Spectrum Sensing Smart Codec Design for Cognitive Radio

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Abstract: Recently, Cognitive Radio has been proposed as a promising technology to improve spectrum utilization. A highly flexible SDR (Software defined Radio) system needs to configure each of its blocks to give optimum performance over the available bandwidth. Present work discusses an approach for rate adaptive coder yielding minimum BER (Bit error rate) for emergency services over cognitive radio. The results verify the efficiency of the algorithm which configures the convolution encoder to produce a lower BER for increased Bandwidth available. This can be readily implemented in the SDR library functions. This has been tested by FPGA implementation of the convolution encoder using Matlab HDL coder. The coder output of the FPGA implemented VHDL code has also been presented.

Key-Words: - Cognitive Radio, SDR library, Rate Adaptive Coder, BER, FPGA implementation.

1 Introduction
Current wireless networks are characterised by a static spectrum allocation policy, where governmental agencies assign wireless spectrum to license holders on a long-term basis for large geographical regions \cite{1}. Over last couple of years spectrum demand has increased many folds. Spectrum allocation policy has faced spectrum scarcity in particular spectrum bands. In contrast, a large portion of the assigned spectrum is used sporadically, leading to underutilization of significant amount of spectrum \cite{2}. Hence, dynamic spectrum access techniques were proposed to solve these spectrum inefficiency problems.

The key enabling technology of dynamic spectrum access techniques is Cognitive radio. Joseph Mitola III and Gerald Q. Maguire who first officially presented the idea of Cognitive Radio \cite{3}, define it as “Cognitive radio is an intelligent wireless communication system that is aware of its Radio Frequency (RF) environment, and uses the methodology of understanding-by-building to learn from the environment and adapt its internal states to statistical variation in the environment by making changes to adjustable parameters, namely transmit power, carrier frequency and modulation strategy, all in real Time” \cite{Mitola 1999}.

This Paper introduces the Cognitive Concept, defines the problem as coder adaption to available bandwidth. Thereafter, putsforth the algorithm of the Smart Codec for problem solution justifying its applicability by presenting the simulation and Hardware implementation results. Earlier work included transmitter power required and modulation strategy for WiMax System. It was shown that the OQPSK system in place of the conventional QPSK system improves BER performance and requires a lower transmit power \cite{4}.

2 Cognitive Radio
A typical Cognitive Cycle begins with Radio scene analysis, identifying the spectrum holes (unoccupied or underutilized spectrum spaces). Performs channel estimation for the channel capacity, channel state, transmit power, transmit frequency etc. Issues signal for transmit power control and spectrum management (work on channel estimation has regards use of RS encoder for presence of Burst Errors has already been carried out \cite{4}). Finally establishes connection with proper
initial handshake with receiver. Figure below shows the cognitive cycle [3].

Fig. 1. Cognitive Cycle

Depending on the set of parameters taken into account in deciding on transmission and reception changes, and for historical reasons, we can distinguish certain types of cognitive radio. The main two are:

2.1 Full Cognitive Radio ("Mitola radio"):
In which every possible parameter observable by a wireless node or network is taken into account.

2.2 Spectrum Sensing Cognitive Radio:
In which only the radio frequency spectrum is considered.

2.3 Licensed Band Cognitive Radio:
In which cognitive radio is capable of using bands assigned to licensed users, apart from unlicensed bands, such as U-NII band or ISM-Band. The IEEE 802.22 working group is developing a standard for wireless regional area network (WRAN) which will operate in unused television channels.

2.4 Unlicensed Band Cognitive Radio:
This can only utilize unlicensed parts of radio frequency spectrum. One such system is described in the IEEE 802.15 Task group 2 specification, which focuses on the coexistence of IEEE 802.11 and Bluetooth.

Main Functions of Cognitive Radio:
1. Spectrum Sensing- This involves Primary Transmitter detection. Cognitive Radios must have capability to determine if a signal from a primary transmitter is locally available. Matched Filter detection, Energy detection, etc are the methods utilized for Primary Transmitter detection. A method called Cooperative detection is also sometimes utilized, wherein information from multiple Cognitive Radio users is incorporated for primary user detection.

2. Spectrum Management- Spectrum analysis & Spectrum decision are the important tasks to be carried out in Spectrum Management.

3. Spectrum Mobility- This should ensure seamless operation & accordingly exchange operating frequencies.


Present work is for the Spectrum Sensing Cognitive Radios. Once a bandwidth is available, if the available bandwidth is wide enough we have two options:

- To transmit bulk data at higher data rate e.g. real time applications like Mobile Services.
- 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).

