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Software Defined Radio: Advancement to Cognitive Radio and Basic challenges in Spectrum Sensing

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Abstract: Software Defined Radio, is an architecture in which the components like modulator/demodulator, mixer, amplifier, coder/decoder are Implemented on software as a replacement for hardware. This paper presents the evolution of CR from an SDR. Due to the increase in wireless communication applications, the electromagnetic frequency spectrum is getting busy in a non uniform way. The solution to above problem is Cognitive Radio Technology. Cognitive Radio is a device which senses the frequency spectrum to detect the white space on frequency spectrum. These white spaces are called as spectral holes and they can be used by the secondary users when primary users are in idle state. This whole criteria of sensing the frequency spectrum is called as Spectrum Sensing. Spectrum sensing and basic challenges in spectrum sensing are also discussed in this paper.

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INTRODUCTION

It was Joseph Mitola, who got the idea of a radio in 1993[1]. A radio that could be reconfigured and adapted to the environment conditions. Mitola named this radio as Software Defined Radio. In mid 1990s, the SDR came into reality and was used for military purposes where each hardware component was replaced by a software code. In late 1990s, the SDR was spread from military to commercial uses. Software Defined Radio: Advancement to Cognitive Radio and Basic challenges in Spectrum Sensing But SDR could be reconfigured only by demand not according to the environment conditions. Then came the Cognitive Radio into existence, which adapts itself according to the environment activities [2][3].

A combination of SDR and CR could do which was almost impossible just a decade ago. A cognitive radio is the best application of Software Defined Radio. The purpose behind a cognitive radio is to make efficient use of electromagnetic frequency spectrum. CR is an intelligent wireless technology device where the unused spectrum is utilized by the secondary users without causing any interference to the primary users. CR senses the spectrum and detects the white spaces or spectral holes present and then these empty bands are allocated to the secondary users. The basic functions of a CR are: (a) Spectrum sensing (b) Spectrum management (c) Spectrum mobility and (d) Spectrum sharing. Spectrum sensing is most complicated task in cognitive cycle which is the basic task in cognitive cycle.

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SOFTWARE DEFINED RADIO

In SDR, the baseband operations like coder/decoder, frequency band and modulation/demodulation techniques can be altered based on the requirements. The radios with different coders, frequency bands or modulation technique can be replaced by just a single SDR with software code. There are some problems to be faced while changing a Hardware Defined Radio into a Software Defined Radio. First, there is an increase in the computations and increases the power consumption and hence decreases battery life. Secondary, the ADC/DAC converters must as close as possible to the antenna. SDRs are used to make the radios for technologies like Wi-Fi, GSM and CDMA etc [5].

A software defined radio is the one in which all the functions of physical layer are implemented on software[4].

Model for SDR

A basic architecture of an SDR consists of computer system with a sound card, analog-to-digital converter, followed by a form of RF front end. Significant amounts of processing are done either on software or hardware. In SDR transceiver, the signal can be received and transmitted as well. Figure below shows the block diagram of an SDR model, SDR is similar to a conventional radio with special property of parameterization or reconfigurability that differentiates SDRs from other transceivers. In reconfigurability the parameters can be changed as per the requirements. As shown in fig.1 the analog signal is received by the antenna An SDR works on Intermediate Frequency(IF), the signal received is to be

converted in to IF signal. The IF tuner is followed by a filter. The IF signal is then digitized by passing through an Analog to Digital Converter. The main purpose of filters in radios is to remove aliasing frequency signal in digital signal. Then we have different platforms for processing the digitized signal. It may be software or hardware platform [6][7].

