STATE COMITEE OF COMMUNICATIONS, INFORMATIZATION AND TELECOMMUNICATION TECHNOLOGIES OF THE REPUBLIC OF UZBEKISTAN

TASHKENT UNIVERSITY OF INFORMATION TECHNOLOGIES

Approved for defence
The head of department
____
«____»__________2013г.

Graduate qualification work

on theme:

Application of cognitive radio technology in wireless networks

Graduating student ________________ **Grigoriev I.A.**

Supervisor_________________ **Kadirov A.A.**

Reviewer _______________ **Khalbaev B.A.**

Consultant on safety _______________ **Amurova N.Y.**

Tashkent 2013

STATE COMITEE OF COMMUNICATIONS, INFORMATIZATION AND TELECOMMUNICATION TECHNOLOGIES OF THE REPUBLIC OF UZBEKISTAN

TASHKENT UNIVERSITY OF INFORMATION TECHNOLOGIES

Faculty: RRT Department: Radiocommunication devices

Specialty Mobile communication systems (5524400)

Approved

the Head of department

____

« __ »______________ 2013 г.

Task

On graduate qualification work of student Grigoriev Ivan Aleksandrovich

On theme "Application of cognitive radio technology in wireless networks":

1 The theme is approved by the University order № 78-08 from 24.01.2013

2 The deadline for submission of finished work 08.06.2013г.

3 Source data for work: Literature on corresponding subject, surveys, international practice, figures and presentations featuring cognitive radio networks.

4 Contents of explanatory material (a list of issues to be considered and developed): 1. Overview of software-defined radio and cognitive radio technologies. 2. Studies on cognitive radio carried out by ITU under preparation for WRC-12.
3. Application of cognitive radio technology in wireless networks. 4. Safety of vital activity.

5 List of graphic material: Presentation material

____

____

6. Date of assignment of the task 01.02.2013

Supervisor ________________

Task is taken ______________

7. Consultants on different chapters

The name of chapter	Consultant	Signature, data	
		Task is given	Task is taken
Chapter 1	Kadirov A.		
Chapter 2	Kadirov A.		
Chapter 3	Kadirov A.		
Chapter 4	Amurova N.		

8. Schedule of works

№	The name of chapter	Deadline	Signature
1.	Overview of software-defined radio and cognitiv radio technologies.	15.02.2013	
2.	Studies on cognitive radio carried out by ITU under preparation for WRC-12.	15.03.2013	
3.	Application of cognitive radio technology in wireless networks.	15.04.2013	
4.	Safety of vital activity	15.05.2013	

Graduate student _____________ «___» ___________ 2013

Supervisor ____________ «___» ___________ 2013

This work is devoted to cognitive radio technology and its application in wireless networks. Overview of cognitive radio fundamentals, principles and techniques is presented. IEEE 802.22 as the first cognitive radio standard and two major techniques for dynamic spectrum access were considered in detail. Also calculation is provided to define detection threshold, which is necessary to protect DVB-T signal in fixed reception mode.

Данная работа посвящена технологии когнитивного радио и её применению в беспроводных сетях. Представлен обзор основных принципов и методов когнитивного радио. Детально рассмотрены стандарт когнитивного радио IEEE 802.22 и два основных метода для осуществления динамического доступа к спектру. Также проведен расчет значения порога обнаружения, необходимого для защиты сигнала DVB-T в режиме фиксированного приема.

Ushbu ish kognitiv radio tehnologiyasi va uning simsiz tarmoqlarda qo'llanishiga bag'ishlangan. Kognitiv radio asosiy printsiplari va metodlarining tahlili taqdim etilgan. IEEE 802.22 kognitiv radio standarti va spektrdan dinamik tarzda foydalanishni ta’minlashning ikki asosiy metodi batafsil ko’rib chiqilgan. Shuningdek, qo’zg’almas qabul rejimida DVB-T signalining himoyasini ta’minlash uchun zarur bo'lgan aniqlash ostonasi hisoblangan.

CONTENTS

INTRODUCTION

The evolution of broadcasting, digital television and wireless communication systems in the world is going on rapidly and issues of frequency spectrum efficiency is becoming more and more important. With the increasing demand of wireless application, the insufficiency of spectrum is more and more serious; on the contrary, the utilization of some licensed spectrum is always low.

President of Uzbekistan Islam Karimov, in his report at the meeting of the Cabinet of Ministers dedicated to the socio-economic development in 2012 and the most important priorities of economic program for 2013, noted that: «Accelerated implementation of measures and projects in the sphere of information, communication and telecommunication technologies becomes increasingly important. We must realize that without a radical move towards introduction of modern information and communication systems in all sectors of the economy, in our everyday life, it is difficult to see the future. We need to eliminate the backlog by many kinds of information services and reach the rank of advanced countries with a high level of information and communication technologies as soon as possible» [1].

To date, the main mechanism for spectrum allocation is based on licensing, which means fixing a particular frequency band or a nominal frequency for the particular user. At the moment, practically the entire frequency range is allocated and licensed. But the experience of countries reveals insufficient effectiveness of these mechanisms to access the spectrum in conditions of rapidly evolving technologies, and radio applications.

Mechanism of dynamic spectrum management or dynamic spectrum access (DSA) can significantly improve the efficiency of spectrum use. Results of research conducted within the ITU-R showed that the introduction of technology of software-defined radio with use of cognitive control mechanisms (cognitive radio) is one of the approaches to ensure more efficient use of the radio spectrum due to the dynamic and flexible management. One example of this approach is that the secondary stations or users for which the band was not originally granted, are given the opportunity to use a frequency range granted to primary users if this range is not used by the primary user at the moment. To date, this approach can be achieved by implementing of programmable radio and cognitive radio technologies.

Therefore, the study of cognitive radio technology, its features and application issues is of high importance to achieve more efficient spectrum use.

This work is devoted to the investigation of cognitive radio technology and its application in wireless networks, the consideration of studies on cognitive radio at international level and analysis of issues of implementation and protection of existing services, especially broadcasting service.

1 OVERVIEW OF SOFTWARE-DEFINED RADIO AND COGNITIVE RADIO TECHNOLOGIES

1.1 Software-defined radio as a basis for cognitive radio implementation

1.1.1 General remarks

Software defined radio (SDR) is the key technology enabler for cognitive wireless networks [2]. SDR technology brings radio electronics into the digital age [3], thus opening up many new degrees of freedom in wireless system design.

Reconfigurability in radio development is not such a new technique as one might think. Already during the 1980s reconfigurable receivers were developed for radio intelligence in the short wave range. These receivers included interesting features like automatic recognition of the modulation mode of a received signal or bit stream analysis.

We refer to a transceiver as a software radio (SR) if its communication functions are programmable. Based on the same hardware, different transmitter/receiver algorithms, which usually describe transmission standards, are implemented in software.

A software-defined radio (SDR) is a practical version of an SR: the received signals are sampled after a suitable band selection filter [4].

The basic concept of the SDR is that the radio can be totally configured or defined by the software so that a common platform can be used across a number of areas and the software used to change the configuration of the radio for the function required at a given time. There is also the possibility that it can then be re-configured as upgrades to standards arrive, or if it is required to meet another role, or if the scope of its operation is changed.

The SDR concept is equally applicable for the commercial world as well. One application may be for cellular base stations where standard upgrades frequently occur. By having a generic hardware platform, upgrades of standards can easily be incorporated. Migrations for example from UMTS to HSPA and on to LTE could be accommodated simply by uploading new software and reconfiguring it without any hardware changes, despite the fact that different modulation schemes and frequencies may be used.

There are many opportunities for considering the use of the SDR concept. As time progresses and the technology moves forward, it will be possible to use the concept in new areas and also for cognitive radio implementations.

1.1.2 SDR definition

Many definitions have appeared that might cover a definition for a SDR. The SDR Forum themselves have defined the two main types of radio containing software in the following fashion:

- ***Software Controlled Radio:*** Radio in which some or all of the physical layer functions are Software Controlled. In other words this type of radio only uses software to provide control of the various functions that are fixed within the radio.
- ***Software Defined Radio:*** Radio in which some or all of the physical layer functions are Software Defined. In other words, the software is used to determine the specification of the radio and what it does. If the software within the radio is changed, its performance and function may change.

International Telecommunication Union (ITU) defines SDR as follows:

- ***Software-defined radio:*** A radio transmitter and/or receiver employing a technology that allows the RF operating parameters including, but not limited to, frequency range, modulation type, or output power to be set or altered by software, excluding changes to operating parameters which occur during the normal pre-installed and predetermined operation of a radio according to a system specification or standard.

1.1.3 Levels of SDR design

It is not always feasible or practicable to develop a radio that incorporates all the features of a fully software defined radio. Some radios may only support a number of features associated with SDRs, whereas others may be fully software defined.

SDR Forum was established as an Industry Organization to address SDR technology on 1995 and now it is called the Wireless Innovation Forum, WINNF.

In order to give a broad appreciation of the level at which a radio may sit, the SDR Forum has defined a number of tiers.

These tiers can be explained in terms of what is configurable.

- Tier 0: A non-configurable hardware radio, i.e. one that cannot be changed by software.

- Tier 1: A software controlled radio where limited functions are controllable. These may be power levels, interconnections, etc. but not mode or frequency.

- Tier 2: In this tier significant portion of the radio is software configurable, including frequency, modulation and waveform generation / detection, wide/narrow band operation, security, etc. The RF front end still remains hardware based and non-reconfigurable.

- Tier 3: The ideal software radio where the boundary between configurable and non-configurable elements exists very close to the antenna, and the "front end" is configurable. It could be said to have full programmability.

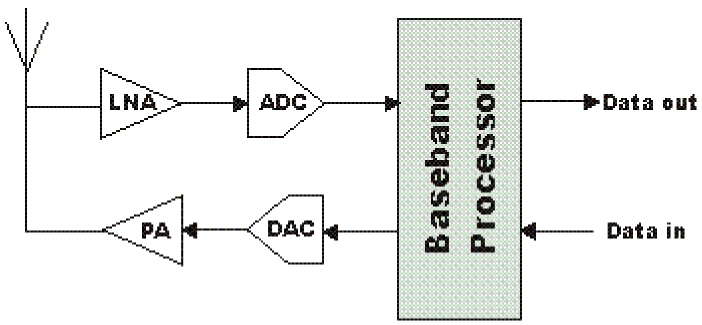


Figure 1 - Block diagram of an 'Ideal' Software Defined Radio

- Tier 4: The ultimate software radio is a stage further on from the Ideal Software Radio. Not only does this form of software defined radio have full programmability, but it is also able to support a broad range of functions and frequencies at the same time. With many electronic items such as cellphones having many different radios and standards a software definable multifunction phone would fall into this category.

1.1.4 Principles of SDR design

The conventional heterodyne radio receiver shown in Figure 2, has been in use for nearly a century. Let's review the structure of the analog receiver so comparison to a digital receiver becomes apparent [5].

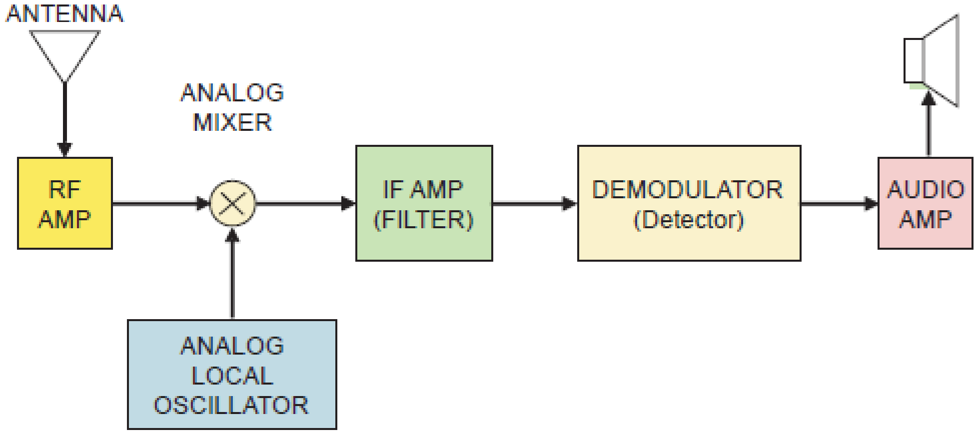


Figure 2 - Analog Radio Receiver Block Diagram.

First the RF signal from the antenna is amplified, typically with a tuned RF stage that amplifies a region of the frequency band of interest. This amplified RF signal is then fed into a mixer stage. The other input to the mixer comes from the local oscillator whose frequency is determined by the tuning control of the radio. The mixer translates the desired input signal to the IF (Intermediate Frequency) as shown in Figure 3.

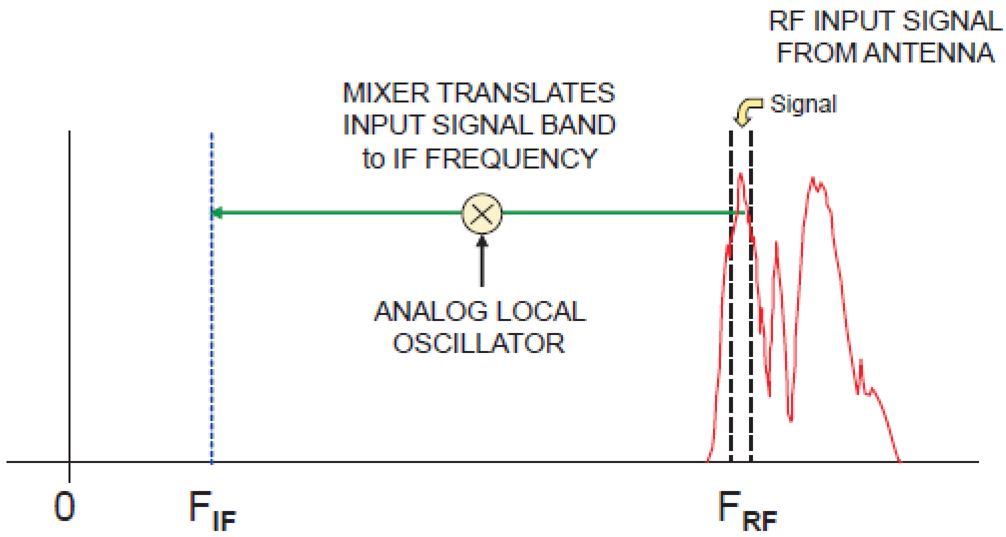


Figure 3 - Analog Radio Receiver Mixer.

The IF stage is a bandpass amplifier that only lets one signal or radio station through. Common center frequencies for IF stages are 455 kHz and 10.7 MHz for commercial AM and FM broadcasts.

The demodulator recovers the original modulating signal from the IF output using one of several different schemes. For example, AM uses an envelope detector and FM uses a frequency discriminator. In a typical home radio, the demodulated output is fed to an audio power amplifier which drives a speaker.

The mixer performs an analog multiplication of the two inputs and generates a difference frequency signal. The frequency of the local oscillator is set so that the difference between the local oscillator frequency and the desired input signal (the radio station you want to receive) equals the IF.

For example, if you wanted to receive an FM station at 100.7 MHz and the IF is 10.7 MHz, you would tune the local oscillator to 100,7 - 10,7 = 90 MHz.

This is called “downconversion” or “translation” because a signal at a high frequency is shifted down to a lower frequency by the mixer.

The IF stage acts as a narrowband filter which only passes a “slice” of the translated RF input. The bandwidth of the IF stage is equal to the bandwidth of the signal (or the “radio station”) that you are trying to receive.

For commercial FM, the bandwidth is about 100 kHz and for AM it is about 5 kHz. This is consistent with channel spacings of 200 kHz and 10 kHz, respectively.

1.1.5 SDR receiver

Figure 4 shows a block diagram of a software SDR Receiver Mixer defined radio receiver. The RF tuner converts analog RF signals to analog IF frequencies, the same as the first three stages of the analog receiver.

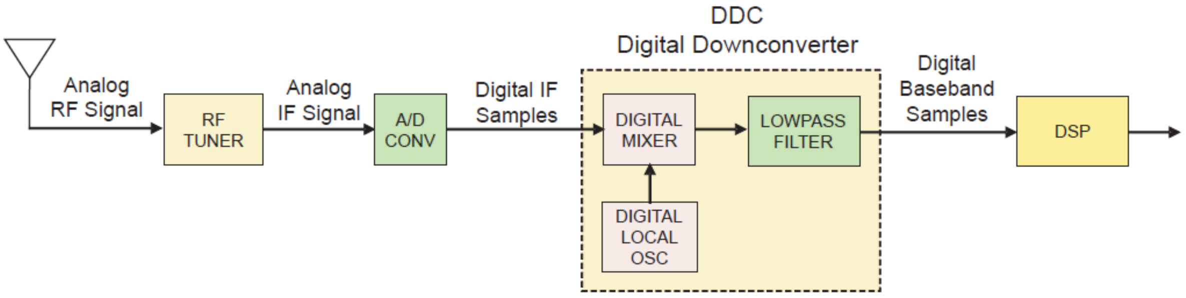


Figure 4 - SDR Receiver Block Diagram.

The A/D converter that follows digitizes the IF signal thereby converting it into digital samples. These samples are fed to the next stage which is the digital downconverter (DDC) shown within the dotted lines.

The digital downconverter is typically a single monolithic chip or FPGA IP, and it is a key part of the SDR system.

A conventional DDC has three major sections:

• A digital mixer

• A digital local oscillator

• An FIR lowpass filter

The digital mixer and local oscillator translate the digital IF samples down to baseband. The FIR lowpass filter limits the signal bandwidth and acts as a decimating lowpass filter. The digital downconverter includes a lot of hardware multipliers, adders and shift register memories to get the job done.

