International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 2 Issue 2, February- 2013

SDR Design for Cognitive Radio using MIMO-Turbo Coder

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***Abstract*— Software Defined Radio (SDR) is one of possibilities to realize the structure of device with a high mobility, flexibility and reconfigurability. This technology can provide the seamless shifting between existed air-interface standards. Extending the flexibility further, a system capable to sense the spectrum space available for communication and adapt to it is Cognitive Radio. Obviously SDR in Cognitive Radio should be configured not only to independent standards, protocols and services but also to the extensively dynamic nature of bandwidth allocation. Moreover this need of dynamic allocation of Spectrum space is a must to cater to its increased demand. Cognitive radio is envisioned as the ultimate system that can sense, adapt and learn from the environment in which it operates. Sensing the available bandwidth an SDR (Software defined radio) in a Cognitive System, tunes the circuits in the System for transferring data at optimum data rates, permissible by the space available. So it is a must for the SDR to accordingly add processing circuits to maintain the System performance at variable working frequencies. This paper discusses the critical issue of designing the SDR for the Cognitive radio and also presents some useful results obtained to configure the SDR for higher bandwidth available in Cognitive Radio. Results of Frequency Hopping Spread Spectrum (FHSS) implementation, Codec Algorithm modifications, and decoder iterations variation and performance improvement using OQPSK are depicted in the paper.**

***Keywords*— SDR (Software defined radio), Cognitive Radio, Codec algorithms, FHSS (Frequency Hopped Spread Spectrum), Matlab programming**

I. Introduction

Radio spectrum is one of the most scarce resources for wireless communications and its demand is growing rapidly in order to support a wide range of high data rate applications over wireless system. On the other hand, practical measurements have revealed that some of the allocated spectrum bands are not utilized efficiently in many geographical locations.

In many bands, spectrum access is a more significant problem than physical scarcity of spectrum, in large part due to legacy command-and-control regulation that limits the ability of potential spectrum users to obtain such access. Cognitive radio (CR) offers an approach to alleviating the congestion: they continually sense the spectrum, detect and utilize unoccupied channels.

Cognitive radio is an intelligent wireless communication system that is aware of its environment, and uses the methodology of understanding-by-building to learn from the environment and adapt its internal states to statistical variations in the incoming RF by making corresponding changes in certain operating parameters in real time.

A radio is a kind of device that wirelessly transmits or receives signals in the radio frequency (RF) part of the electromagnetic spectrum to facilitate the transfer of information. Traditional hardware based radio devices limit cross functionality and can only be modified through physical intervention. By contrast, software defined radio technology provides an efficient inexpensive solution that can be enhanced using software upgrades.

SDR is a flexible architecture that is applicable to many radio channels. Joseph Mitola coined the term software radio, to signal the shift from digital radio to multiband multimode software defined radios. The most benefit is loading an appropriate program instead of having to build extra circuitry for different types of radio signals and communication protocols.

This paper organized as follows. Section II briefly explains the Software Defined Radio and Cognitive Radio. In Section III, various types of coders that varies the performance of the signal. The results of these coders carried out using MATLAB is shown in Section IV. Finally, Section V concludes the paper and gives the future work to be done.

II. SDR and CR

The introduction about Software Defined Radio (SDR) and Cognitive Radio (CR) are given below:

A. Software Defined Radio

A number of definition are there for Software Defined Radio and it is also known as Software Radio. Software Defined Radio is defined as "*Radio in which some or all of the physical layer functions are software defined*".

The use of this technologies allows new wireless features and capabilities to be added to existing radio systems without requiring new hardware. SDR defines a collection of hardware and software technologies where some or all of the radio's operating functions are implemented through modifiable software or firmware operating on programmable processing technologies.

There are various hardware platforms and the software platforms that are used for defining the software radios. The hardware of a SDR platform consists of the Radio Frequency (RF) parts, communications links to the software based signal processing elements, Application-Specific Integrated Circuits (ASICs), Field-Programmable Gate Arrays (FPGAs), Digital Signal Processing (DSPs), General Purpose Processors (GPPs).

The SDR software platform consists of the GNU Radio, Open-Source SCA Implementation – Embedded (OSSIE), Wireless Open-Access Research Platform for Network (WARPnet), Cognitive Radio Open Source System (CROSS), High Power SDR, Flex Radio Systems, etc.

B. Cognitive Radio

Depending upon the set of parameters taken into account deciding on transmission and reception changes and for historical reasons, we can distinguish various types of Cognitive Radio. The main types are: Full Cognitive Radio and Spectrum Sensing Cognitive Radio.

The main problem of Spectrum Sensing Cognitive Radio is in designing high quality spectrum sensing devices and algorithms for exchanging spectrum sensing data between nodes. Increasing the number of cooperating sensing nodes decreases the probability of false detection.

The applications of Spectrum Sensing Cognitive Radio are emergency network, WLAN higher throughput, transmission distance extensions, etc.

The main functions of Cognitive Radio are spectrum sensing, spectrum management, spectrum mobility, spectrum sharing.