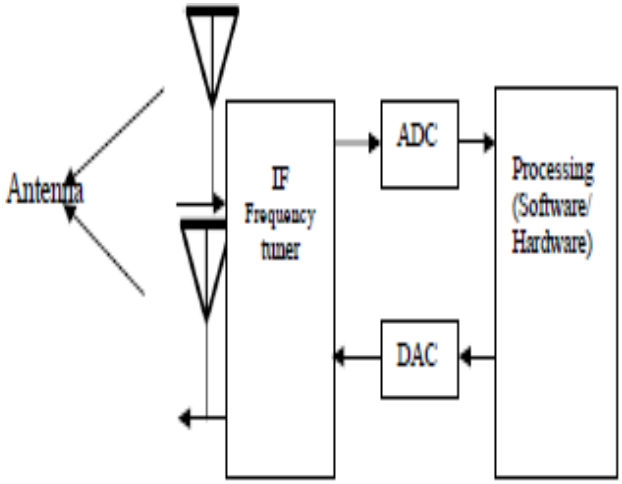

Figure 1: SDR transceiver model

Based on the operations, an SDR can function like:

1. Multiband system: Here the SDR supports more than one frequency band.
2. Multiservice system: It provides various services like telephony, data, streaming and video etc.
3. Multichannel system: It supports more than one transmission and receiver channel at a time.
4. Multistand system: That supports multiple standards. A multistandard system can come under a single standard family.

SDR Receiver

Figure 2 shows the basic model of an SDR receiver. The received analog is converted to analog IF signals by RF tuner. The IF signal is then converted into digital form by passing the signal through an analog to digital converter as shown. . These samples are fed to the next block which is the digital down converter (DDC) shown within the spotted border. The DDC is typically a huge chip or FPGA IP, and it is a heart of the SDR system. Digital Down Converter mainly comprises of mixer, local oscillator and a low pass filter. A combination of mixer and local oscillator is used in digital down counter to change the frequency of input signal. Here the function of low pass filter is to down sample the signal and the signal bandwidth is limited. Then this baseband signal is fed to a software platform like DSP where operations like modulation demodulation are carried out.

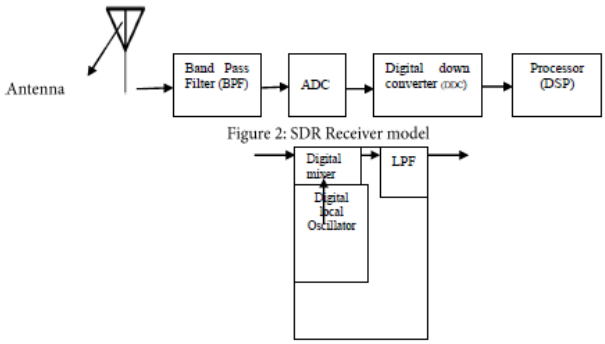

Figure 2: SDR Receiver model

Figure 3: Digital Down Converter

SDR Transmitter

For any system, receiver and the transmitter work in reverse way. A basic block of an SDR transmitter is shown in figure 4. The signal which is fed to the transmitter part is a baseband signal coming out of the DSP processor as shown in figure 4. The hardware part used here in SDR is the Digital Up converter(DUC) like we have DDC in receiver block. The function of Digital Up converter (DUC) is to convert the baseband signal back to Intermediate Frequency signal The D/A converter that follows convert the digital IF samples into the analog IF signal. Then the analog IF signal is converted to RF frequencies by RF up converter. Finally, the power amplifier boosts signal energy to the antenna.

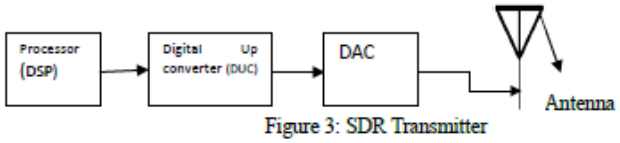

Figure 3: SDR Transmitter

Figure 4: SDR Transmitter

SDR Implementation Platforms

An SDR can be implemented on both, a software or a hardware kit. Some of the basic platforms are **Software Platforms are**:

1. GNU Radio: Python is the platform to write all radio applications and other signal processing components are explained using C++. GNU Radio Companion (GRC) is a graphical tool for producing signal flow graphs and source code.
2. Open-Source SCA Implementation Embedded (OSSIE): It works on the JTRS software communications architecture (SCA)[8].
3. Wireless Open-Access Research Platform for Network: In this syste that is built in the region of client server architecture in Python [9]. The WARP net uses PCAP (packet capture) API to communicate with the WARP board directly.