The digital baseband samples are then fed to a block labeled DSP which performs tasks such as demodulation, decoding and other processing tasks.

Traditionally, these needs have been handled with dedicated application specific ICs (ASICs), and programmable DSPs.

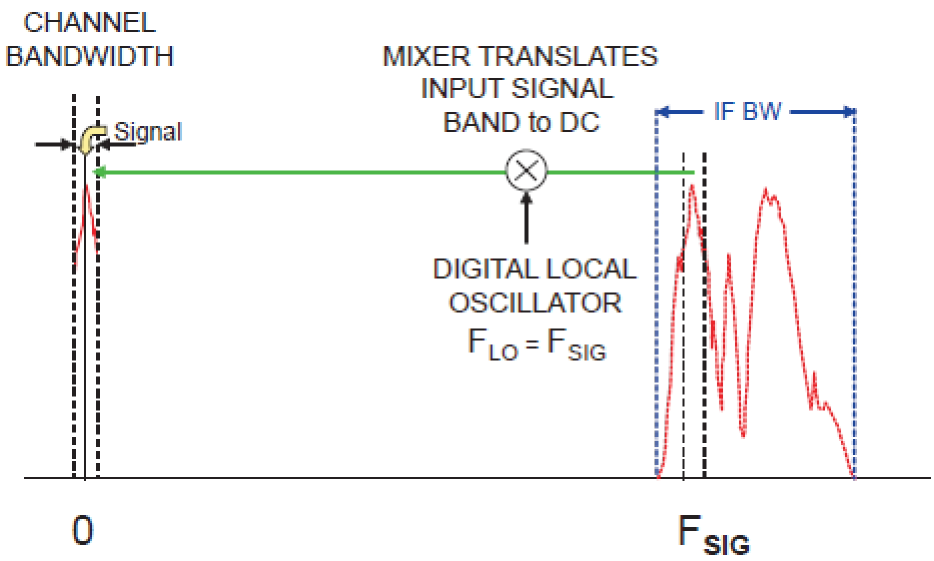


Figure 5 - SDR Receiver Mixer.

At the output of the mixer, the high frequency wideband signals from the A/D input (shown in Figure 5 above) have been translated down to DC as complex I and Q components with a frequency shift equal to the local oscillator frequency.

This is similar to the analog receiver mixer except *there*, the mixing was done down to an IF frequency. *Here*, the complex representation of the signal allows us to go right down to DC. By tuning the local oscillator over its range, any portion of the RF input signal can be mixed down to DC. In effect, the wideband RF signal spectrum can be “slid” around 0 Hz, left and right, simply by tuning the local oscillator. Note that upper and lower sidebands are preserved.

1.1.6 SDR transmitter

The input to the transmit side of an SDR system is a digital baseband signal, typically generated by a DSP stage as shown in Figure 6.

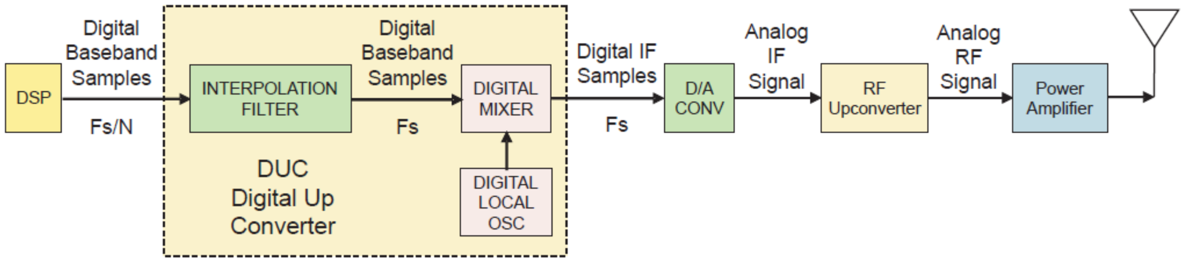


Figure 6 - SDR Transmitter Block Diagram.

The digital hardware block in the dotted lines is a DUC (digital upconverter) that translates the baseband signal to the IF frequency. The D/A converter that follows converts the digital IF samples into the analog IF signal. Next, the RF upconverter converts the analog IF signal to RF frequencies. Finally, the power amplifier boosts signal energy to the antenna.

1.1.7 SDR receiver example

In this section we provide an example architecture of SDR receiver, which represents a fully integrated 90 nm CMOS receiver operating in the 800 MHz to 5 GHz band [6]. Unlike the classical SDR paradigm, which digitizes the whole spectrum uniformly, this receiver acts as a signal conditioner for the analog-to-digital converters, emphasizing only the wanted channel. Thus, the ADCs operate with modest resolution and sample rate, consuming low power. This approach makes portable SDR a reality.

The example receiver operates as a signal conditioner to shape the composite band incident to the front-end, which comprises different standards including the desired channel, so that the ADC digitizes the desired channel with high fidelity. Frequency downconversion is indispensable, and zero-IF direct conversion is the most suitable choice for its high flexibility and low image rejection requirements. This software-defined radio receiver is intended to tune and detect any desired channel in the 800 MHz–5 GHz band therefore, it cannot have any meaningful RF preselect filter (Fig. 7).

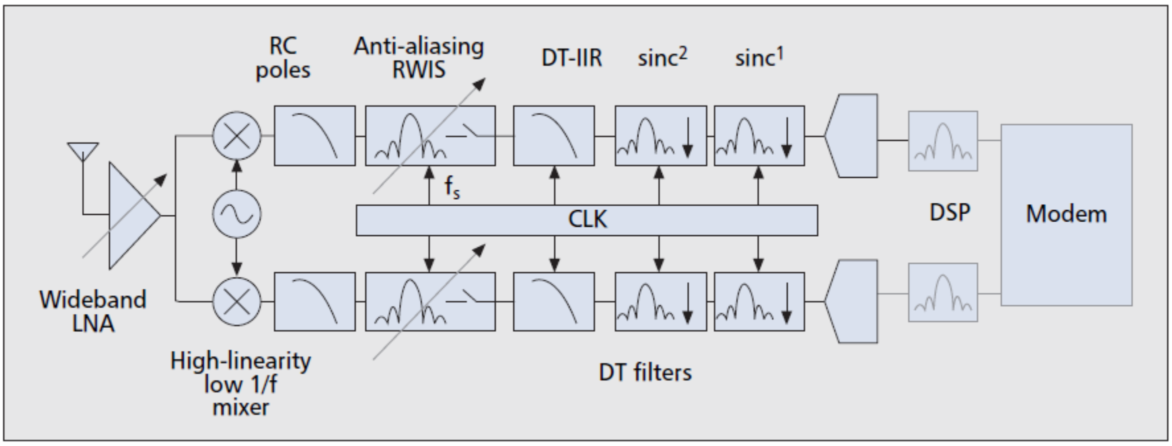


Figure 7 - Proposed SDR architecture.

The entire band is amplified by the wideband low-noise amplifier (LNA) uniformly. A complex mixer driven by a wide tuning-range synthesizer tunes the bandwidth of interest to zero IF. The zero IF architecture mandates high second-order linearity and low flicker noise for the mixer.

The zero IF channel bandwidth varies from 100 kHz of GSM standard to 8 MHz in 802.11g WLAN. This channel is accompanied on either side by a very wide array of unwanted signals. Therefore, a strong anti-aliasing filter has to be implemented. Moderate suppression is also needed at non-aliasing frequencies.

Key circuit blocks for this SDRX are wideband LNA, highly linear low-flicker mixer, wide tuning range synthesizer, and programmable anti-aliasing filters.

1.1.8 SDR Generalized architecture

Standardized Hardware Architecture developed by SDR Forum is shown in Figure 8.

SDR defines a collection of hardware and software technologies where some or all of the radio’s operating functions (also referred to as physical layer processing) are implemented through modifiable software or firmware operating on programmable processing technologies.

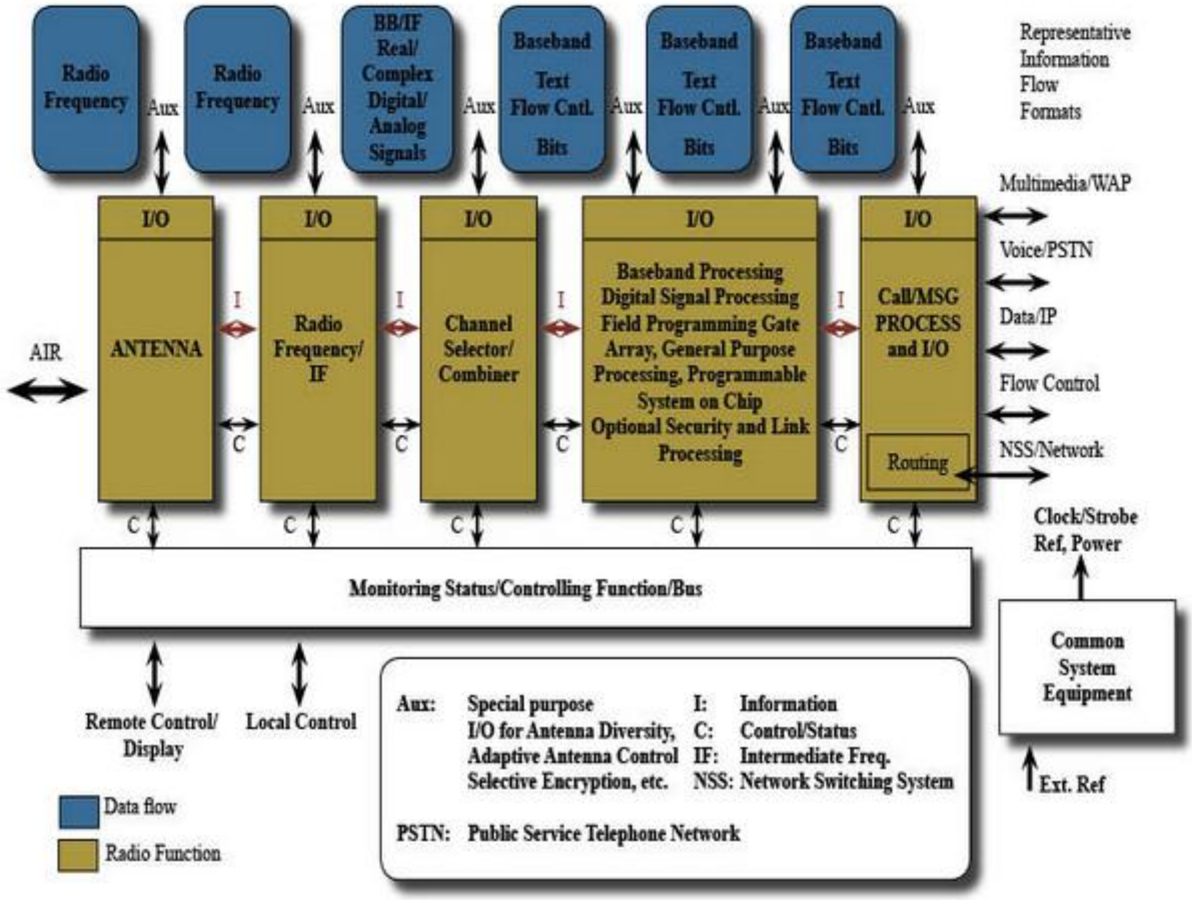


Figure 8 - Generalized Functional Architecture of SDR (Standardized Hardware Architecture by SDR Forum [7]).

These devices include field programmable gate arrays (FPGA), digital signal processors (DSP), general purpose processors (GPP), programmable System on Chip (SoC) or other application specific programmable processors. The use of these technologies allows new wireless features and capabilities to be added to existing radio systems without requiring new hardware.

1.2 Theory and principles of cognitive radio

1.2.1 General remarks

A *cognitive radio* (CR) is an SDR that additionally senses its environment, tracks changes, and reacts upon its findings.

A CR is an autonomous unit in a communications environment that frequently exchanges information with the networks it is able to access as well as with other CRs [4].

The concept of cognitive radio is proposed first by Mitola [8], and the language for cognitive function is investigated in [9]. In [10], the detailed expositions of signal processing and adaptive procedures are presented. In [11], the major characteristics of cognitive radio networks arc presented from physics layer to transport layer, as well as cross-layer dcsign.

When cognitive radio is proposed, an intelligent communication technology is expected, including observe, orient, plan, learn, decide and act [8][10].

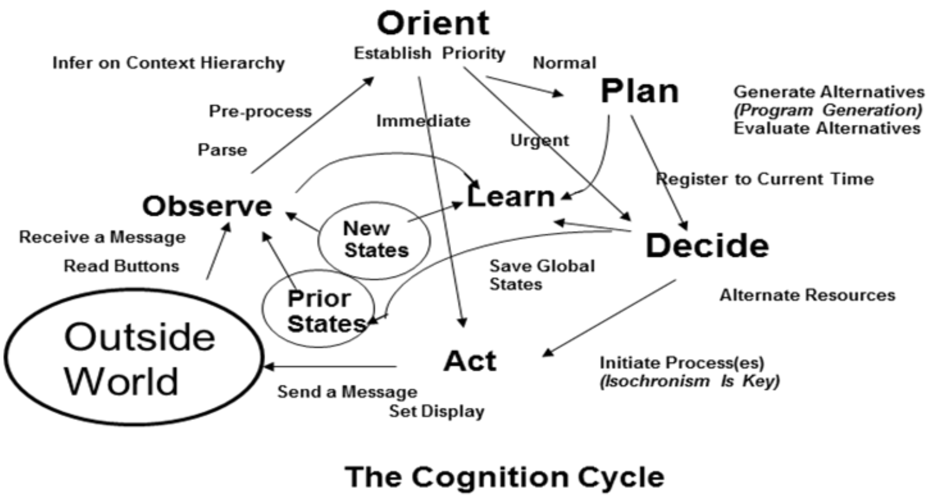


Figure 9 - Observe, orient, plan, learn, decide and act, OODA mechanism.

The basic idea of the initial cognitive cycle is concluded as Figure 9. The receivers obtain the channel quality information and the interference information from the surrounding radio environment by observing. After the transmitters receive the necessary feedback information from their corresponding receivers, they determine the strategies, which react to the radio environment. For more intelligent function, machine learning is adopted for estimating the utilities of possible strategies to improve system performance.

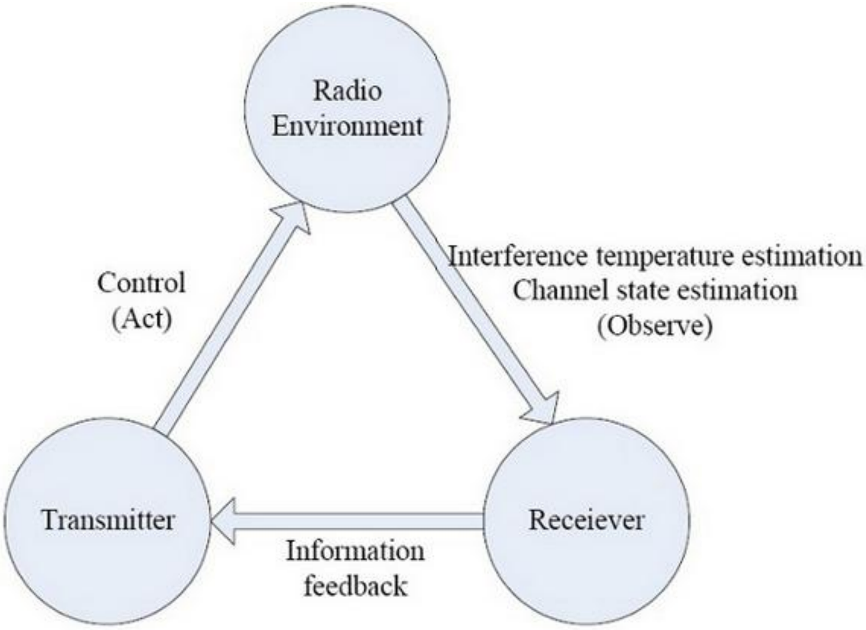


Figure 10 - Initial cognitive cycle.

Based on the initial cognitive cycle model, cognitive radio is studied to be utilized further for spectrum sharing between licensed/primary users and unlicensed/secondary users in licensed spectrum. In that case, the secondary users are not allowed to cause too large interference that may interrupt the communication or decrease the service quality of primary users.

In the dynamic spectrum model [12], it is assumed that the primary users may not always use the spectrum. Hence, the secondary users can opportunistically utilize the spectrum when it is not being occupied by the primary users, as shown in Figure 2. According to the primary users' spectrum usage pattern, based on the experimental results in [13] and [14], the spectrum usage can be modelled as an ON-OFF process: ON (OFF) state represents when the spectrum is occupied (unoccupied) by primary users. The spectrum dynamics can be modelled as a semi-Markov process as in [15].

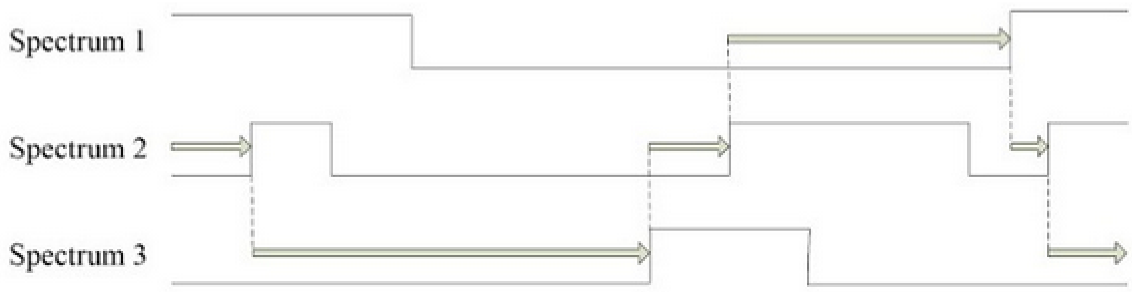


Figure 11 - Dynamic spectrum model.

