Gamut sensing in cognitive radio networks: A brief survey by using the concept of design thinking

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Abstract. With an unprecedented intensification in mobile customer and mobile multimedia services radio telecommunications in general the need for more bandwidth is escalating every day. To accommodate such a large amount of wireless technologies huge bandwidth is needed. This necessitated the need to address spectrum scarcity as the spectrum is a scarce resource. But it is evident from many gamut measurement studies that much of the gamut is used in an inefficient way and its fullest potential is not exploited. This gives rise to the technology of cognitive radio networks. Having said this let us try to brief the operation of intelligent radio networks (CRN). The overview of this paper presents a detailed account of the concept of gamut sensing which a crucial step in CRN is. We address the different performance metrics related to spectrum sensing and present a brief idea of some of the research activities that are related to spectrum sensing by different researchers.

1. Introduction
In the USA, the Federal Communications Commission (FCC) is the regulatory body that assigns spectrum to licensed users. The drastic growth in the count of wireless communication technologies and the increase in the count of devices that make use of the wireless communications concept mandate more gamut resources. Most of the gamut is licensed and used for communications by companies who have paid for the spectrum. But many of the spectrum measurement statics pronounce that the spectrum that is allocated for a particular user is not fully utilized. Most parts of the gamut remain idle generally over long period and are underutilized. Particularly those assigned for television telecast remain misspent which results in gamut wastage. This is overall scenario in all parts of the world.

The above discussion paved the way for developing technologies that could make use of the licensed gamut bands by other users when the authorization customers are not using the band. This is the concept of design thinking in which the gamut sensing is the iterative process that teams use to understand users, challenge assumptions, redefine problems and create innovative solutions to Cognitive radio Networks with an acronym CRN and it involves three phases emphasize, ideate, define and it is most useful to tackle problems that are ill-defined or unknown. In user experience (UX) design, it’s crucial to develop and refine skills to understand and address rapid changes in users’ environments and behaviours. The authorization customers are known as the Primary users and the
denial customers are termed secondary users or cognitive users. It is to be understood that the secondary users that have not paid for the license can gain access to the authorized spectrum only on a temporary basis and the moment the primary user returns to transmit in its licensed band the secondary user will have to leave that particular gamut band and look for another gamut band to continue its transmission. Design teams use design thinking to tackle ill-defined/unknown problems because they can reframe these in human-centric ways and focus on what’s most important for users. The greatest challenge in the cognitive radio networks is the sharing of the most licensed spectrum in a way of not interfering with the other primary users' transmission. The temporarily unused gamut that is licensed for an authorized user is known as the gamut hole or white space [1].

The paper is planned as follows. In section 2 a short discussion of cognitive radio network components and its working is presented. In section 3 the different phases of cognitive radio technology operation that are termed as cognition cycle are addressed. In section 4 the definition and various types of gamut holes are presented. In section 5 the gamut sensing aspect which is crucial to the performance of the cognitive radio networks is detailed. In section 6 a general model for gamut sensing used by most of the spectrum sensing approaches are presented. In section 7 sensing schedule paradigms are briefed. Section 8 presents the various performance evaluation metrics of gamut sensing. In section 9 some of the research activities carried out in the area of gamut sensing are briefed.

2. Cognitive radio network components and working

The intelligent radio network consists of two major elements namely the primary network and the secondary network or the cognitive components. The Primary elements are licensed customers and they have the top priority in gaining access to the network. The secondary components are frequency-agile radios that are equipped with the characteristic to sense the environment to detect the gamut holes and adapt its transmission parameters to make transmission in the gamut holes [GH].

Cognitive capability is the radio technology captures information about the radio environment it is working. This could be achieved by the use of highly sophisticated methodologies like autonomous learning and action decision to account for variations that occur in the radio environment in temporal and spatial domains. Dynamically programming the radio elements to meet the demands of the radio environment is termed as reconfigurability. In the Cognitive radio network paradigm, it includes programming the radio elements to perform transmission and reception in different frequencies and using different transmission access technologies.

In short, the intelligent radio network is centered on the concept of obtaining the best available spectrum to perform transmission. This is made possible by the use of cognitive capability and reconfigurability. The secondary user usually alters its transmission power level and modulation methods to avoid interference. The intelligent radio network may consist of two types of architecture namely infrastructure based CRNs and Adhoc Cognitive radio networks. The infrastructure based architecture consists of a central controller called the base station similar to the one in cellular network whereas the central entity is absent on Adhoc Cognitive Networks.

3. Cognitive cycle

The basic knowledge of the working of the intelligent radio network in the introductory section let us present a brief overview of the operations that constitute the cognitive cycle.

To adapt to the dynamic spectrum environment the intelligent radio network is in need of spectrum aware operations that are named the cognitive cycle [5]. The cognitive cycle consists of four major elements namely gamut sensing, gamut decision, gamut sharing, and gamut mobility.

The phenomenon in which the secondary user or the cognitive user continuously monitors the available spectrum band in its vicinity to detect the unused portion of the licensed gamut (ie) gamut holes is gamut sensing.