Once a high bandwidth is sensed, we have two options and they are:

- To transmit small packets of data with high accuracy, required in Emergency Services (time bound emergency information should take care of data reduction to minimum possible size so as to utilize low data rates where BER is low).
- To transmit bulk data at higher data rate e.g. real time applications like Mobile Services.

III. Codec Variation and Techniques

To transmit small packets of data with high accuracy one must lower down the Bit error rate. The coders used in this paper are shown below:

A. Reed-Solomon Coder

The Reed-Solomon codes are block-based error correcting codes with a wide range of applications in digital communications and storage. Reed-Solomon codes are used to correct errors in many systems such as storage devices, wireless or mobile communication, satellite communication, etc.

The Reed-Solomon encoder takes a block of digital data and adds extra "redundant" bits. Errors occur during transmission or storage for a number of reasons. The Reed-Solomon decoder processes each block and attempts to correct errors and recover the original data. The number and type of errors that can be corrected depends on the characteristics of the Reed-Solomon code.

B. Convolutional Coder

A convolutional code is a type of error correcting code in which each m-bit information symbol to be encoded is transformed into an n-bit symbol, where m/n is the code rate ($n \geq m$) and the transformation is a function of the last k information symbols, where k is the constraint length of the code.

The convolutional codes are used extensively in numerous applications in order to achieve reliable data transfer including digital video, radio, mobile communication and satellite communication.

The encoder has n modulo-2 adders that can be implemented with a single Boolean XOR gate and n generator polynomials – one for each adder. Several algorithms exist for decoding convolutional codes. For relatively small values of k, the viterbi algorithm is universally used as it provides maximum likelihood performance. Longer length codes are more practically decoded with any of several sequential decoding algorithms, of which the Fano algorithm is the best known. Both viterbi and sequential decoding algorithms return hard decisions: the bits that form the most likely codeword.

C. Turbo Coder

The Turbo coder is a High-performance forward error correction (FEC) codes, developed in 1993. It is the first practical codes to closely approach the channel capacity, a theoretical maximum for the code rate at which reliable communication. Turbo coders are used in 3G mobile communications, satellite communications as well as other applications where designers seek to achieve reliable information transfer.

The Turbo coder consists of two convolutional encoders. The outputs of the turbo encoder are the information sequence, together with the corresponding parity sequence produced by first encoder and the parity sequence produced by the second encoder block, the input to second encoder is through interleaver, which scrambles the data bit sequence.

The turbo decoder consists of M elementary decoders, one for each encoder in turbo encoding part. The SDR should choose the number of decoder iterations based on the value of BER that is tolerable and real time applications must also take into considerations the time required for the decoding.

ISSN: 2278-0181
Vol. 2 Issue 2, February- 2013

D. FHSS Technique

Frequency Hopping Spread Spectrum (FHSS) is a method of transmitting radio signals by rapidly switching a carrier among many frequency channels, using a pseudorandom sequence known to both transmitter and receiver. It is utilized as a multiple access method in the frequency-hopping code division multiple access (FH-CDMA) scheme.

The SDR should make use of Frequency Hopping Spread Spectrum (FHSS) Techniques. The SDR in Cognitive Radio has the advantage of the inherent frequency hopping nature. Slow or Fast FHSS can be adopted depending upon the availability of Spectrum holes, feasibility of implementation and the data security needed.

IV. RESULTS AND DISCUSSION

The MATLAB software is used for getting the output waveforms of various coders, FHSS implementation and retrieval of original sequence.

The Fig.1 shows the results of FHSS implementation. The x-axis plots the bit sequence & the y-axis depicts the signal level. It is also evident from the figures that the spectrum of the signal is significantly spread and it is transmitted with a large numbers of frequencies.

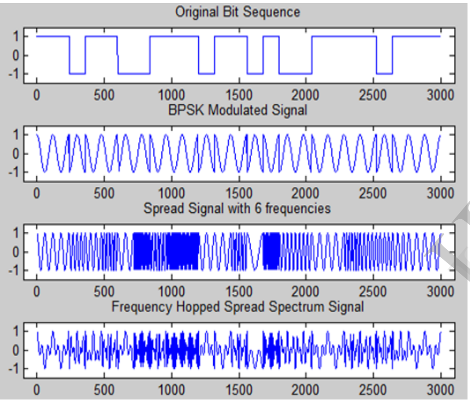

Fig.1 FHSS implementation

The SDR should use OQPSK, in place of the QPSK modulator-demodulator of the existing Wi-Max System. In OQPSK, we are using an offset of π/4. The π/4 shifted QPSK modulation is a quadrature phase shift keying technique which can be demodulated in a coherent or non-coherent fashion. In π /4 QPSK, the maximum phase shift is limited to +/- 135 degrees. By offsetting the timing of odd and even bits, the in-phase and quadrature components will never change at the same time. This will limit the phase shift to not more than 90° at a time. This reduces amplitude fluctuations and the phase shifts from maximum of 180° to a maximum of 135° and helps improve spectral efficiency.

In the fig.2, the plot of Signal to Noise Ratio (SNR) vs Frame Error Rate (FER) for Reed-Solomon coding with QPSK signal is shown. The frame error rate can be reduced as the SNR ratio is increased.