In this model, with perfect spectrum sensing, which means that the secondary users detect the spectrum status error-freely and justify the status in time if some primary user comes back, the secondary users and primary users do not interfere with each other. The research challenge focuses on how to discover and utilize the spectrum opportunities more efficiently. Considering the error of spectrum sensing, the possible interrupt to primary users should be investigated. The schemes need to achieve a balance of the tradeoff between the utility of secondary users and the influence to primary users.

1.2.2 Interference temperature model

In the interference temperature model [16], both primary and secondary users can co-exist on the same spectrum. The secondary users' interference to the primary receivers should not exceed a threshold. Interference temperature is introduced into cognitive radio by Federal Communications Commission (FCC) as a metric for the measurement of interference in a radio environment. In order to prevent the negative impact to the primary users, the interference temperature limit is used to indicate the allowed worst RF environment. In order to protect the primary users' communications, the interference caused by secondary users must be kept below the interference temperature limit at the primary receivers. That is, the primary users' Quality-of-Service (QoS) is considered acceptable if the secondary users' interference is kept below a given interference temperature limit. The maximum interference tolerance can be calculated as following:

$$Q_{max} = \xi \, T_{max}$$

where ξ - Boltzmann's constant,

T_{max} - the interference temperature limit.

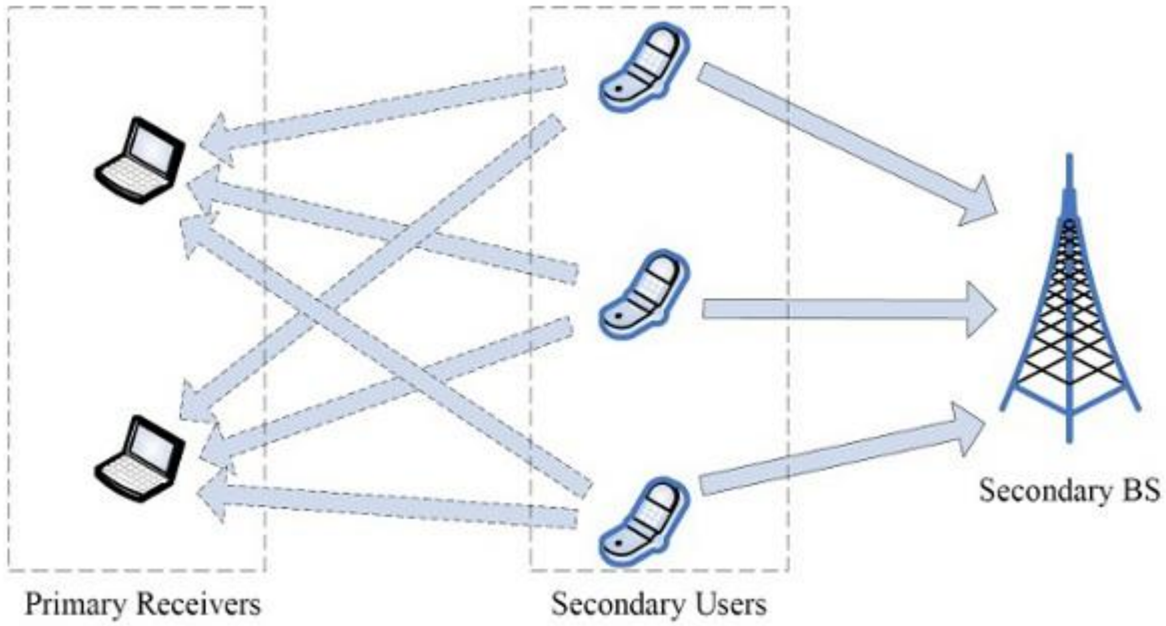


Figure 12 - Interference temperature model

In [17] the capacity of cognitive user is analyzed with the assumption that the cognitive user estimates the statistic results of its interference to the primary user through various fading channels. The average and peak interference constraints are considered respectively in [17]. With this model, an extra interference temperature constraint is added into the problems compared with conventional wireless communication systems, as shown in Figure 12.

1.2.3 Cognitive cooperation

In [18] and [19], it is assumed that the cognitive user can obtain and transmit the messages that the primary user will send. The capacities of both primary users and secondary users are obtained. Based on these, [20] analyzes the capacity of a cognitive user who transmits simultaneously with a primary user, in the condition that the primary user can achieve the data rate just as it would in the absence of the cognitive radio user. [21] extends the results of [20] to multiple access channels (MAC) and gives a heuristic scheme to achieve the maximum sum-rate.

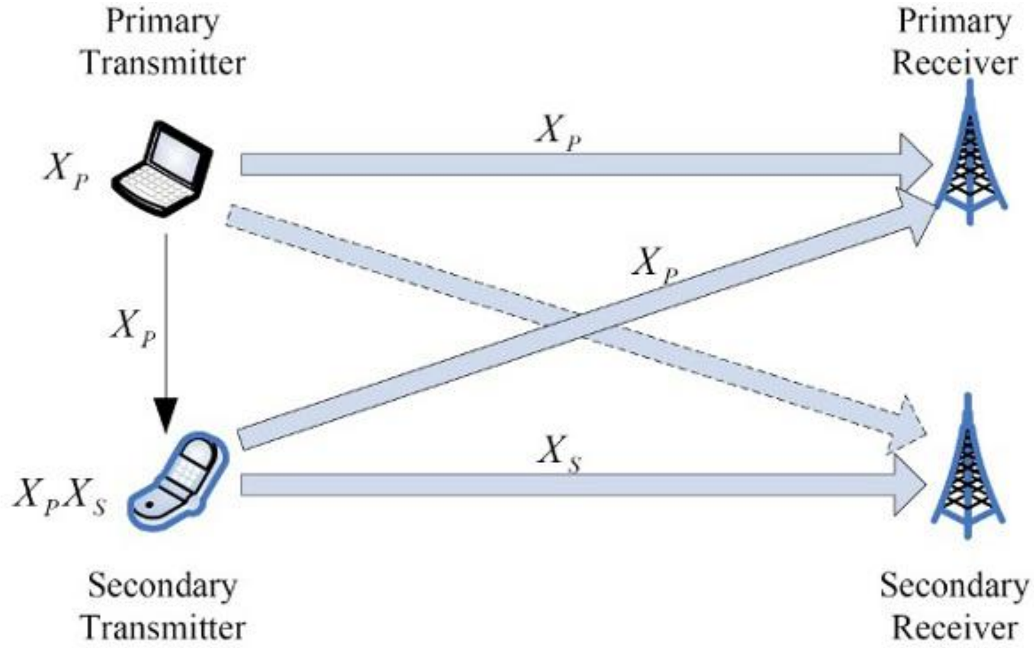


Figure 13 - Cognitive cooperation model

In this model, there exists a tradeoff that the secondary transmitter sends primary data or secondary data, as shown in Figure 13. Transmitting primary data can increase the primary throughput and improve the capability of interference tolerance of primary users. On the other hand, transmitting secondary data can increase the secondary throughput and decrease the interference to primary users.

1.2.4 PHY-layer spectrum sensing

Spectrum sensing is a neccesary technology of cognitive radio. With efficient spectrum sensing, the spectrum opportunities could be discovered. From PHY-layer view, the spectrum sensing can be divided into three categories, non-coherent detection, coherent detection and feature detection [22].

The most usual non-coherent detection method is energy detection. The advantages of energy detection are short sensing time and low complexity. In addtion, it does not need any aprior information. However, because of the uncertainty of noise, there exists a SNR wall. The signal can not be detected if its

SNR is lower than the SNR wall. As the signal is detected according to the signal strength, it can not distinguish different kinds of signal.

When the signal has the corresponding pilot, the coherent detection can be adopted. The matched filter is one of the coherent detection methods, but the performance is affected by high complexity, unstable time clock and the length of pilot. Because of these factors, the implement is limited in practice.

Feature detection utilizes the properties of signal to detect whether there is any primary user nearby. As the signal has periodic features because of frame structures but the noise does not have any period, cyclostationary detection can be used to distinguish the signal and the noise. Using pattern recognition, different kinds of signal can be distinguished by comparing the cyclostationary properties of the detected signal with aprior known signal properties. Although the performance is better than energy detection, the SNR wall still exists. If the signal strength is not too low, the signal can be recognized from the unstable noise.

1.2.5 MAC-layer spectrum sensing

On spectrum sensing, there exists a tradeoff between sensing time and sensing veracity. The sensing methods which have high veracity always need long sensing time. A two-level spectrum structure is proposed to balance the tradeoff between these two aspects. Energy detection is adopted to discover primary users cursorily. Then, if it is possible that there exists any primary user, more elaborate spectrum sensing is deployed.

Because of the fading effect, the spectrum sensing results of one user is not always accurate. Therefore, the cooperation between secondary users is necessary [24]. There are two kinds of cooperation, centralized cooperative spectrum sensing and distributed cooperative spectrum sensing.

In centralized cooperative spectrum sensing, a centralized controller collects the sensing results from different users, and fuses the collected data altogether to obtain a table for available spectra. The results obtained by centralized cooperative spectrum sensing are accurate relatively, but it needs long sensing time, large computational capability and heave overhead.

Distributed cooperative spectrum sensing lets each user detect the signal and obtain the table of available spectrum respectively. By communicating with the neighbour users, the chosen spectrum is determined. How to sense the spectrum accurately by exchanging limited information is still an open problem.

1.2.6 Radio resource allocation

Dynamic spectrum management is an efficient method to avoid the interference between primary users and secondary users. When some spectrum is idle, the cognitive radio systems choose the spectra which have low interference. If the primary users come back to use the spectrum occupied by secondary users, the cognitive radio systems should obtain the information in time. Based on the information, the secondary users choose another spectrum from the candidate spectrum set, or decrease the transmit power to avoid too large interference to primary users if there is no other candidate spectra.

In cognitive radio networks, the power control schemes need to consider not only their own utilities, but also the influence to primary users. Game theory is an efficient method for distributed power control. Spectrum allocation and power control affect each other, so joint spectrum allocation and power control are investigated [23]. For multi-hop networks, routing is also an important issue. The performance of cognitive radio networks can be optimized by designing appropriate routing, spectrum allocation and power control schemes.

1.2.7 Spectrum marketing

On spectrum pricing, a framework for coordinating dynamic spectrum is proposed. In [25], the dynamic pricing strategy is proposed for competitive agile spectrum access markets. Sharply value in cooperative game is used to evaluate the contribution of each system in spectrum marketing. The investigation on spectrum pricing is also introduced into IEEE 802.22 standardization.

On the contrary of spectrum pricing, spectrum auction [26] is also a practical way for spectrum marketing. Each system announces a price to other systems according to the utilities and costs if it can win the auction and get the spectrum.

Based the economic theory, the systems can approach the optimal performance by maximizing their own profits.

1.2.8 Application and standardization

Cognitive radio is used widely in several areas of wireless communication. In [27], the application of cognitive radio in wireless emergence networks is investigated combined with relaying to enhance the coverage performance in the disasters. In [28], cognitive radio is employed for military application.

IEEE 802.22 is the first wireless standard applying cognitive radio. The secondary users use TV spectrum to improve the spectrum utilization, when it is unoccupied by nearby TV transmitters. Besides IEEE 802.22, other wireless standardization, such as IEEE 802.11n and IEEE 802.16h, also adopt cognitive radio for interference coordination among users in the same system, rather than between two systems. Many researchers are trying to use the idea of cognitive radio in LTE networks.

Summary to the chapter 1

As we have seen SDR is not a young technology as it has been used in military applications for a long time. But as for commercial applications this technology is considered young and dynamically developing. Required DSP components are evolving and becoming more affordable for mass market. As it can be seen complexity of design is lower for SDR compared to traditional solutions while advantages of SDR are on demand. SDR products and technology are a reality today.

SDR design principles were considered comparative to conventional radio. A general hardware architecture is presented.

SDR is the key technology enabler for cognitive wireless networks.

Some models which are developed to characterize cognitive radio were considered. Cognitive radios have the ability to implement protocols and policies beyond traditional communications.

2 STUDIES ON COGNITIVE RADIO CARRIED OUT BY ITU UNDER PREPARATION FOR WRC-12

2.1 Description of agenda item 1.19 of WRC-12

Over twelve years ago, World Radio Communication conference of 1997 (WRC-97) introduced the definition of ***adaptive systems*** in the Radio Regulations. Such systems were limited to the medium and high frequency bands where propagation conditions vary significantly. Adaptive systems were capable of modifying their parameters, including frequency and power, in order to improve the quality of reception.

WRC-97 adopted Resolution 729 on the "Use of frequency adaptive systems in the MF and HF bands", which called for further studies on the issue with their results to be reported to a future WRC. The resolution introduced regulatory elements for adaptive systems, prohibiting their operation in the bands used by safety services as well as by the radio astronomy, radiodetermination, amateur and broadcasting services.

Further technological developments enlarged the capabilities of adaptive systems. In this respect, an important role is played by software, which makes it possible to analyse the radio environment and adjust system characteristics to specific operational situations. Such a combination of radio equipment and software offers new solutions for resolving the problem of frequency congestion and improves the overall efficiency of spectrum use. Following these technological advances, the two new concepts of software-defined radio (SDR) and cognitive radio systems (CRS) were created.

By the WRC-07, a common concern within ITU-R was the protection of existing services from potential interference from SDR and CRS systems. Consequently, WRC-07 adopted new agenda item 1.19 requiring WRC-12 to consider regulatory measures for the introduction of SDR and CRS.

1.19 *«to consider regulatory measures and their relevance, in order to* *enable the introduction of software-defined radio and cognitive radio systems, based on the results of ITU R studies, in accordance with Resolution **956 (WRC 07)**».*

In this regard, WRC-07 adopted Resolution **956 (WRC-07)** [29] «Regulatory measures and their relevance to enable the introduction of software-defined radio and cognitive radio systems», inviting ITU-R to study the need for regulatory measures related to the application of SDR and CRS. The resolution also resolved that WRC-12 should consider the results of the studies and take the appropriate actions. The task of conducting the necessary studies was assigned to ITU-R Working Party 1B.

By April 2010, Working Party 1B had reached common views on many related issues. It was recognized that SDR and CRS are technologies and not radiocommunication services. These technologies can be used in any radiocommunication service.

SDR and CRS are to comply with the provisions of the Radio Regulations applicable to the service under which they operate.

In addition, Working Party 1B established the definitions for these two technologies, which are given (over) in a simplified form.

It was also emphasized that the introduction of SDR and CRS should not impose additional constraints on other services sharing the same frequency band.

The definition of cognitive radio adopted by ITU is given in ITU-R Report 2152 [30] and sounds as follows:

Cognitive radio systems: *a radio system employing a technology, which makes it possible to obtain knowledge of its operational environment, policies and internal state, to dynamically adjust its parameters and protocols according to the knowledge obtained and to learn from the results obtained*.

Cognitive radio system (CRS) uses a technology to gain knowledge about its operating and geographical environment, the steady rules and its internal status; dynamically and autonomously adjusts its operational parameters and protocols according to the received knowledge in order to achieve pre-set goals and learns from the results [31]. Thus, CRS looks for free bandwidth and the ability to work without disturbing others and without breaking the rules of use of the frequency bands.

The analysis of the results of the studies and methods proposed for WRC-12 agenda item 1.19 have been reflected in text of the Conference Preparatory Meeting [32].

With respect to SDR, it was concluded that no changes to the Radio Regulations are necessary in order to introduce this technology. The current regulations can encompass the implementation of SDR. Technical and operational considerations related to SDR will be addressed in ITU-R Recommendations and Reports [32].

The situation regarding CRS is different. For cognitive radio systems, there were two views. The first view was that no changes were needed to the Radio Regulations (Method B1 Option A); however, there is an option to develop an ITU R Resolution to provide guidance to the ITU-R for future studies on cognitive radio systems (Method B1 Option B). The second view (Method B2) supported the development of a WRC Resolution to provide guidance for future studies and guidance for the implementation of cognitive radio systems and with no further changes to the Radio Regulations. All methods support the suppression of Resolution 956 (WRC-07). [32].

The studies have identified important aspects related to the introduction of SDR and CRS. In the case of Land mobile service, spectrum is getting congested, e.g. due to the rapidly increasing Internet/data traffic and the need of broader bandwidth. CRS technologies may yield significant benefits by providing increased spectral efficiency of existing spectrum and mitigate the problem of congestion (e.g. capacity gain). IMT systems may, for example, in the future employ CRS and utilize the benefits of CRS such as mitigation of congested spectrum usage.

A common concern within the ITU-R is the protection of existing services from potential interference from the services implementing CRS technology, especially from the dynamic spectrum access capability of CRS.

In addition, a service using SDR and/or CRS should not adversely affect other services in the same band with the same or higher status. Thus, the introduction and operation of stations using SDR and/or CRS technologies in systems of any radiocommunication service should not impose any additional constraints to other services sharing the band.

For example, the introduction of SDR and/or CRS in a frequency band(s) shared between terrestrial and space services should not adversely affect either of these services by either imposing any additional constraints to the operation of terrestrial or space services.

Any system of a specific service using SDR and/or CRS in a frequency band allocated to that service should be operated in accordance with the provisions of the Radio Regulations and administration rules governing the use of the bands and the protection criteria defined in the relevant ITU-R Recommendations.

2.2 Deployment scenarios of CRS

As a result of ITU-R research in preparation for WRC-12, 4 possible scenarios for the deployment of CRS have been identified. They are not exhaustive, nor mutually exclusive:

1) Use of CRS technology to guide reconfiguration of connections between terminals and multiple radio systems

In this scenario, multiple radio systems employing different radio access technologies are deployed on different frequencies to provide wireless access.

