an independent link. The logical radio layer implements this abstraction [24].

E. **Device manager***:* The radio configuration is being loaded by the device manager into hardware components and sets-up the logical radios.

F. **Configuration manager***:* the configurations that are available on the physical radio for rapid loading into the hardware are being determined by the configuration manager. It also interacts with modules libraries below to determine which radio modules are needed to meet user requirements.

G. **Module libraries:** the module libraries are collections of radio functions. For example, modulations (AM, FM, BPSK, QPSK, etc.), error control, encryption, and adaptive algorithms. The module libraries are built with a variety of tools (e.g. general purpose compilers, cross compilers, hardware design languages, and FPGA design tools). Coordinating the multiple sources that may go into building a specific module is a challenging task.

H. **Rules engine and policies***:* to limit the operations of the radio due to regulatory, geographical, or physical constrains the policies are used. Policies should be usable independent of a particular radio. To interpret policies and to determine the allowed operation (device managers, logical radios, middleware, and hardware drivers) a “rules engine” is used.

I. **Smart controller***:* all of the radio resources outlined above are being managed by a “smart controller”

software definition to radios brings or opens a wide range of opportunities to enhance radio communications and wireless networking services. With that flexibility a challenge to reliability and robustly manage all the components that make up a cognitive radio.

VIII. TV WHITESPACE NETWORKS

Geo-Location White Space Spectrum Databases (GL-WSDBs) is a technology that will enable the sharing of spectrum and is existing as an expert in co-occurrence planner and manager of White Space Devices (WSDs), A fixed WSDs queries the GL-WSDB to access locally available TV channels in order to build dynamic spectrum wireless broadband networks and provide broadband Internet connectivity and associated services.

TVWS technology is now inseparably connected with the concept of an enabling and monitoring database. With a geo-location database approach, the Primary User (PU) may be registered in a database and the CR user will have to first determine its location and then interrogate the databases periodically in order to find the free and available channels [6].

However, [6,17] argues that in the future, both database and spectrum sensing techniques will be used together in order to have flexibility and achieve maximum efficiency for secondary use of shared spectrum without incurring undue interference to the surrounding networks. According to [8, 16], explanation is given as how the basics of enabling and authentication spectrum database works. In short, the database combines information about spectrum in use with information about the geography of the region and performs a propagation model calculation to determine where current

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broadcasting networks coverage, reach and on which frequencies are in use.

IX. Conclusion

Spectrum sharing based on cognitive radio is expected to enable dynamic spectrum networks such as the recently proposed and experimentally tested TV white space networks [6]. This is just the beginning of a widely anticipated emergence of future wireless networks based on cognitive radio [5, 16]. Whereas the technology of full-fledged spectrum sensing based cognitive radio is in waiting spectrum sharing based on geo-location spectrum databases will dominate in the near future.

There are great benefits that cognitive radio offers to members of the radio community including spectrum regulators network device manufacturers and operators. This paper has given an overview of cognitive radio technologies, as the future development for efficient spectrum sharing in wireless networks, so called dynamic spectrum networks. Some of the challenges in cognitive radio that are remaining to be solved are: computationally efficient and accurate spectrum sensing algorithms. Furthermore, efficient management of cognitive radio devices with possible interference between primary, secondary users and also interference between secondary users.

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