4. Cognitive Radio Open Source System (CROSS): CROSS is a cognitive radio system where sockets are used for inter-component communication

Hardware Platforms are:

1. ASICs (Application-Specific Integrated Circuits).
2. FPGAs (Field-Programmable Gate Arrays)
3. DSPs (Digital Signal Processors).
4. GPPs (General-Purpose Processors).

SDR Based Technologies

SDR also provides flexibility to other radios to increase the efficiency and reduced cost. An SDR can be used by different technologies to get useful results.

Adaptive Radio Technology: In this radio system the performance is monitored by the transiever itself and the performance measure parameters are modified to enhance the performance

Cognitive Radio Technology: CR is used to increase the usage of frequency spectrum efficiently using Spectrum Sensing.

COGNITIVE RADIO TECHNOLOGY

As there is an increase in the requirement of high data rates the electromagnetic frequency spectrum must be used in proper manner. A CR (a latest version of an SDR) is the solution of above problem to make proper use of the spectrum and this technology has got more attention from different research communities. A CR utilizes the spectrum when primary user is not present and allocates the spectrum to Secondary Users.

F. Characteristics of a Cognitive Radio are

Observation: A CR can predict the information about the environment where it works.

Adaptability: CR can be reconfigured based on requirements.

G. Cognitive cycle: A Cognitive Radio performs the following functions:

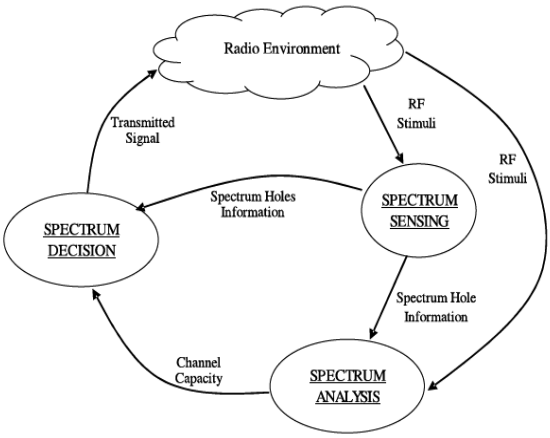

Figure 5: Cognitive Cycle

Different tasks performed by Cognitive Radio are (a) Spectrum Sensing (b) Spectrum Analysis (c) Spectrum Decision. In a cognitive cycle. Spectrum Sensing is the most difficult process to perform. Spectrum Aanalysis and Spectrum Decision tasks mainly concentrate on analyzing and allocation of the spectral holes to Secondary Users.

SPECTRUM SENSING

Due to the increase in the wireless communication applications, number of users are increasing in direct proportional manner which results in the high requirement of high data rates. Joseph Mitola invented Cognitive Radio in 1990s. This device has the capabilities of detecting the frequency spectrum and finding the spectral holes and these spectral holes are then allotted to the Secondary (unlicensed) Users till the Primary Users gets active. When Primary Users are sensed then the Secondary users either need to move to other spectral holes or to change their power levels. This is called as Spectrum Sensing. There are different Spectrum Sensing techniques as below[10]

Spectrum Sensing is mainly classified into three main types, transmitter detection, cooperative sensing and interference based sensing. In this paper transmitter detection or non-cooperative technique types are discussed in brief.