Two possible examples of this scenario are identified.

In one example, some terminals are reconfigurable and can adjust their operational parameters and protocols to use different radio access technologies. Such terminals can autonomously make decisions on these adjustments based on obtained knowledge required for making these decisions. Also, radio systems may assist terminals in obtaining knowledge and guide terminals in their reconfiguration decisions (e.g. using Cognitive Pilot Channel (CPC)).

In another example, some terminals have the capability to communicate with different radio systems, e.g. based on the subscriptions, but they cannot reconfigure their operational parameters and protocols to use different radio access technologies. Additional stations can be deployed to serve as a bridge between multiple radio systems and terminals. Such stations can obtain knowledge about the operational environment, and adjust their operational parameters and protocols to connect to one or more different radio systems simultaneously while providing connection to terminals using one radio access technology.

2) Use of CRS technology by an operator of radiocommunication systems to improve the management of its assigned spectrum resources

To illustrate this scenario, consider an operator who already owns a network and operates in assigned spectrum and decides to deploy another network, based on a new generation radio interface technology in the same or other assigned spectrum, covering the same geographical area. Taking into consideration the non-uniform nature of radiocommunication needs within this area, an operator having more than one network based on different radio technologies could dynamically and jointly manage the deployed resources, in order to adapt the configuration of the networks to maximize the overall network capacity.

3) Use of CRS technology as an enabler of cooperative spectrum access

In this scenario, information on spectrum use is exchanged amongst the systems in order to avoid mutual interference.

Two examples are identified for cooperative spectrum access:

– Example one: there may be variations in the occupancy of the assigned spectrum in a specific location at a specific time. Thus, in order to improve the efficiency of the spectrum use, it may be possible to take advantage of parts of the unused spectrum resulting from these variations. The capability to predict these variations in advance or to exchange information amongst systems/networks on the usage of their respective assigned spectrum may allow operators to share their respective assigned spectrum resources.

– Example two: in a network (public or private), the base stations are deployed according to the operator plan; such plan in many cases leaves coverage holes and areas lacking capacity. These cases may be solved by deploying additional base stations using CRS technology managed by the same operator or by new entrant operators, when allowed by regulator body. In fact such networks may suffer from mutual interference due to the fact that they are using the same frequency band. The CRS technology may allow collaboration between these networks to resolve the interference issue.

4) Use of CRS technology as an enabler of opportunistic spectrum access

In this scenario, information on spectrum use aimed to avoid mutual interference is not exchanged amongst the systems.

Compared to example one of the previous scenario, in this scenario there is no "*a priori*" determination of the spectrum to be eventually accessed by an interested party. In this scenario CRS may access parts of unused spectrum in bands shared with other radio systems without causing harmful interference. In this case, the selection of the spectrum to be eventually accessed is made on a real time basis following, amongst other things, a radio scene analysis.

2.3 CRS challenges and opportunities

Administrations considering the introduction of CRS technology to enable dynamic spectrum access may benefit from detailed considerations of operating characteristics of the incumbent stations. In particular the protection requirements for stations of any radiocommunication service and the RAS with an allocation in the targeted band should be considered to ensure an environment free of harmful interference, especially when the CRS technology only relies on a spectrum sensing technique to identify the use of the band(s).

Some concerns were expressed with respect to the use of the CRS technology to dynamically access the spectrum.

Spectrum exclusively allocated to passive services, where stations are only receiving could be a concern when considering the use of CRS for dynamic spectrum access. Another concern expressed by satellite operators in the EESS using passive sensors is the possibility of CRS attempting to operate in bands not exclusively allocated to passive services (RAS, SRS (passive) or EESS (passive)) on a worldwide basis, as such systems could identify those bands as free of any other active system and therefore ideal for usage. Furthermore, the SRS and EESS operate satellite links in frequency bands shared with other services. If one of these services plans to implement CRS technology, it will be necessary to take into account the regular but quasi sporadic operation of these links. For example, an EESS earth station may track a satellite in a low-Earth orbit. The satellite would then start transmitting towards the Earth station as soon as it has reached an elevation of typically 5 degrees above the local horizon. Any CRS station operating as part of the other services sharing the frequency band may have sensed that the particular frequency channel of the satellite link is unused and have occupied it. CRS stations might still cause harmful interference to the EESS station sharing the same frequency band. Similarly, some administrations have established local quiet or coordination zones around their radio astronomy stations, restricting emissions at frequencies outside the usually-allocated passive service bands. CRS relying on spectrum-sensing alone might misinterpret the lack of signal in locally-protected radio astronomy bands. Therefore, CRS may require both geo-location capabilities and knowledge of local spectrum regulations. In addition, all emissions, including those of CRS stations, are prohibited in passive bands listed in RR No. **5.340**.

CRS using dynamic frequency search operations in the FSS or BSS bands will need to consider that many earth terminals do not transmit continuously or are receive-only terminals and the downlink signals are at low power flux-densities. The detection of FSS and BSS receivers by a CRS may represent technical issues that may need to be studied. The use of data bases that would contain the locations and frequencies of the earth terminals could be a solution, especially in countries where the number of earth stations is not very large and the required information could be collected. However, in countries where the deployment is ubiquitous and where the location of an earth station may be temporary, the use of database is challenging. Furthermore, the data base may need to contain information that an FSS/BSS operator would consider sensitive and not want to disclose.

Other satellite services (e.g. EESS, RDSS, MetSat and MSS) that use downlink receive-only terminals or have low power signals will also need special consideration and studies for the implementation of CRS. In addition it should be noted that RNSS is fully operational at all times in all locations on Earth and CRS devices that dynamically search for spectrum do not appear to be appropriate for use in RNSS frequency bands.

The BS could be susceptible to interference resulting from the application of CRS technology. The BS is often planned on a noise-limited basis. As such, broadcast receivers are expected and are frequently called upon to operate at or near noise limits. Consequently, the non-detection of a broadcast signal by a sensing device in one location may not indicate that a frequency allocated to the BS is available for other users. Furthermore, broadcast receivers are particularly sensitive to interference from signals in adjacent, multiple adjacent, local oscillator and image channels. However, some administrations have demonstrated compatibility and authorized the use of available spectrum in the UHF bands through licence-exempt devices which operate on a non-interference and non-protection basis. The use of a geo-location capability and capability to access a database enables CRS to avoid interference with other users in the TV UHF band.

Frequency bands allocated to the BS are also utilized by electronic news gathering (ENG) systems such as wireless audio and video transceivers. The use of cognitive techniques to locate these ENG devices and to avoid their operating frequencies may be difficult. However, these difficulties may be addressed by administrations.

Any use of SDR or CRS technologies in bands used for safety-of-life operations needs careful consideration.

Fading and shadowing effects may result in the hidden node problem, in which CRS stations/terminals may not be able to detect the presence of a protected station, and hence bring interference to them. A database solution, in which the location information of the protected stations as well as other data will be employed, is one of the possible choices to avoid the hidden node problem.

These issues need to be addressed by further ITU-R studies on the deployment and use of CRS.

In response to these concerns and as per its definition, CRS is a policy-based adaptive radio system. With respect to implementation, the term means that policies including national and international regulations are translated into radio behaviour controls. For instance, despite the fact that receive-only bands (e.g. the bands covered by RR No. **5.340**) may appear as vacant spectrum, CRS will not only be aware that these bands cannot be accessed for transmissions, but appropriate radio behaviour controls will ensure that no transmissions occur. It is also important to note that one of the implicit assumptions made in the various concerns expressed above is the absence of a need for a CRS station to obtain the proper authorization from the relevant Administration prior to the use of the spectrum. In fact, RR Article **18** (RR No. **18.1**) and national regulations do not permit any unauthorized access to the spectrum, even when unused.

2.4 CRS capabilities and their applicability to facilitate coexistence in shared bands

The ITU-R has identified a basic, but not exhaustive, range of capabilities of CRS that may facilitate coexistence with existing systems. The following elements could be considered as examples of capabilities of CRS:

– spectrum sensing capability including collaborative and cooperative sensing;

– positioning capability of the transmitters and receivers (geo-location);

– access to information on the spectrum usage, local regulatory requirements and policies, e.g. through access to a database or access to a logical or physical cognitive pilot channel;

– capabilities to adjust operational parameters based on the obtained knowledge.

It is important to note that these CRS capabilities do not prevent CRS to be operated as any other existing systems under a predetermined allocation and assignment regime.

In fact, these capabilities of CRS may help improve coexistence amongst radio communication systems deployed under the current regulatory regime (predetermined allocation and assignment). For example, in bands allocated to both active services and RAS, CRS technology can be incorporated in a RAS station (receive-only station) taking advantage of any intermittent emissions from the stations of the active services. The RAS also makes increasing use of interference mitigation techniques. In bands shared with active services, some techniques rely on knowing the nature of the signals that they are attempting to mitigate and could be thwarted by changes in modulation scheme. For such circumstances radio astronomy interference mitigation algorithms may fail, or work with significantly degraded effectiveness.

There are already examples where CRS features have been employed.

In the MS, the radio local area networks (RLAN) in 5 GHz use spectrum sensing capability in the form of dynamic frequency selection (DFS), as described in Recommendation ITU-R M.1652, Report ITU-R M.2115 and Resolution **229 (WRC-03)**, to allow the system to obtain knowledge of its environment, in order to avoid interference to RLS using the same band.

Some administrations are authorizing license exempt devices to access the bands below 1 GHz shared with BS. A set of CRS capabilities is needed to ensure sharing with BS without causing harmful interference.

In conclusion, there are challenges to sharing through cognitive technologies that should be considered before administrations authorize them in particular services. However, the capabilities of cognitive radio systems, particularly with devices querying a database in which parameters (such as locations, frequencies, regulations and policies, etc.) for protected stations are registered, not only have the potential to make more efficient use of spectrum, but to also offer more versatility and flexibility, through the increased ability to adapt their operations based on internal and external factors. Cognitive radio systems may have a profound effect on many aspects of communications, including interoperability, as well as on spectrum utilization and allocation.

WRC-12 decided that nor SDR neither CRS need in any particular regulation and corresponding changes in Radio regulations. The point is that CRS is a technology, which may be implemented in any radiocommunication service and therefore it should be implemented only in accordance with Radio Regulations. Implementation of CRS do not make administrations free of responsibility to protect other stations complying Radio Regulations. Thus it can be stated, that regulation of CRS is left for national or regional level.

Summary to the chapter 2

Three major outcomes should be selected upon ITU-R studies on applications of CRS and electromagnetic compatibility issues:

- CRS technologies may yield significant benefits by providing increased spectral efficiency of existing spectrum and mitigate the problem of congestion (e.g. capacity gain);

- The introduction and operation of stations using SDR and/or CRS technologies in systems of any radiocommunication service should not impose any additional constraints to other services sharing the band.

- any system of particular service employing SDR and/or CRS in a frquency band, allocated to this service shall operate in accordance with Radio Regulations and administrative rules, which regulate spectrum utilisation and protection criterias, defined in corresponding ITU-R Recommendations.

However, recognizing the need in further research of technical and operational aspects of CRS implementation, the Radiocommunication Assembly adopted a Resolution 58 «Studies on the implementation and use of cognitive radio systems» [33]. It should be noted that regulatory aspects are excluded out of these studies.

3 APPLICATION OF COGNITIVE RADIO TECHNOLOGY IN WIRELESS NETWORKS

3.1 General remarks

Currently, a practical application of CRS is obtained in bands traditionally allocated to television (TV) broadcasting. This is due to features of the frequency-territorial planning of terrestrial TV broadcasting. To avoid mutual interference between radio transmitting stations, for nearby broadcasting stations assigned different frequency bands. As a result, the network of terrestrial TV broadcasting in separate areas forms the unused bandwidth, so-called "white space" (Figure 14). The task is to use this frequency resource for applications other than TV broadcasting, for example, for wireless broadband access. In addition, a lot interest in these bands are due to favorable radio propagation conditions in these bands. This example is based on the fourth deployment scenario of CRS implementation which was described in Chapter 2.

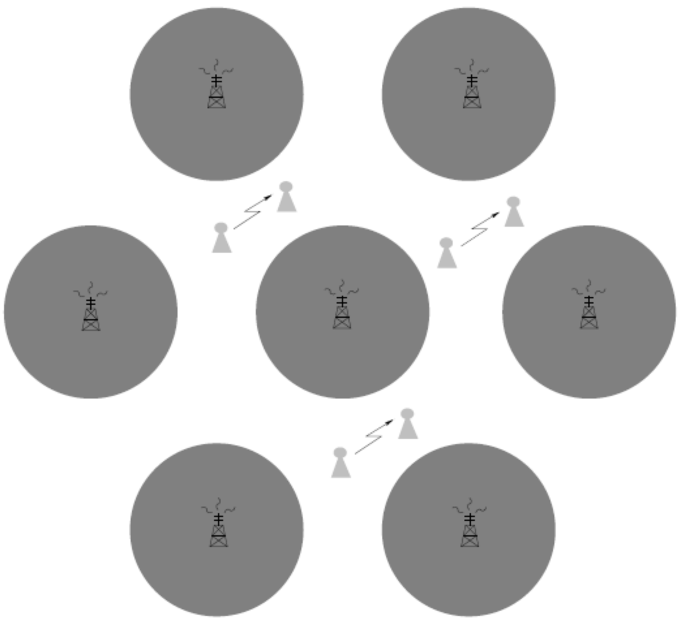


Figure 14 - Understanding of white spaces.

A specific area of the cognitive radio field is the area of dynamic spectrum access in which a cognitive radio network dynamically identifies and uses portions of the spectrum that are not being used by other systems (white spaces). The white space may consist of unused frequencies or unused fragments of time in a given location (Figure 15) [34]. Since the white space is unused television channels over a given area, it is primarily frequency white space; however, there is a time component, since if the spectrum availability changes, the cognitive network must adapt quickly so as not to cause harmful interference to the licensed transmissions. This is particularly so for protecting licensed wireless microphone operations.

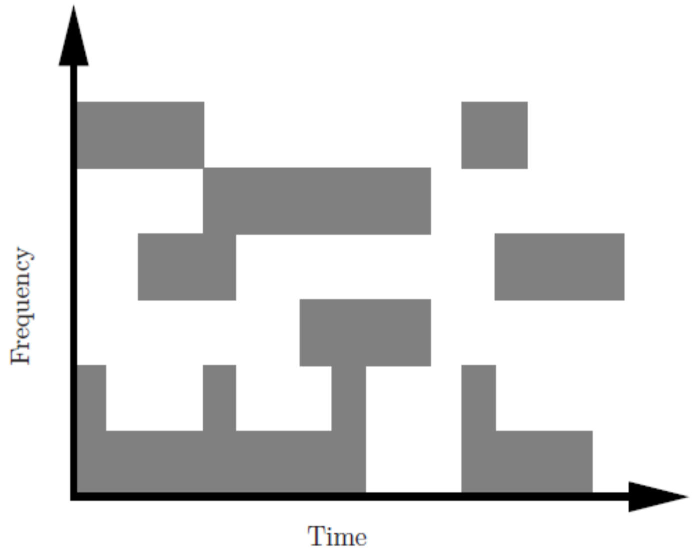


Figure 15 - White spaces in frequency and time domain.

3.2 Potential cognitive techniques for white space devices

There are several methods that can be used by a cognitive radio network to be aware of its spectral environment. Two main techniques have been proposed to assist the white space devices in finding unoccupied channels.

3.2.1 Spectrum Sensing

With spectrum sensing, WSDs try to detect the presence of the protected incumbent services in each of the potentially available channels. Spectrum sensing essentially involves conducting a measurement within a candidate channel, to determine whether any protected service is present. When a channel is determined to be vacant, sensing might also be applied to adjacent channels to determine what constraints there might be on transmission power, if any (Figure 16).

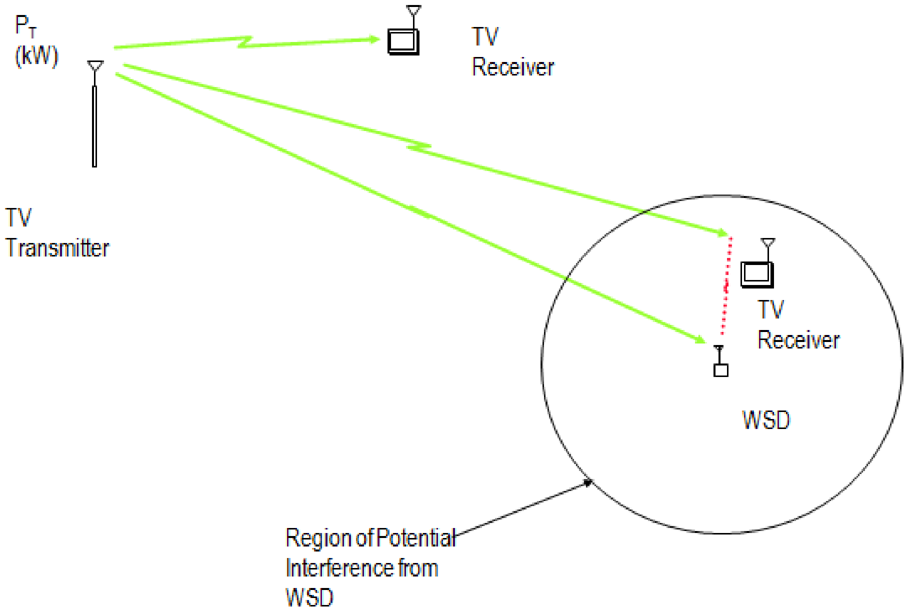


Figure 16 - Sensing in the Broadcast Bands.