On identifying the spectrum holes the cognitive radio has to decide as to select which spectrum holes considering its QOS (Quality of service) requirement. This phenomenon is named spectrum decision. Apriori information of the primary users’ activity is used in decision algorithms to incorporate dynamic spectrum characteristics. Spectrum decisions combine the processes of spectrum selection and route information. Gamut sharing is the phenomenon in which the spectrum is shared by multiple
Cognitive radios and coordinating the multiple CRs to prevent collisions. The process involves resource allocation so that interference to the primary users is neutralized. Gamut mobility is the phenomenon in which the secondary or the cognitive user, on the arrival of the Primary user needs to vacate the gamut and give it to the primary users and the CR user has to identify another spectrum hole that suits its QOS requirement to continue transmission.

4. The concept of spectrum holes

The basic need for the intelligent radio network operation is to identify the unused gamut bands that are not currently used by the authorised primary users. These unused portions are known as the gamut holes or white spaces.

The gamut holes may be named Frequency spectrum hole, Temporal gamut hole, and spatial gamut hole[6,7,8]. A frequency gamut hole is one that consists of a contiguous frequency band where the activities of the cognitive user cause no interference to the working of the Primary user.

A frequency band which a primary user does not occupy for a specific period of time is called a temporal gamut hole. A frequency band in a defined geographic region that is occupied by the primary user is the spatial gamut hole. If a cognitive user is in a region outside the defined geographic region it can gain access to this spectrum band.

Gamut holes are classified as black space, Gray space, and white space on the basis of spaces [2].

- Black spaces are the spectrum holes in which the dominance of high power interferers is found to dominate for a definite period of time.
- Gray spaces are the type of spectrum holes in which there is partial dominance of low power interferers.
- White spaces are the spectrum holes in which there is a complete absence of interferers. Broadband thermal noise and impulsive noise that belong to the category of natural noise is only present in the environment.

5. Gamut sensing

In cognitive radio technology, the unlicensed secondary users are allowed to access the limited licensed gamut band. Although the gamut can be shared only the licensed primary users are given priority to access the gamut. Hence the secondary users are mandated to monitor the activities of the primary user. Continuous monitoring is to be done to deal with the problem of interference and collisions which are crucial factors in determining the efficient performance of the cognitive radio networks. Gathering the results of the primary user’s activity is the important task of gamut sensing.

The results of gamut sensing are used by secondary users to gain access to the gamut. In a nutshell gamut sensing is the process in which the secondary users continuously monitor the activity of the primary user to detect the free bands which are called the gamut holes(GH).

Gamut sensing is a very important phenomenon for cognitive radio networks. It is very important for the cognitive radios to locate the gamut holes. Gamut sensing may be categorized as out of band sensing and in-band sensing. Out of band sensing is the sensing concept in which the secondary users look for the available unused portions of the licensed spectrum over a wide frequency range. In-band sensing is a concept in which the presence of primary users is detected by cognitive radio users in their course of monitoring the spectrum band. In-band sensing is done to mitigate the effect of interference.

Gamut sensing techniques basically aims to detect the presence or absence of the primary user. Matched filter discover [3] [4], energy discover [9], feature discover are some of the well-known gamut sensing approaches. Gamut sensing can also be carried out on the basis of the Eigen Values [10] and Momentum [11]. Autocorrelation based spectrum sensing [12] is also done in some research. Euclidian distance [13] [14] based spectrum sensing, wavelet [15] method also known as edge detection, cyclo stationary detection [16][17][18],waveform based detection, covariance-based sensing [19, 20, 21, 22] sensing based on fast sensing, learning/reasoning [23], sensing based on measurement [24], Multi taper sensing [16] [25], geolocation based sensing [26, 27] are some of the other advanced spectrum sensing methods.

The method in which the spectrum is sensed may be classified into different categories namely those that are in need of the details about the primary user in advance, those that are not dependent on the
knowledge of the primary users’ signal, those that can sense signals of the primary users operating in narrowband and those that have the capability to sense the primary users’ signal operating in broadband [28].

In short, the gamut sensing consists of three functions namely Primary user detection, sensing operation and cooperation. Primary user detection involves the cognitive radio user to collect information about the local radio environment. Having gained the knowledge of the location information of itself and its neighbors the cognitive radio user arrives at a decision as to the presence of primary user transmission and hence identifies the current gamut knowledge. Sensing control involves every intelligent radio user to participate in sensing the dynamic radio environment.

6. Sensing schedule
Sensing schedule [29] may be defined as the phenomenon that combines the concept of when to sense the channel and what means need to be considered for sensing the gamut. The sensing schedule is also a very important factor that contributes to the efficient performance of a cognitive radio network.

7. Conclusion
In this paper, we have stressed the importance of the spectrum sensing process in cognitive radio networks. We have given a detailed description of the concept of gamut holes and a generic spectrum sensing model is presented. We have also presented a note on the performance evaluation metrics of spectrum sensing and a description of a few of the many research activities that are carried out by different researchers in the area of spectrum sensing. This will give other researchers to figure out novel research problems in the spectrum sensing arena. Some of the different simulation tools available for simulating cognitive radio networks are OPNET, NETSim, MATLAB, NS2, NS3, CogNs.

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