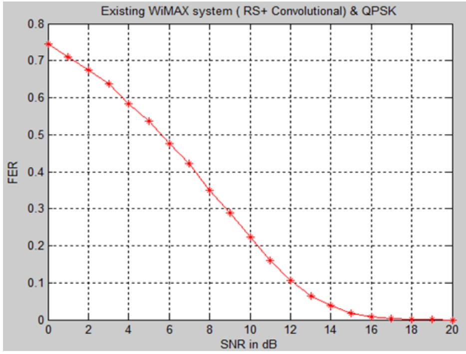

Fig.2 Plot for RS+Convolutional with QPSK

This fig.3 shows the plot of SNR vs FER for Reed-Solomon + Convolutional coding technique with OQPSK. Here the reduction of FER is improved compared to QPSK signal.

The fig.4 shows the plot of SNR vs FER for turbo coding and decoding technique. Here the reduction of FER is further more improved compared to other convolutional and RS coding technique.

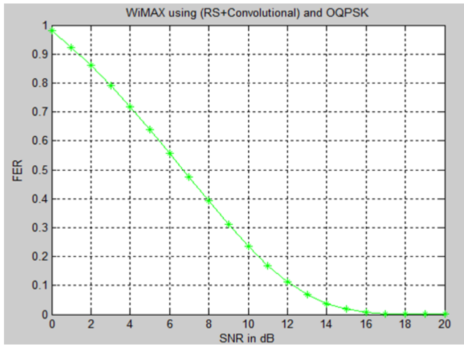

Fig.3 Plot for RS+Convolutional with OQPSK

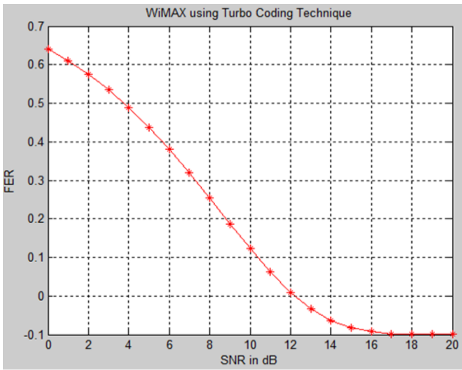

Fig.4 Plot for Turbo coding technique

In the fig.5, the Frequency Hopped Spread Spectrum (FHSS) demodulation and retrieval of Binary PSK is given. Six arrays are created by point to point multiplication of the received sequence with the six different carrier frequencies. One of such six arrays is shown in these figures.

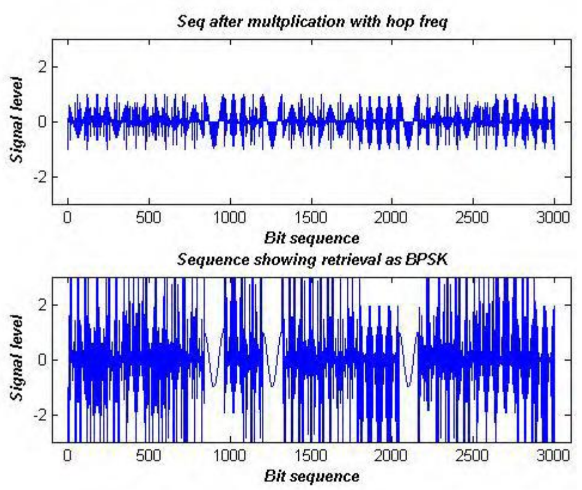

Fig.5 FHSS Demodulation and Retrieval of BPSK signal

The retrieval of the original bit sequence is shown in the fig.6. Finally, all the demodulated arrays are clubbed together to generate the received bit sequence and hence the entire bit sequence.

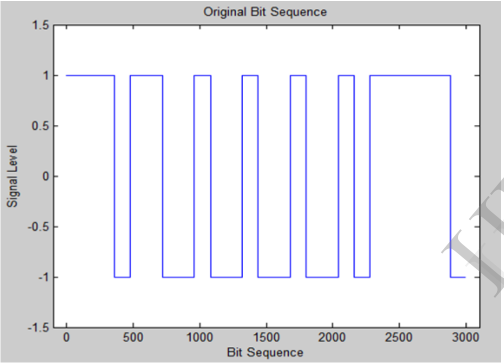

Fig.6 Retrieval of entire bit sequence

V. CONCLUSION

Cognitive users monitor the spectrum and are allowed to use it as long as it does not interfere with primary users to whom it has been licensed. SDR will have a key role to play, in the Cognitive Systems. The SDR algorithms for successful data transmission in bandwidth available are proposed here. CODEC adaptations, OQPSK to replace QPSK, the implementation of FHSS Modulation & demodulation in MATLAB, to be utilized to maintain the BER at high data rates and the perceptual coding techniques for lossless data compression are presented. The degree of compression and modification in already existing algorithms is again another critical issue to handle by SDR.

The future work of this paper is to provide the subcarrier and power allocation problem for orthogonal frequency division multiple access (OFDMA)-based cognitive radio (CR) systems.

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