So for sensing only WSD some channels may have to be permanently excluded, because the occupying service is not amenable to detection by sensing, such as passive service. For example, in the band 608-614 MHz some countries have stations for radio astronomy services which cannot be protected by sensing.

However, sensing technique can be applied only if the signal characteristics of the protected service are known and if spectrum sensing implemented in WSDs adapts to any change in these characteristics.

A significant advantage of spectrum sensing (stand alone) would be that it does not rely on any existing local infrastructure, such as connection to a database. This could be important where access to the internet is more limited, or when WSDs are used to provide only local connectivity between multiple devices, without requiring access to e.g. the Internet.

So far analyses of sensing performance assume that detection is carried out independently by each device (Figure 17), in ignorance of results found by other cognitive devices in the same location. The emergence of cooperative sensing, in which devices share their findings, may bring in the future the potential to improve sensing reliability.

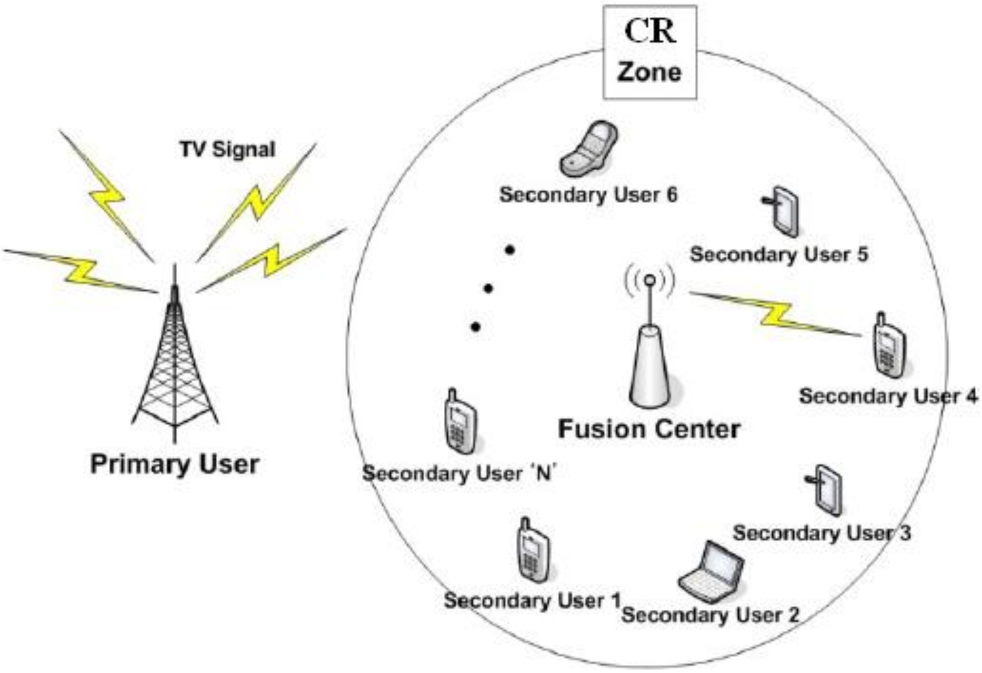


Figure 17 - Independent sensing model

The cooperative sensing devices (Figure 18) could for example, cover an area, be on different heights, or one device could act as a master (head) and collect the results from the others [35].

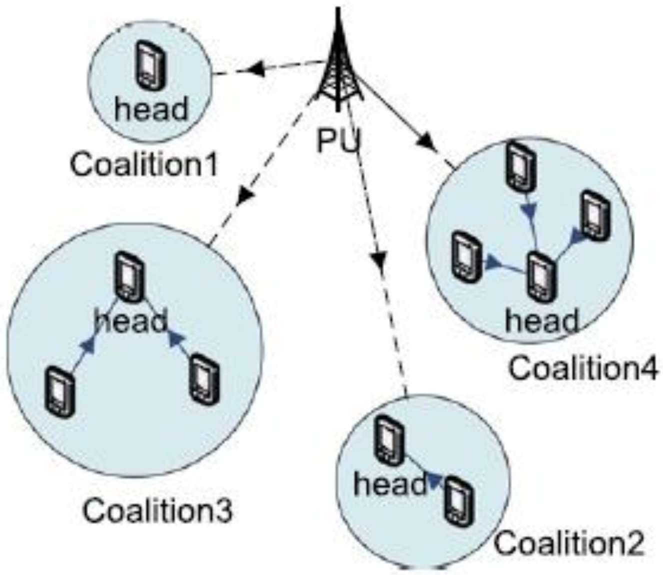


Figure 18 - Cooperative sensing model.

Key parameters for spectrum sensing include:

- Sensing threshold
- Periodicity of re-sensing on channels that have been detected as vacant
- Sampling duration

Sensing methods can be in general divided to two categories: energy detection and feature detection. The energy detection method is used to detect the signal power in the channel under study. The detector can be either wide band matching the channel bandwidth or narrow band with a possibility to slide it across the channel. The advantage of an energy detector is that it is independent of the radio system to be detected and as such future proof and capable of adapting to any new system introduced into the band. A disadvantage is the required low sensitivity due to the noise floor and the possibility of false detections.

A feature detector would use certain known characteristics of the signal that is to be detected. This may be a specific pilot carrier signal, preamble, continual or scattered pilots in an OFDM signal, certain periodicity (GI) or sequence in the signal in the time or frequency domain. Using these features will result in a processing gain, which will enable detection below the noise floor in the usual sense. It should be noted that the feature detectors are not in general trying to demodulate the signal and thus are not able to access most of the information carried by the signal. Still they are able to detect the type of the signal e.g. DVB-T or DVB-T2, and thus decreasing the possibilities of false alarms. A drawback in the feature detector is its dependence on the specific features and that it may have difficulties to adapt to any new radio system introduced by the incumbent in the band later. To some extent this may be solved by designing some flexibility within the detector, e.g. by updating the software after the product is placed on the market.

3.2.2 Hidden node problem

A problem with the sensing is the shadow fading problem, which can result in the hidden node problem. This situation occurs when a signal transmitted by the user/station of primary/secondary service (e.g. TV transmitter) is not received by a CRS due to the shadowing effect of terrain or other obstacles (Figure 19). In this case the CRS will obtain false information and starts co-channel transmission, which causes harmful interference to the TV receivers in the vicinity of the CRS. This so called hidden node problem could be solved by combining sensing information from multiple cognitive radio devices, however, this combined information needs to be processed in a centralised manner. This distributed sensing is still under study, therefore relying only on sensing may not be a reliable method for obtaining the knowledge of environment at the initial stage of CRS introduction

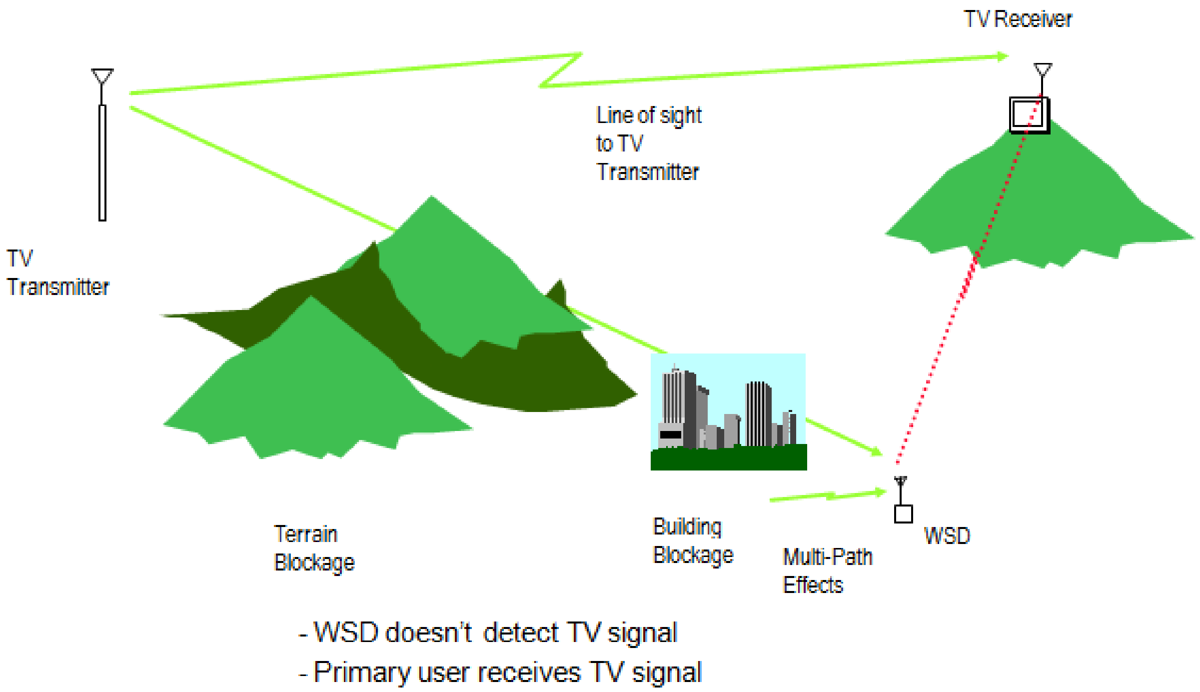


Figure 19 - Understanding of hidden node problem.

For a high height scenario, i.e. WSD antennas at height of e.g. 10 or 30 meters, the hidden node problem will be reduced.

3.2.3 Geo-location.

In this approach, WSDs would measure their location and consult a “geo-location” database to determine which frequencies they can use at their location (i.e. the location which they have indicated to the database). Parameters such as location accuracy, frequency of database enquiry and quality of the database are essential. As an example, the accuracy of the location measured by a WSD installed under the control of an operator is expected to be better compared to an ad hoc installation.

WSDs are not allowed to transmit until they have successfully determined from the database which channels, if any, are available in their location. This requires that the initial access to the database is done by some other means than using white space frequencies.

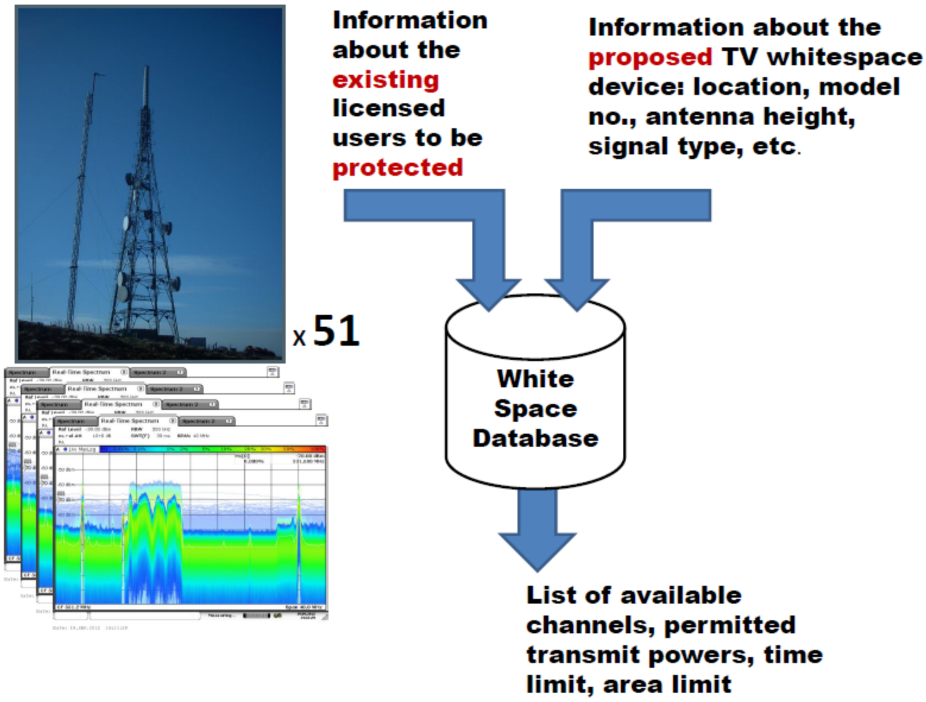


Figure 20 - Analysis of information of existing services to be protected and WSD location in order to create a list of available channels and permitted parameters on a Database.

In the case where there are several access points available that are connected to each other by some means (e.g. a core network or a distribution system), triangulation or some other network based positioning method can be used to measure the WSD location. This measured position may be used by the WSD, or by an access point (e.g. a master WSD), to query the database for available radio channels, bandwidths and corresponding maximum transmit powers.

Using the geo-location approach would require that the WSD has valid information about the available channels, either by including the time validity of the received information or by requiring sufficiently frequent re-consultation with the database.

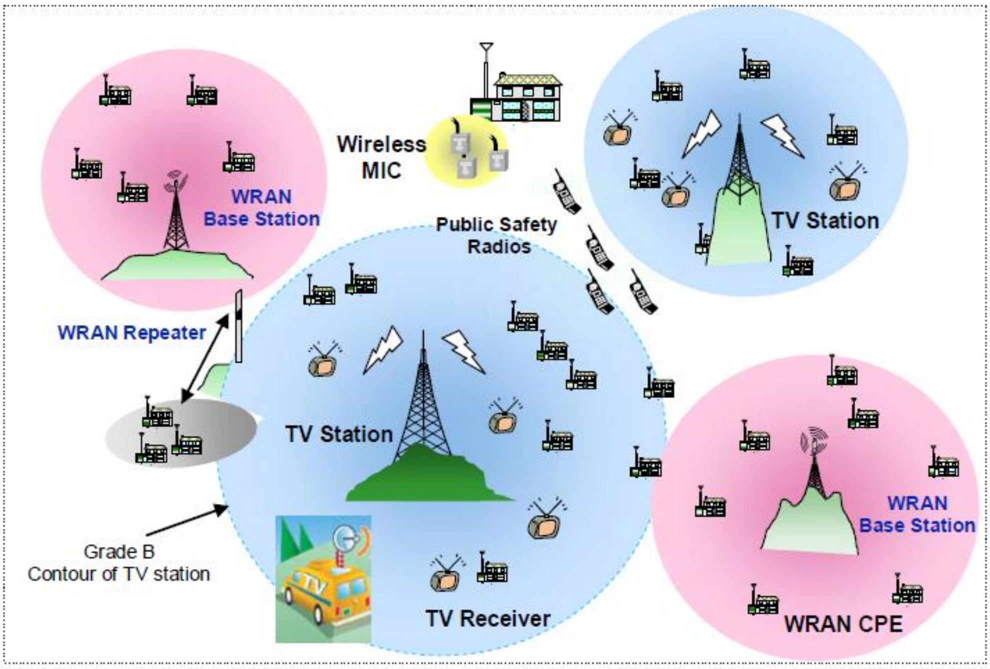


Figure 21 - A Typical Radio Environment for Cognitive WRANs. This map aggregates the knowledge of all local wireless activities

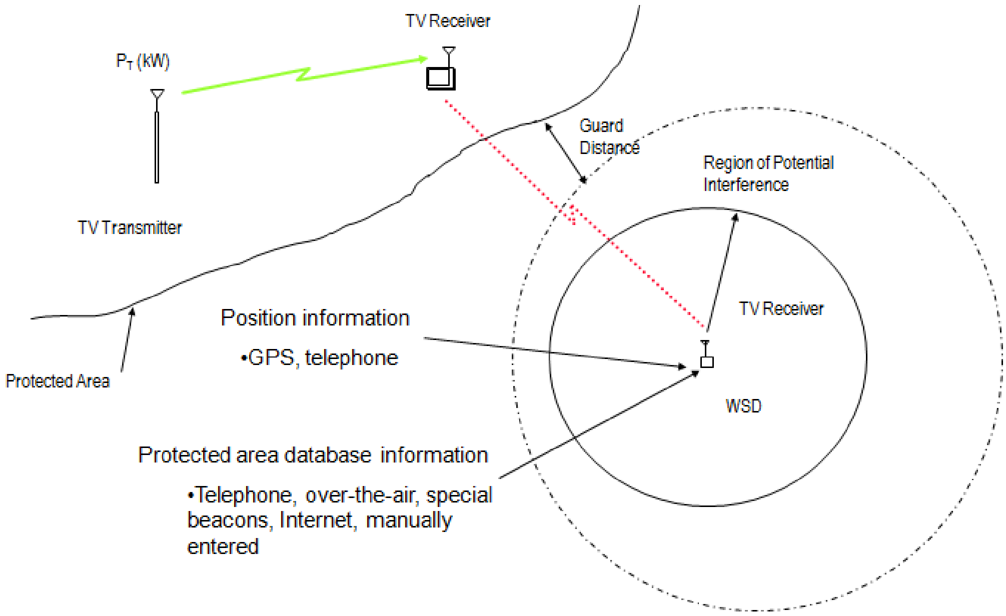


Figure 22 - General understanding of geo-location method.