H. Transmitter Detection: This method is based on the detection of primary transmitter and it has three types

1. Energy Detection: Here the cognitive radio works on the energy being sensed from the input signal. The main parameter used in energy detection in Threshold value i.e. If the threshold value is exceeded then the primary user is present otherwise the spectrum is free and can be utilized by the Secondary User.

2.

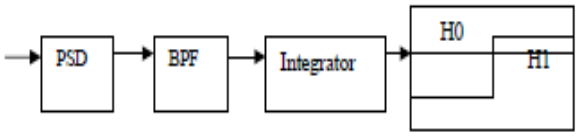

Figure 6: Energy detector block diagram

As shown above the input signal is given to a bandpass signal of a bandwidth W and then fed to an integrator. The integrated signal is then compared with a threshold value as discussed above. Systematically, signal detection can be condensed to a simple recognition problem, dignified as a proposition test,

$$p(k)=n(k)\ldots\ldots\ldots\ldots\ldots\ldots\ldots H0 \quad (1)$$

$$p(k)=h^*s(k)+n(k)\ldots\ldots\ldots\ldots\ldots H1 \quad (2)$$

Where p (k) is the sample to be analyzed at each instant k and n (k) is the noise of variance.

Consider y (k) be a sequence of established samples k €{1, 2….N} at the signal detector, then a decision rule stated as:

H0…….if €<v (H0 indicates user is absent)

H1……if €>v (H1 indicates user is present) (3)

Where e = E $|y(k)|^2$ is signal's estimated energy and v is noise variance. Energy detection method has some disadvantages like more sensing time, noise effects the performance and spread spectrum signals cannot be detected using energy detection method [11].

3. Matched Filter

In this method the Signal to Noise Ratio is increased by the filter used here. In this method we need to know about some features of primary users like frequency of operation, types of Modulation etc because the received signal has to be demodulated by cognitive radio. Matched filter method is similar to the method of correlation where an unknown signal is convoluted with the filter whose response is time shifted and mirrored version of a reference signal.

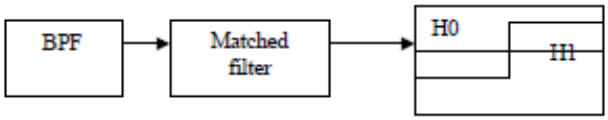

Figure 7: Matched filter

$$y(n) = \sum_{k=-\infty}^{\infty} x(k)h(n-k)$$

Where x is unknown signal and h is impulse response.

4. Cyclostationary Feature Detection

Periodicity property of a signal plays an important role to differentiate the noise and input signal in cyclostationary feature detection technique. As the name ,the input signal is detected based on the cyclostationary property of the signal, and the noise here is assumed to be a WSS noise with almost zero correlation hence it becomes easy to separate the signal and noise.

Cooperative Techniques: In this method, there is an interaction between all the users so that a proper information can be obtained about the spectrum opportunities. A single user may not be able to gather the required information about spectrum usage and multipath fading and shadowing may cause problems.

Primary Receiver Detection: Primary receiver detection is the other spectrum sensing method where the primary receiver is detected and it does not require any modification of primary users and here the primary users are detected based on the leakage power emitted by the secondary users.

BASIC CHALLENGES IN SPECTRUM SENSING

1. Sometimes it becomes very difficult to find the primary users as it takes much time.
2. Selection of modulation techniques complicates the spectrum sensing.
3. Hardware requirement is also a big challenge in spectrum sensing proper components must be chosen with appropriate processors.
4. Multipath fading, Noise or interference may interrupt the processor
5. Spectrum sensing gets complicated when primary users adopts different transmission standards.

CONCLUSION

This paper presents the basic concept of a Software Defined Radio and its basic platforms of operation, both hardware and software platforms are summarized and also how the SDR changed into a cognitive radio. Need of spectrum sensing is also summarized here. This paper also summarizes the different types of spectrum sensing techniques followed by discussion about different types of primary transmitter detection methods and finally we discussed the basic challenges faced in Spectrum Sensing.

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