Present work focuses on the second option for improving the BER performance of the system.

3 Modelling & Simulation of Spectrum Sensing Smart Codec For Cognitive Radio

The first step in modelling was to prepare a simple Digital Communication System model to test the encoder decoder design. This was done using Matlab Simulink. The Model is as shown in fig. 2. After testing the functionality of the codec in the DCOM System a gate level model of the encoder
was prepared, noting the fact that Matlab Simulink to HDL Converter supports only the behavioral level blocks. The Gate Level design of the Encoder is as shown in fig. 3. These steps were carried out to test the hardware implementation possibility of the codec.

As seen in fig. 1 the Cognitive Cycle begins with Radio Scene Analysis, Scanning for Spectrum Holes. Once the bandwidth is available, in the available bandwidth the transmit frequency is decided. So an M-File for bandwidth selection was written [5], [6]. Now the input signal in a Digital Communication System is a digital data (binary bits), obtained from an analogue source. Common example of analogue source is a Speech signal, which varies from 300Hz to 3300Hz. This will decide how many digital data bits are present over the observation time. In the model data bits are randomly generated to represent random speech signal. The bit generation frequency also changes, considering the variations in human speech. We are not concerned with the amplitude variations. Adaption is with regards to frequency & it should be shown that it is dependant on channel bandwidth and is independent on the frequencies in Input data. It is therefore that the model as been worked out for varying frequencies of input data & performs equally well over the entire specified range of frequencies of input data. Thus, the model now takes the shape with three parameters as user defined viz.

1. Input data start frequency,
2. Input data End Frequency and
3. Observation Time.

A simple Digital Communication System for commercial communication working over the available bandwidth was modeled with rate ½ convolution encoder [4], [7]. This was termed as a non adaptive system, wherein it was found that as Bandwidth increases the BER also increases (graph plotted is shown in fig. 5).

To make the system adaptive i.e. as bandwidth increases one should be able to send data with higher accuracy, the codec algorithm is made efficient with additional bits and additional sequential & combinational logic. This definitely increases the computational time but drastically reduces the BER. High speed processors should take care of this increase in computational time. Typical values of computation time required for varying number of bits per frame is quoted in Table 1.

The reduction in BER with adaptive coder is plotted and the corresponding graph is shown in fig.6. The convolution encoder in Matlab was HDL coded and the code was downloaded in FPGA [8], [9]. The Input data bits and coded output of the rate ½ encoder is also presented in the results. The entire work flow can be briefly depicted in the block diagram shown in fig.4.

### 4 Results

To observe the results in the form of bits on the computer screen and to plot the graphs the working frequencies were scaled down. The model works equally well at high frequencies and was tested for few sample data at high frequencies. The problem faced was that the simulation time taken increases to hours, due to the computational time required in finding the checksum bits that are derived from input bit streams. High frequency is high data bit rate i.e. more no of bits in a given frame. Every checksum bit is derived with a combinational and sequential logic utilizing the input as the input bit stream.

The first model was of a simple non adaptive digital communication system wherein the codec does not adapt to the available bandwidth. It was found that as the bandwidth increases the BER increases, as is clear from graph in fig 5.
The second model was prepared with an algorithm to adapt to the increasing bandwidth and utilizing this bandwidth to make the data more secure i.e. to reduce the BER.

![Fig. 5. BER on Y-Axis vs. Bits per frame on X-Axis for non adaptive Codec](image1)

The graph in fig. 6 shows that the adaptive codec reduces the BER with increase in frame size that has resulted from increase in bandwidth.

![Fig 6. BER on Y-Axis Vs. Bits per frame on X-Axis for adaptive Codec](image2)

The simulation output of the FPGA implemented HDL code of convolution encoder is shown in fig.7 & fig.8

![Fig 7. 0 to 7 input bits & 0 to 10 output coded bits waveform](image3)

![Fig 8. 4 to 7 input bits & 0 to 15 complete coded bits waveform.](image4)

4 Conclusion

Cognitive radio is an innovative technology proposed to increase spectrum usage by allowing dynamic allocation of the unused spectrum in changing environments. 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. We have proposed the design of a Smart Codec using convolution codes wherein the codec senses the spectrum available and accordingly modifies the algorithm for coding –decoding. An increase in bandwidth is utilized for reducing the BER. The hardware encoder had been realized by downloading the HDL code into FPGA.
References:


Fig. 2  Simulation Model of Simple Digital Communication System, prepared in Matlab Simulink

Fig. 3  Gate Level Design of the Convolution Encoder for Simulink to HDL Conversion