3.3 Practical implementation of CRS in IEEE 802.22 cognitive wireless network standard

3.3.1 IEEE 802.22 development.

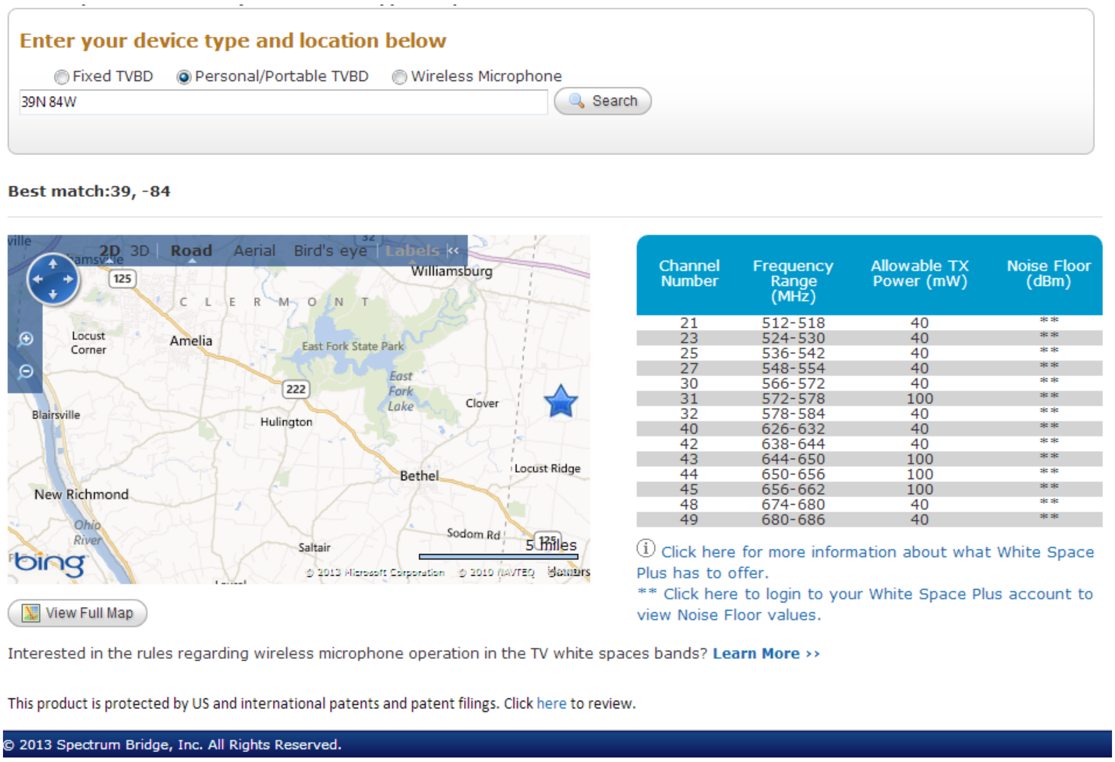
Starting with a Notice of Inquiry by the U.S. FCC in December 2002 exploring the possibility of allowing access to the TV broadcast bands for license-exempt devices on a noninterfering basis, and subsequently, a golden opportunity was created to develop a system capable of using these frequency bands on a noninterfering basis to bring broadband access to rural areas — the very areas where there are a large number of vacant TV channels and the population density is less than the typical 60 persons/km^2 for which cabled media such as digital subscriber line (DSL) and coaxial cable technologies make economic sense.

The development of the IEEE 802.22 WRAN standard (802.22 or 802.22 WRAN herein) is aimed at using cognitive radio techniques to allow sharing of geographically unused spectrum allocated to the television broadcast service, on a noninterfering basis, to bring broadband access to hard-to-reach low-population-density areas typical of rural environments, and is therefore timely and has the potential for wide applicability worldwide. IEEE 802.22 WRANs are designed to operate in the TV broadcast bands while ensuring that no harmful interference is caused to the incumbent operation (i.e., digital TV and analog TV broadcasting) and low-power licensed devices such as wireless microphones.

The 802.22 network quickly modifies its operating frequency so as to only operate on channels unused by licensed transmissions. Thus, the 802.22 network must both quickly identify which channels are allowed for use and move to a new unused channel, if the current operating channel becomes occupied by a licensed transmission.

In September 2011 the first database (DB) on protected radio stations was put into operation [36]. In December 2011 FCC made a decision for beginning of commercial operation of DB in 2012. In January 2012 Spectrum Bridge company obtained permission on operation of geo-location DB for TV frequency bands. The

DB has a web-support to facilitate the information presentation for end-users (Figure 23).



Channel Number	Frequency Range (MHz)	Allowable TX Power (mW)	Noise Floor (dBm)
21	512-518	40	**
23	524-530	40	**
25	536-542	40	**
27	548-554	40	**
30	566-572	40	**
31	572-578	100	**
32	578-584	40	**
40	626-632	40	**
42	638-644	40	**
43	644-650	100	**
44	650-656	100	**
45	656-662	100	**
48	674-680	40	**
49	680-686	40	**

Figure 23 - The example of information on unused channels on Spectrum Bridge website.

3.3.2 Features of cognitive WRAN compared to wireless networks of other standards.

The place of 802.22 WRANs which they are intended to occupy in the family and evolution of the various wireless data communication standards developed by the IEEE 802 LAN/MAN Standard Committee is illustrated in Figure 24.

The application for the IEEE 802.22 WRAN standard will be providing wireless broadband access to a rural area of typically 17–30 km or more in radius (up to a maximum of 100 km) from a base station (BS) and serving up to 255 fixed units of customer premises equipment (CPE) with outdoor directional antennas located at nominally 10 m above ground level, similar to a typical VHF/UHF TV receiving installation.

The minimum peak throughput delivered to CPE at the edge of coverage will be equivalent to a T1 rate (1.5 Mb/s) in the downstream (DS) direction (BS to CPE) and 384 kb/s in the upstream (US) direction (CPE to BS), allowing for videoconferencing service.

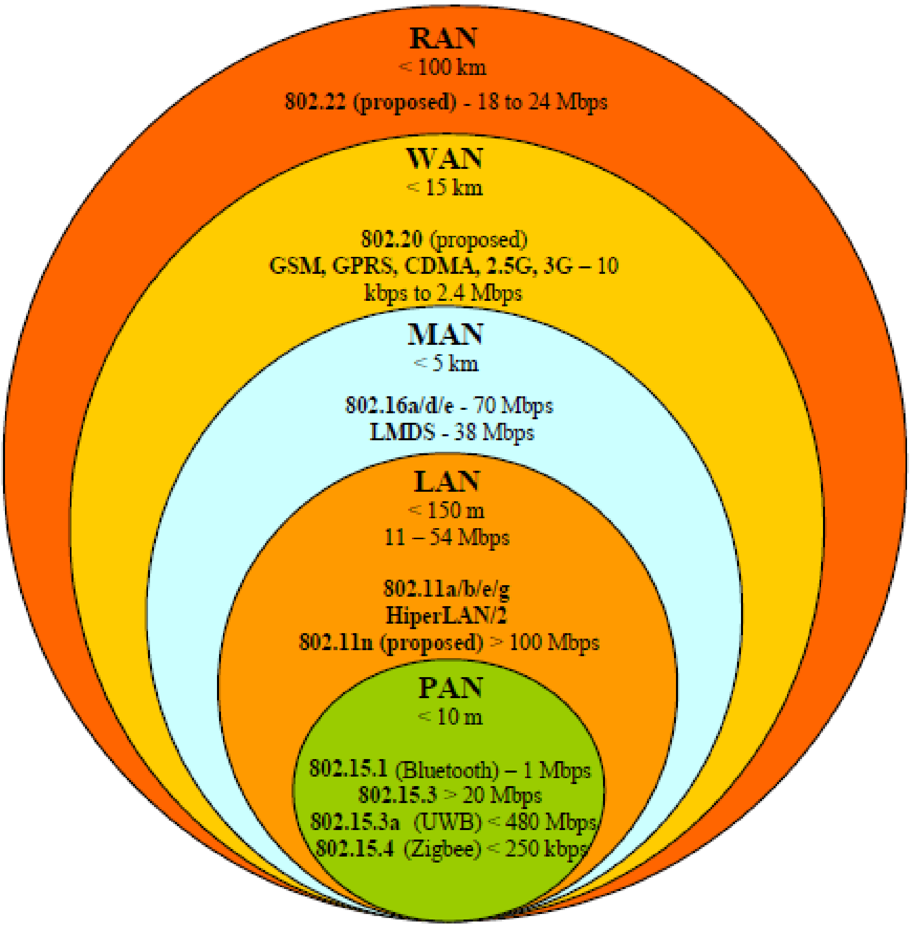


Figure 24. The IEEE 802.22 standard relative to other IEEE 802 wireless data transmission standards.

Due to the extended coverage afforded by the use of these lower frequencies, the physical layer (PHY) parameters must be optimized to absorb longer multipath excess delays than accommodated by other 802 wireless standards.

An excess delay of up to 37 μs can be absorbed by the orthogonal frequency-division multiplexing (OFDM) modulation used.

Beyond the 30 km for which the PHY layer has been designed, the medium access control (MAC) layer will absorb additional propagation delays for coverage distances of up to 100 km through intelligent scheduling to cover cases where advantageous topography allows coverage to such distances.

As shown in Figure 25, the reference architecture for IEEE 802.22 systems addresses the PHY and MAC layers, and the interfaces to a station management entity (SME) through PHY and MAC layer management entities (MLMEs), as well as to higher layers such as IP, asynchronous transfer mode (ATM), and IEEE 1394 through an IEEE 802.1d compliant convergence sublayer.

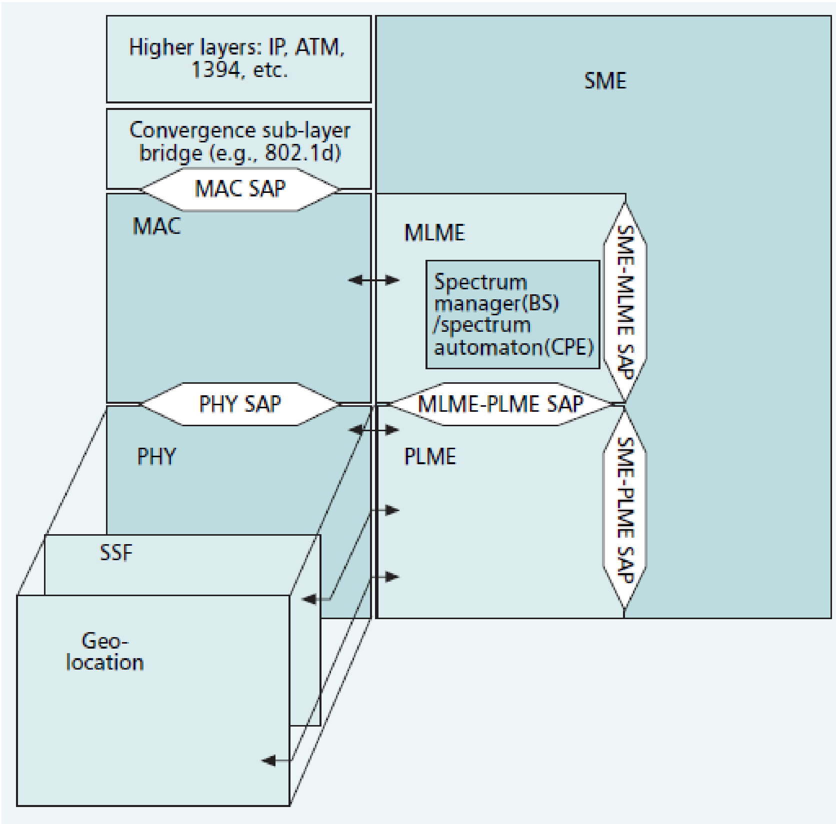


Figure 25 - The IEEE 802.22 reference architecture.

At the PHY layer there are three primary functions: the main data communications, the spectrum sensing function (SSF), and the geolocation function, with the latter two providing necessary functionality to support the cognitive abilities of the system.

The PHY interfaces with the MAC through the PHY service access point (SAP), as well as to the MLME and the SME through the PHY layer management entity (PLME) and its SAPs.

Table 1 tabulates the typical IEEE 802.22 features compared to IEEE 802.16e, its closest “relative” among the IEEE 802 family. IEEE 802.22 will define a single air interface based on 2048-carrier orthogonal frequency-division multiple access (OFDMA) to provide a reliable end-to-end link suitable for NLOS operation.

Since it is not always possible to have paired TV channels available, IEEE 802.22 is initially defining a single time-domain duplex (TDD) mode, with plans to define a frequency-division duplex (FDD) mode as a future amendment to the standard.

Table 1 - IEEE 802.22 features compared to IEEE 802.16.

	IEEE 802.22	**IEEE 802.16e**
Air interface	OFDMA	OFDMA, OFDM, Single Carriers
Fast Fourier transform	Single mode (2048)	Multiple modes (2048, 1024, 512, 128)
OFDMA channel profile (MHz)	6, 7, or 8 (according to regulatory domain)	28, 20, 17.5, 14, 10, 8.75, 7, 3.5, 1.25
Burst allocation	Linear	Two dimensional
Subcarrier permutation	Distributed with enhanced interleaver	Adjacent or distributed
Multiple-antenna techniques	Not supported	Support multiplexing, space time coding, and beamforming
Superframe/frame structure	Support a superframe structure based on groups of 16 frames. Frame size: 10 ms	Superframe is not supported. Supported frame sizes: 2, 5, 10, or 20 ms.
Coexistence with incumbents	Spectrum sensing management,geolocation management, incumbent database query, and channel management.	Not supported.
Self-coexistence	Dynamic spectrum sharing	Master frame assignment
Internetwork communications	Over-the-air coexistence beacon or over-the-IP-network.	Over-the-IP-network (primarily)

The granularity of frequency spectrum for WRAN is a TV channel as shown in Table 1. To support the various TV channel bandwidths in use in the world (6, 7, and 8 MHz channels), the sampling frequency, carrier spacing, symbol duration, signal bandwidth, and data rates will be scaled by the channel bandwidth for worldwide operation. IEEE 802.22 systems will use a common oversampling factor and the same frame/symbol structure, coding schemes, interleaving, and so on.

Four different lengths of cyclic prefix are defined as 1/4, 1/8, 1/16, and 1/32 of symbol duration to allow for different channel delay spreads while utilizing the spectrum efficiently.

Due to the physical size of antenna structures at these lower frequencies, IEEE 802.22 will not support multiple-antenna techniques such as multiple-input multiple-output (MIMO) or beamforming.

3.4 Calculation of detection thresholds for protection of broadcasting service in the band 470-790 MHz from emissions of white space devices

In this section we will try to provide a methodology for calculation of detection threshold in case of digital broadcasting protection. For simplicity, we consider only broadcasting reception for fixed (rural and urban) conditions. The problem of interference between broadcast service and WSD is schematically depicted in Figure 26. If a WSD transmits near the antenna of a broadcasting receiver using the same frequencies, it might cause harmful interference. However, the WSD has to avoid any harmful interference by collecting information on spectrum for transmissions using the cognitive techniques. Let us make an assumption that if the WSD cannot identify any broadcasting transmissions, it may be concluded that there are no nearby active receivers in that spectrum (because there would be nothing for them to receive).

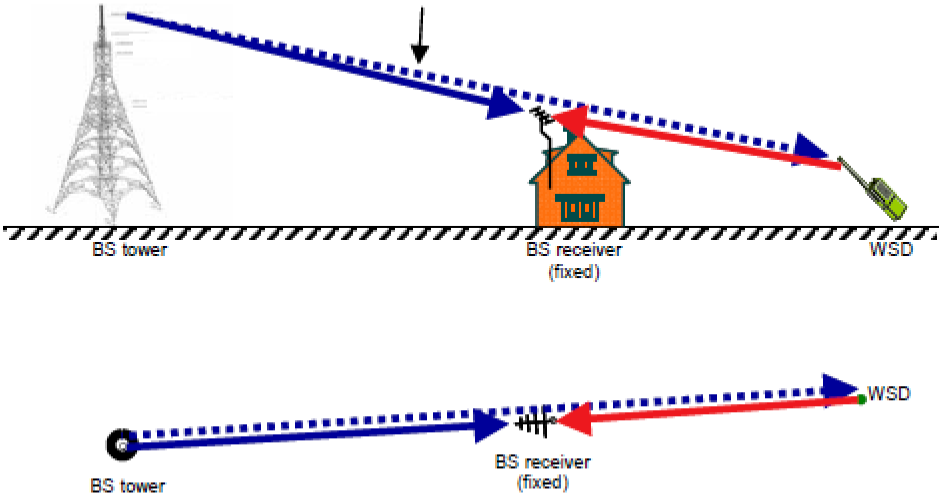


Figure 26 - Interference scenario example.

As an initial data we have technical characteristics of broadcasting service on DVB-T standard as given in table 2.

Table 2 - DVB-T parameters used in the study.

Parameter	**Units**	**Fixed reception rural**	**Fixed reception urban**	**Comment**
Link BW	MHz	7,60	7.60	Bandwidth occupied by link
Thermal noise density	dBm/Hz	-173.98	-173.98	κT_0
Receiver noise figure	dB	7	7	NF (Rec. ITU-R BT.1368)
Noise power (including NF) over link BW	dBm	-98.17	-98.17	P_n = kTB - NF plus any noise rise
Gaussian confidence factor	N/A	1.645	1.645	N/A
Shadowing loss standard deviation	dB	5.5	5.5	P.1546
Total loss standard deviation	dB	5.5	5.5	Root of sum of STD squares
Loss margin	dB	9.05	9.05	L_{margin}
Minimum SNR at cell-edge	dB	21	21	SNR_{min} for DTT 64 QAM, 2/3 for fixed reception
Target "mean" received signal level	dBm	-63.12	-63.12	$P_{target} = (P_n + SNR) + L_{margin}$
e.i.r.p.	dBm	79.15	72.15	P
Receiver Antenna Gain (inc. feeder losses)	dBi	9.15	9.15	G_a (Rec. ITU-R BT.1363)
Max allowed path loss	dB	156.42	149.42	$L_p = (P - L_w + G_a) - P_{target}$
DTT transmitter height	m	200	100	H_t
DVB-T Rx heighr	m	10	10	H_r
cell Size	km	52.9	31.15	Rec. ITU-RP.1546
Minimum median field strength at 650 MHz	dBµV/m	56.21	56.21	

It is noted that all these parameters are based on single transmitters, only, and that single frequency networks (SFN) were not considered. The values provided in Table 1 are for reference configurations.

The electric field strength available for spectrum sensing at WSD antenna will not be a fixed value, but will exhibit a statistical variation affected by WSD position and also propagation variations with time. The statistics of this variation are understood to have a normal distribution characterized by a median value and a standard deviation. An illustration of how signals might vary with location is shown in Figure 27.

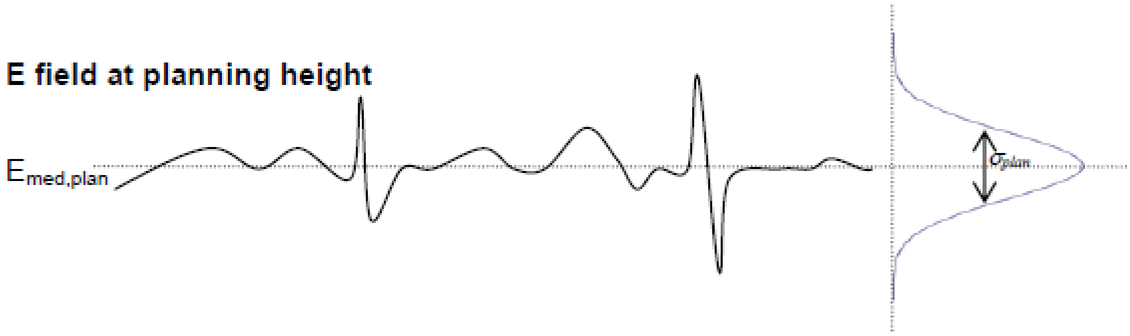


Figure 27 - Variation of Electric field strength at planning height.

At the height at which TV reception is planned, the signal variation is characterized by a median electric field strength, $E_{med,plan}$, and a standard deviation, σ_{plan}.

For sensing at WSD height, H_{WSD}, the important parameters are the median electric field strength at that height, E_{sense} and the standard deviation of the signal variation, σ_{sense}.

In calculating a sensing threshold, we must consider the required sensing reliability. Should the sensing device fail to detect the primary service, co-channel interference will result which could affect a considerable number of DTT receivers. To prevent this, a very high reliability of detection is required, typically 99.99% in the planned area.

Obviously, this is the most important parameter when looking to detect reliably the presence of DTT signals above a certain level in order to assume whether the channel is used or not.

For calculating the detection threshold for WSD, first we need to calculate the DTT field strength at the WSD receiver antenna “E_{med}”, which is obtained by subtracting the height loss from H_{DTT} to H_{WSD} (“$L_{HDTT-HWSD}$”) from the planned DTT field strength “$E_{med,plan}$” and so that:

$$E_{med} = E_{med,plan} – L_{HDDT-HWSD} \tag{1}$$

The height loss LHDDT-HWSD can be calculated according to the prescription given in ITU-R Rec. P.1546.

After having calculated E_{med}, we can then define a detection threshold E_{sense} given by:

$$E_{sense} = E_{med} - \mu_{sense}\sigma_{sense} \tag{2}$$

The power available to the WSD and that should be sensed, P_{sense} can be derived by considering the frequency, f_{sense}, the antenna gain of the device, G_{sense} and the polarization loss L_{pol}, resulting from misalignment between the antenna of the white space device and the polarization of the primary signal to be detected. Also, for a mobile WSD a margin for Body Loss “Lbody_loss” has been considered. The result is given by:

$$P_{sense} = E_{sense} - 20 \log(f_{sense}\,(MHz)) - 77{,}2 + G_{sense} - L_{pol} - L_{body\_loss} \tag{3}$$

Here in table 3 we present the calculation results for fixed DVB-T outdoor receiver and outdoor WSD.

Table 3 - calculation results for fixed DVB-T outdoor receiver and outdoor WSD.

DTT	**DTT fixed outdoor. planned for SubUrban area**		**Units**
Percentage location in the target detection area:	95%		
DTT receiver autenna height	10 m		
WSD	**Mobile Outdoor at 1.5 m**	**Fixed Outdoor at 30 m**	
$E_{med,plan}$	56.21	56.21	dBμV/m
$L_{HDTT-HWSD}$	17.01	-9.84	dBμV/m
E_{med}	39.20	66.05	dB
Sensing reliability	99.99%	99.99%	%
$\sigma_{1,5m}$	5.50	5.50	dB
μ_{sense}	3.72	3.72	dB
f_{sense}	650.00	650.00	MHz
G_{sense}	0.00	0.00	dBi
L_{pol}	3.00	3.00	dB
L_{body_loss}	3.00	0.00	dB
E_{sense}	18.74	45.59	dBμV/m
$P_{sense\_1,5m}$	-120.71	-90.86	dBm

3.5 Perspectives of introduction and development of CRS in Uzbekistan

In Uzbekistan, research on use of radio frequency spectrum associated with the use of cognitive radio technology, carried out in preparation for the Communications Administration of Uzbekistan to the WRC-12 agenda item 1.19 of the conference, in accordance with Resolution 956 (WRC-07) [29]. In detail, the results of studies were discussed in Chapter 2 of this work.

Due to frequency bands allocation features the 470-790 MHz band is considered as the potential band for introduction of CRS in Region 1. Region 1 includes Europe, Africa, parts of Asia, including Uzbekistan.

In accordance with the Table of Frequency Allocations in Uzbekistan 470-790 MHz frequency band is allocated to the broadcasting service, the land mobile service, the aeronautical radionavigation service, radiolocation and radio astronomy. The most intensely this band is used by broadcasting service, also transition to digital television broadcasting is planned.

The strategy of transition to digital broadcasting provides parallel broadcasting in digital and analog standards until the required level of subscriber equipment penetration is achieved. The use of analogue broadcasting in the border area is carried out in accordance with the agreement "the Geneva-06", on the basis of which the transition period ends in 2015. In the interior regions switch-off time of analogue broadcasting can be determined by considering specific situation.

In Uzbekistan, the band 470 - 790 MHz is also used by the aeronautical radionavigation service and cable television.

Based on international experience, we can say that perspectives for development of cognitive systems in the band 470 - 790 MHz depend on the availability of affordable radio frequency spectrum to them in the "white space" and the range of permissible technical parameters of cognitive systems that provide electromagnetic compatibility with existing services.

In order to be able to talk about the perspectives of application of cognitive radio in the Republic of Uzbekistan, it is necessary to conduct a research on the assessment of available spectrum volume in the frequency band from 470 to 790 MHz.

In the study should be taken into consideration the following [37]:

- analogue and digital plan Geneva-06;
- frequency-territorial plan of transition to digital terrestrial television broadcasting in the Republic of Uzbekistan for 2010-2015;
- distribution of aeronautical radionavigation service, which is designated for government use (the band from 645 to 790 MHz). The use of WSD in these bands is not desirable, but it is possible to consider perspectives for spectrum release in these bands;
- the frequency band from 698 to 800 MHz is allocated to the mobile service for LTE technology implementation.

For development of protection criteria for existing radio services in implementation of cognitive devices ITU-R Recommendations and Reports can be taken as a basis, for example, potential models for application of cognitive radio systems and possible deployment scenarios are given in ITU-R Report M.2115 [38] and M.2117 [39].

Summary to the chapter 3

The practical issues of cognitive radio application in wireless networks were considered in this chapter. The first cognitive radio standard IEEE 802.22 and its comparison with other popular wireless network standards was provided. Dynamic access to spectrum is a key feature of IEEE 802.22 and cognitive technology is a key enabler to implement this feature in reality.

Two major techniques for cognitive functionality were reviewed. Protection of DVB-T broadcasting from WSD interference was considered in detail for the case of fixed reception at the planning height 10 m. However WSD may operate in mobile outdoor and fixed outdoor scenario corresponding to WSD height 1.5 m and 30 m. Calculations of sensing detection thresholds were carried out for both cases.

4. SAFETY OF VITAL ACTIVITY

4.1. Working conditions

Appropriate working conditions in workplaces are significant factor of efficiency of business.

4.1.1. An industrial microclimate

The most significant physical factor is the industrial microclimate, which is characterized by a level of temperature and air humidity, and also intensity of a radiation level.

The used computers do not require the creation of the special microclimatic conditions for operation and normally functions within the limits of values of temperature and humidity, allowed for the man. In sort that computers are sources of heat releases, there is a possibility of rising of temperature and descending of air humidity on work stations promoting a skin irritation. The microclimatic conditions in a room with a computer should meet the following requirements:

- Temperature of an environment in cold period of year 20 - 22°C, and 22 - 25°C in warm period;
- Relative humidity of air 30 - 60 %;
- The contents of a dust - max. 0.0001 kg/m at the dimension of particles max. 3 microns.

Another one of conditions of healthy and high-efficiency work is the provision of cleanness of air. Atmospheric air contains in its structure these in percentage terms:

- Nitrogen…………………………. ….. 78,8 %
- Oxygen …………………………. …… 20,25 %
- Argon, neon and other inert gases …… 0,93 %

- Carbonic gas ………………………… 0,03 %

Air of such structure is most favorable for breath of the man.

Network equipment and the workstations, considered in the given degree work do not produce any harmful substances during their operation. Thus, aerial environment in a room where they work does not render harmful effects on human organism and meets the requirements of first category of works.

The optimum norms of temperature, relative humidity and rate of movement of air in a working area of industrial rooms are normalized as given in the Table 4.

Table 4 - Normalized parameters of microclimate in industrial rooms.

Year season	Category of works	Temperature,° C	Relative humidity,%	Rate of air movement, m/s
Cold period	I	22 - 24	40 – 60	0,1
Warm period	I	23 - 25	40 – 60	0,1

4.1.2. Industrial lighting

The lighting is one of the major factors influencing to the productivity of work. The rationally arranged lighting on work stations of operators is an essential metric of high level labor culture, integral part of scientific organization of work and aesthetics of production. The requirements to rational room lighting are reduced to the following:

- Correct choice of light sources and lighting systems;
- Creation of a necessary level of lighting of working surfaces;
- Limiting of blinding action of light, elimination of patches of reflected light;
- Provision of uniform lighting.

The acceptable level of lighting in a room can be found if we sequentially solve two tasks:

1. To determine a required level of lighting of operator’s work station by external light sources.

2. If the required level of lighting appears unacceptable for other operators working in considered room, it is necessary to find a way of saving of required contrast of the representation by other means. For example, it is possible to arrange light flow taking into account the location of workstations and means of displaying of information.

At designing and organization of computer operator’s workstation it is necessary to undertake actions on preventing the direct and reflected patches of light. Direct patches of light occur as a result of presence of light sources directly in sight of the operator, reflected patches of light appear as a result of presence of reflecting surfaces inside of field of view. The direct patches of light can be reduced by any of the following ways: to apply reflected lighting; to use several light sources of smaller power instead of one of high power; to use means of screening of direct light from eyes of the operator.

The reflected patches of light can be reduced by the following ways:

- to use diffused light;
- to apply matted surfaces;
- to allocate direct light sources so that a visual angle of working square by the operator do not concur with an angle of incidence of light from source.

The important task is the choosing the sort of lighting (natural or artificial) and choosing a working room according to it (with windows or without windows). Natural lighting is most favorable for the working personnel. The productivity of work at natural lighting is higher than at artificial one. For sufficient natural lighting the square of windows should take not less than 1/3 part of the total square of walls. However, it is necessary to take into account that the application of natural lighting has many disadvantages: as a rule arrival of light from only one side, the space non-uniformity of illumination, etc. For elimination of these disadvantages is necessary to apply extras. The application of double light (combination of natural and artificial lighting) physiologically non-effectively and negatively affects the sight, promotes early tiredness.

The application of artificial lighting helps to avoid many of the examined weaknesses and to establish an optimum lighting mode. However, the application of rooms without windows in a number of cases establishes feeling of constraint and uncertainty for working personnel. It appears especially strongly in small size rooms. In the large rooms the given disadvantage is practically absent, so it's preferable to use here the artificial lighting - filament lamps and luminescent lamps.

Accordingly to standards, the value of lighting by luminescent lamps should not be below 300 lx in a horizontal plane for aggregate system of lighting. In view of visual operation of high accuracy the value of illuminance can be increased up to 1000 lx. Apart from the illuminance, color of coloring of a room and spectral characteristics of used light renders the large influence on the operator's activity. It is recommended, that the ceiling should reflect 80-90 %, wall - 50-60 %, and floor - 15-30 % of light, falling on them. A room, where PC is located should be light and clean. The ceilings and walls are recommended to be colored tint. In rooms where the computer equipment is placed, the conditions fit to the given requirements must be created.

4.1.3. Technical measures of protection from electric shock

All technical measures can be conditionally divided into two groups. The technical protective measures of the first group provide protection of the personnel from electric shock in case of their touch to current-carrying parts. These include:

- The supervision over conditions of isolation of electro technical devices and sections of power supply network;
- Blocking and protective guards;

- Optimum arrangement of equipment, providing severance between current-carrying parts;
- Trouble signaling (light, acoustic), marking and preventive placards;
- Protection against junction of a high voltage to the side of a low voltage;
- Application of low (42 V and 12 V) voltages;

Use of an individual protective insulating means.

The technical measures of the second group provide protection from electric shock at a touch to carcass of electro installation in case of breakdown of insulation of current-carrying parts, followings concern to them:

- Protective grounding;
- Protective zeroing;
- Protective cutoff (disconnection);
- Double isolation;
- Application of isolation transformers.

4.1.4. Electric isolation of current-carrying parts

It is known that the reliability and longevity of electro technical equipment in many respects depend on a state of electric isolation of current-carrying parts. The insulation failure is frequently a main reason of many electric traumas, crashes and fires. The physical meaning of isolation, as protective measure consists in limiting down of current, passing through a body of a man, to safe value. The reliable isolation depends on many factors and is provided with application of its certain type (operational, strengthened and double), appropriate insulating materials, rational construction of an electric equipment, standard states of the industrial environment and, at last, by correct organization of preventive maintenance in the process of technical maintenance.

As a rule, the electro technical equipment has operational isolation, which should endure extreme mechanical, electric and thermal loads, which are possible under operational conditions.

The protective ground is a deliberate junction of noncurrent-carrying metal parts of electric equipment, lighting rods and dischargers with ground. The designation of protective grounding is to lower to safe value the voltage, which originates on noncurrent-carrying parts of electro installations in case of a fault to field at an insulation failure of conductors, carrying an operational current for the equipment.

4.2 Sedentary lifestyle and its causes to human health

A sedentary lifestyle is a type of lifestyle with no or irregular physical activity. A person who lives a sedentary lifestyle may colloquially be known as a couch potato. It is commonly found in both the developed and developing world. Sedentary activities include sitting, reading, watching television, playing video games, and computer use for much of the day with little or no vigorous physical exercise. A sedentary lifestyle can contribute to many preventable causes of death. Screen time is the amount of time a person spends watching a screen such as a television, computer monitor, or mobile device. Excessive screen time is linked to negative health consequences.

4.2.1 Health effects.

A lack of physical activity is one of the leading causes of preventable death worldwide.

Sitting still may cause premature death. The risk is higher among those that sit still more than 5 hours per day. It is shown to be a risk factor on its own independent of hard exercise and BMI. The more still, the higher risk of chronic diseases. People that sit still more than 4 hours per day have a 40 percent higher risk than those that sit fewer than 4 hours per day. However those that exercise at least 4 hours per week are as healthy as those that sit fewer than 4 hours per day.

A sedentary lifestyle and lack of physical activity can contribute to or be a risk factor for:

- Anxiety
- Cardiovascular disease
- Mortality in elderly men by 30% and double the risk in elderly women
- Deep vein thrombosis
- Depression
- Diabetes
- Colon cancer
- High blood pressure
- Obesity
- Osteoporosis
- Lipid disorders
- Kidney stones

4.2.2 Solutions

One response that has been adopted by many organizations concerned with health and environment is the promotion of active travel, which seeks to promote walking and cycling as safe and attractive alternatives to motorized transport. Given that many journeys are for relatively short distances, there is considerable scope to replace car use with walking or cycling, though in many settings this may require some infrastructure modification.

Implementing wellness programs is becoming another popular trend among organizations. Wellness programs can be unique to each organization and can focus on a variety of objectives. For example, some organizations try to get their employees moving through exercise classes at lunch, or walking challenges among co-workers. Other organizations offer a number of different screenings for employees, such as cholesterol or blood pressure screenings.

It is essential that wellness programs have specific goals that provide a specific direction for the program. Goals can include tracking the number of participants who improved their fitness level, or the number of participants screened.

Incentives for increased activity may include doing activities that the person enjoys, such as walking with a friend or playing in a sports league.

4.3 Monotony

"Monotone - stress caused by the monotony of the operation, you can not switch attention, increased requirements as to the concentration and to the stability of attention"

In the course of business, in addition to the state of a state of fatigue monotony, negative effect on the mental state and human performance. "The state is caused by the actual experience of monotony and the apparent monotony of the work performed on the movements and actions. Under the influence of experiences monotony person who can not is a mental state to restrain or eliminate becomes lethargic, indifferent to the work. Monotonicity condition also adversely affects the human body, resulting in premature fatigue ".

"In the physiological basis of monotony is the inhibitory effect of monotonous repetitive stimuli. Monotony and can be experienced in mild, not tedious work ". Adversely affect the performance and experienced as unpleasant feeling. Reduces mental tension accompanied by a half-asleep state, decreased mental activity.

Historically, the monotony of work has attracted the most attention of psychologists. This was facilitated by the spread of assembly-line labor with the monotony of working operations, poverty, education and experience of the "psychological vacuum" in the minds of working on an assembly line. Value problems monotony of work increases with the advent of monotonous sensory and intellectual activity.

"The severity of this problem is not only in lost productivity and increased accidents, but also a change in personality, infringement of its contact with others, which leads to conflicts at work and at home"

A great contribution to the study of monotonous activity contributed research in the field of differential psychology. Even in his earliest works were shown the role of typological features of human resistance to repetitive work, the development of the state of monotony (VI Christmas, IA Liovochkin, NP Fetiskin, etc.).These studies revealed that the state of monotony is developing faster and more pronounced in individuals with a strong nervous system compared to those with a weak nervous system. NP Fetiskin also found that more resistant to monotony face the inertia of the nervous processes. These features form a typological typological complex monotony stabled. Opposite typological features (strong nervous system, the mobility of nervous processes, etc.) do not contribute to the stability of the monotony and form monotophobious typological complex. Research in this area have found that individuals with monotofilm typological complex state of monotony there is one and a half hours later than in those with monotophobious typological complex. Distinct and operational performance. We monotonofilly operating class performed on 33% more likely, and marriage was out in 31% of cases, while the lack of monotophobious marriage not found a single person. It is also significant that among the first positive attitude to work to meet more often occured. Persons with a typological set of not contributing monotostablity, in a shorter time than the others, fired from his job. In particular, A I Samoilov found that among workers engaged in monotonous work, dominated by people with a weak nervous system. «In general, obtained by monotonic manufactures data confirm the results of numerous laboratory experiments on a large resistance to the monotonous factor of persons with a weak nervous system». In studies Fetiskina NP an association of resistance to monotony with the properties of temperament, proved more resilient person with high rigidity (which can be associated with strongly expressed their inertia of the nervous processes), low neuroticism and introversion. In addition, resistance to monotony was higher in individuals with low and high self-esteem, the average level of claims. Also influenced by sex workers: women's resistance is higher than that of men. Contact monotostablity with a weak nervous system due to the fact that these people are more sensitive than people with a strong nervous system. Monotonous work leading to the development of such a state as a mental satiety, which in its characteristics opposite of monotony. So instead of apathy, boredom, irritation of the workers there, aversion to work, even aggressiveness. Analysis of these cases showed that mental drunkenness itself appears in individuals with a weak nervous system.

4.4 Fatigue and functional reserves of the body

The problem of fatigue is one of the important in physiology and is inextricably linked with the concept of adaptation of health, rehabilitation and functional reserves of the body. With biomedical positions fatigue associated with a particularly appropriate mobilization and utilization of cellular functional reserve, tissue, organ, system and organism levels. In the process of adaptation to the mobilization of functional reserves is carried out in accordance with the characteristics of, and the level of specificity and adaptability functions of the current state of the body. The appearance of fatigue due to the depletion of a specific queue mobilized functional adaptation reserves. Continued activity on the background of the developing fatigue is provided by the inclusion of higher-echelon mobilized reserves adaptation. The exhaustion of functional reserves of adaptation is consistent with the nature of an activity or action adaptogenic factor.

Recreation and prevention of fatigue. Work and leisure - two sides of a single process of life of the organism. Rest - state of rest or of this kind of action, which relieves fatigue and helps restore performance. More I M Sechenov established that the activities of some groups of muscles or limbs helps to eliminate fatigue that occurs during operation, in other muscle groups. This phenomenon is called active rest. Active holidays - a holiday filled with any activity other than work performed. In fatigue, mild to moderate shift work leads to a more rapid and complete recovery efficiency compared to staying alone. Active recreation is also used for mental work. Change of intense intellectual activity with its other views or light physical work leads to a rapid removal of fatigue, the disappearance of fatigue. Mechanisms of active rest, according to one of the hypotheses related to the phenomena of induction in the nerve centers: the active centers that control the activity to be used as outdoor activities, "suggest" to induce and deepen the processes of inhibition in weary centers than contribute to a more rapid recovery of their functionality . According to another hypothesis, the effects of outdoor activities are developed as a result of additional new groups of afferent receptors, thereby increasing the overall tone of the central nervous system, accelerate recovery processes. It appears that these two hypothesis are complementary. In the prevention of the development of fatigue, reducing its depth plays a big role rational organization of work and rest, taking into account the specifics of the work. So, stopping the physical work, the person you once included from the labor process, and therefore can be quite effective methods of passive recreation, especially with heavy physical labor. When mental work brain tends to inertia, continuing mental activity in a given direction. After the end of "working dominance" is completely extinguished, causing a longer CNS fatigue than physical labor. Proper organization of work includes intramuscular breaks, the use of so-called functional music. Shifts of work at different times of the day is undesirable since developed jet lag. Human performance is largely determined by the recovery processes that occur at different stages of life.

Functional music - music created for professional use in field sales, stores or factories. Using functional music solved the problem of increasing productivity, customer loyalty and creating a specialized, prompting a purchase, the atmosphere in the retail space. Functional music is a powerful tool for managing the mood of the potential buyer. Drawing attention of visitors to the products and brands represented in the commercial premises (shops, supermarkets, boutiques, cafes, restaurants, businesses, services, etc.), with the characteristic elements of a sound program, displays functional music as part of the sound atmosphere of commercial premises to the rank of marketing instrument. Compliance with the general atmosphere of functional music shopping facilities and the use of organic advertisements in the program is sound and strong motivating factor motivating the purchase. First functional music began to be used in the elevators of New York skyscrapers, in order that the people would rise in debt to feel more comfortable.

Rigidity (from the Latin. Rigidus - hard, hard) - unwillingness to change the program of action in accordance with the new situational demands. Distinguish between cognitive, affective and motivational rigidity. Cognitive rigidity - not ready to build a new conceptual picture of the world in obtaining additional information that contradicts the old picture of the world. Motivational rigidity - not ready to give up already formed and the needs of the conventional ways of meeting them, or the adoption of new motifs. May find expression in the formation of overvalued ideas. Affective rigidity - unwillingness to change in the binding of certain events with certain affective reactions. Manifests itself in difficulties in emotional learning, in excessive fixation on objects of constancy emotional evaluation of certain events, as well as in the case of the rigidity of motivation, education overvalued ideas.

Summary to the chapter 4

Safety engineering is one of the most important parts of the finally work. Because of utilization given project must be safety and security. In general every human should learn rules of occupation and safety engineering. Here is given how to use equipment and said that hand shouldn’t be bare when working with electricity devices. Also was written how to get safety working with links and cable.

CONCLUSIONS

Cognitive radio currently finds its practical application in VHF/UHF bands traditionally allocated to television broadcasting due to features of the frequency-territorial planning of terrestrial TV broadcasting and advantages of this band. However, this is only beginning as theoretically there is no limit to use cognitive functionality also in other bands.

Anyway analysis was focused on implementation of CRS in TV bands as it is first standardized in IEEE 802.22 standard. The developing IEEE 802.22 standard will allow broadband access to be provided in sparsely populated areas that cannot be economically served by wireline means, or other wireless solutions at higher frequencies, by using cognitive radio techniques to allow operation on a non-interfering basis in the VHF/UHF TV broadcast bands. This will increase the efficiency of utilization of that spectrum, and provide large economic and societal benefits.

Two main cognitive techniques used to find unoccupied channels were considered in detail: sensing and geo-location methods. Analysis showed that there are issues like hidden node problem that do not allow the CRS to operate properly if only based on sensing method. Therefore, in practice CRS uses geo-location database or a combination of geo-location with sensing in order to improve its performance. Sensing has the advantage that no other infrastructure is needed to make use of it.

Calculation of detection thresholds is provided for the case of protection of DVB-T operation from WSD which is based on sensing. Calculation results show that to protect fixed outdoor TV station which have median planned field strength E_{med} = 56.21 dBμV/m, WSD have to conclude the channel as occupied if it finds a signal with field strength more than 18.74 dBμV/m in mobile outdoor operation (WSD height is 1.5 m) and more than 45.59 dBμV/m in fixed outdoor (WSD height is 30 m) operation. These values of field strength correspond to sensed power P_{sense} equal to -120.71 dBm and -90.86 dBm respectively. Other calculated parameters may be seen from table __ in chapter 3.

Cognitive radio is one of the research frontiers in wireless communication field. Both academic and industry researchers have large interest to cognitive radio and gained many achievements. However, based on the there are still some research challenges as follows.

1. Cooperative Sensing: Distributed cooperative spectrum sensing needs further research to balance the tradeoff between accurateness and overhead better.

2. Robust Cognitive Radio: In most of the exist research works, the radio resource allocation is investigated based on perfect spectrum sensing results. Considering the error of spectrum sensing, the resource allocation schemes should restrict the outage probability that secondary users interrupt the communication of primary users.

With respect to the practical implementation in Region 1 of Radio Regulations, which includes Europe, Africa, parts of Asia and also Uzbekistan, the use of 470-790 MHz for CRS may be feasible as it comes from studies at international level. On the other hand perspectives for development of cognitive systems depend on available amount of frequency spectrum in "white space". So one of the future directions of research on CRS is towards the assesment of available spectrum in this band in Uzbekistan.

REFERENCES

1. I.A. Karimov Report at the meeting of the Cabinet of Ministers, devoted to results of social-economic development of the country in 2012 and the most important priority directions of economical program for 2013.
2. Peter Steenkiste, Douglas Sicker, Gary Minden, Dipankar Raychaudhuri Future Directions in Cognitive Radio Network Research. NSF Workshop Report. March 9-10, 2009
3. Peter Koch and Ramjee Prasad, The Universal Handset, IEEE Spectrum, April 2009.
4. Friedrich K. Jondral. Software-Defined Radio—Basics and Evolution to Cognitive Radio, 4 April 2005
5. Rodger H. Hosking. Software Defined Radio Handbook, 2012.
6. Rahim Bagheri, Ahmad Mirzaei, and Mohammad E. Heidari, University of California and WiLinx Saeed Chehrazi, Minjae Lee, Mohyee Mikhemar, Wai K. Tang, and Asad A. Abidi, University of California. Software-Defined Radio Receiver: Dream to Reality.
7. Materials from site http://www.wirelessinnovation.org/
8. J. Mitola, G. Maguire, 1999 Cognitive radio: Making software radios more personal. IEEE Personal Communications.
9. J. Mitola, 2000 Cognitive radio: An integrated agent architecture for software defined radio. Doctor of Technology, Royal Institute of Technology, Stockholm, Sweden.
10. S. Haykin, 2005 Cognitive radio: Brain-empowered wireless communications. IEEE J. on Sel. Areas in Commun.
11. I. F. Akyildiz, W. Y. Lee, M. C. Vuran, S. Mohanty, 2006 NeXt generation/dynamic spectrum access/cognitive radio wireless networks: A survey. Computer Networks (Elsevier).

12. C. Peng, H. Zheng, B. Y. Zhao, 2006 Utilization and fairness in spectrum assignment for opportunistic spectrum access. ACM Mobile Networks and Applications (MONET).

13. A. Motamedi, A. Bahai, 2007 MAC protocol design for spectrum agile wireless networks: Stochastic control approach. Proc. of IEEE DySPAN 2007.

14. S. Geirhofer, L. Tong, B. M. Sadler, 2007 Dynamic spectrum access in the time domain: Modeling and exploiting white space. IEEE Commun. Mag.

15. H. Kim, K. G. Shin, 2008 Efficient discovery of spectrum opportunities with MAC-layer sensing in cognitive radio networks. IEEE Trans. Mobile Computing.

16. Y. Xing, C. N. Mathur, M. A. Haleem, R. Chandramouli, K. P. Subbalakshmi, 2007a Dynamic Spectrum Access with QoS and Interference Temperature Constraints. IEEE Trans. Mobile Computing

17. A. Ghasemi, E. Sousa, 2007 Fundamental limits of spectrum-sharing in fading environments. IEEE Trans. Wireless Commun.

18. N. Devroye, P. Mitran, V. Tarokh, 2005 Cognitive multiple access networks, Proc. of IEEE ISIT 2005.

19. N. Devroye, P. Mitran, V. Tarokh, 2006 Achievable rates in cognitive radio channels. IEEE Trans. Inf. Theory.

20. A. Jovicic, P. Viswanath, 2006 Cognitive radio: An information-theoretic perspective. Proc. of IEEE ISIT 2006.

21. P. Cheng, G. Yu, Z. Zhang, H. Chen, P. Qiu, 2007 On the achievable rate region of gaussian cognitive multiple access channel. IEEE Commun. Letters.

22. A. Sahai, N. Hoven, R. Tandra, 2004 Some fundament limits on cognitive radio. Proc. of 42nd Allerton coference on communication, control and computing.

23. W. Wang, W. Wang, Q. Lu, T. Peng, 2009a An Uplink Resource Allocation Scheme for OFDMA-Based Cognitive Radio Networks. Wiley Int. J. of Commun. Sys.

24. S. M. Mishra, A. Sahai, R. W. Broderson, 2006 Cooperative sensing among cognitive radios. Proc. of IEEE ICC 2006.

25. Y. Xing, R. Chandramouli, C. Cordeiro, 2007b Price dynamics in competitive agile spectrum access markets. IEEE J. on Sel. Areas in Commun.

26. X. Zhou, S. Gandi, S. Suri, H. Zheng, 2 EOF 13 EOF 2008 eBay in the Sky: Strategy-Proof Wireless Spectrum Auctions. Proc. of ACM MobiCom 2008.

27. W. Wang, W. Gao, X. Bai, T. Peng, G. Chuai, W. Wang, 2007c A Framework of Wireless Emergency Communications Based on Relaying and Cognitive Radio. Proc. of IEEE PIMRC 2007.

28. R. Hinman, 2006 Application of Cognitive Radio Technology to Legacy Military Waveforms in a JTRS (Joint Tactical Radio System) Radio. Proc. of IEEE MILCOM 2006.

29. Resolution **956 (WRC-07)** Regulatory measures and their importance to enable introduction software-defined radio and cognitive radio systems.

30. ITU-R Report 2152. Definitions of Software Defined Radio (SDR) and Cognitive Radio System (CRS).

31. Sergey Pastukh, Chairman, ITU-R Working Party 1B - Software-defined radio and cognitive radio systems.

32. CPM Report on technical, operational and regulatory/procedural matters to be considered by the 2012 World Radiocommunication Conference.

33. Resolution 58 «Studies on the implementation and use of cognitive radio systems».

34. Erik Axell. Topics in Spectrum Sensing for Cognitive Radio. Link¨oping Studies in Science and Technology Thesis.

35. Ian F. Akyildiz, Brandon F. Lo ∗, Ravikumar Balakrishnan - Cooperative spectrum sensing in cognitive radio networks: A survey.

36. FCC Public Notice, Office of Engineering and Technology Announces the Opening of Public Testing for Spectrum Bridge's TV Band Database System ET DA 11-2043. - December 22, 2011.

37. Fayzullaev Alisher, On the possibility application of wireless access systems in the Republic of Uzbekistan in frequency band 470-790 MHz. AK:TTE, 2012.

38. Report ITU-R M.2115-1 (12/2009) Testing procedures for implementation of dynamic frequency selection.

39. Report ITU-R M.2117-1 (11/2012) Software-defined radio in the land mobile, amateur and amateur-satellite services.

STATE COMITEE OF COMMUNICATIONS, INFORMATIZATION AND TELECOMMUNICATION TECHNOLOGIES OF THE REPUBLIC OF UZBEKISTAN
TASHKENT UNIVERSITY OF INFORMATION TECHNOLOGIES

REVIEW

On graduate qualification work of student Grigoriev Ivan Aleksandrovich
on theme “Application of cognitive radio technology in wireless networks”

Cognitive radio is one of the research frontiers in wireless communication field. Many researchers are working towards advancing the technology for efficient spectrum use as pressure from spectrum users is growing. Cognitive technologies may be a real solution in many cases not only limited to efficient use of spectrum.

The graduate qualification work of I.A. Grogoriev is devoted to the investigation of this new technology, its basis, features and implementation issues. The main purpose of the work was to analyse the main issues of cognitive radio implementation in wireless networks, including sensing and geo-location techniques and protection of existing services. Also calculation is provided to define a WSD detection threshold for the case of fixed reception of DVB-T signal.

The main shortcoming of the work in my opinion is that standardization process of cognitive radio systems is not considered in detail. Anyway this process is underway and is not certain yet, so this point do not diminish the significance of the work.

In general the graduate qualification work of I.A. Grogoriev deserves an excellent mark and graduating student is worthy of acquiring the bachelor’s degree on the specialty 5524400 – Mobile communication systems.

the Head of television and radio broadcasting department
SUE Centre of electromagnetic compatibility B.A. Khalbaev

STATE COMITEE OF COMMUNICATIONS, INFORMATIZATION AND TELECOMMUNICATION TECHNOLOGIES OF THE REPUBLIC OF UZBEKISTAN
TASHKENT UNIVERSITY OF INFORMATION TECHNOLOGIES

SUPERVISOR’S TESTIMONIAL

On graduate qualification work of student Grigoriev Ivan Aleksandrovich
on theme “Application of cognitive radio technology in wireless networks”

With the increasing demand of wireless application, the insufficiency of spectrum is more and more serious; on the contrary, the utilization of some licensed spectrum is always low. Cognitive technologies are one of the hot topics in world-wide research on finding the ways to overcome the indicated problem.

The graduate qualification work of I.A. Grogoriev is devoted to the study of this new technology and its implementation issues. The main purpose of the work was to consider the implementation of cognitive radio in wireless networks. The consideration of sensing and geo-location techniques and protection of broadcasting service is also included. A calculation is provided to define a WSD detection threshold for the case of protection of fixed reception of DVB-T signal.

During the work on this project student I.A. Grogoriev showed himself as disciplined and responsible student with creative abilities at working with literature and finding new solutions.

The graduate qualification work of I.A. Grogoriev deserves an excellent mark and graduating student is worthy of acquiring the bachelor’s degree on the specialty 5524400 – Mobile communication systems.

the Head of Electromagnetic compatibility
analysis service, State unitary enterprize
Scientific engineering and marketing research
center UNICON.UZ A.A. Kadirov