Software Defined Adaptive Codec 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 software defined 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. Various WiMax Systems to be included in the SDR Library are puttforth. SDR adapts to the best suitable design, yielding lower BER in available channel conditions.

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 [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 [2]. Spectral occupancy measurements consistently show that some bands are under-utilised in some areas at some times. Results from Ofcom website are depicted in fig.1. The blue bands are low signal levels, indicating sparse utilization of the spectrum Space, whereas the brown bands indicate high signal level that is heavy utilization of Spectrum Space. The inefficiency in Spectrum Utilization is obvious. 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 [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" [Mitola 1999].

This Paper introduces the Cognitive Concept, defines the problem as coder adaption to available bandwidth. Thereafter, puttsforth 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 [4]. The results of the same have been depicted here and algorithms included in SDR library.

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 [4]). Finally establishes connection with proper initial handshake with receiver. Figure below shows the cognitive cycle [3].

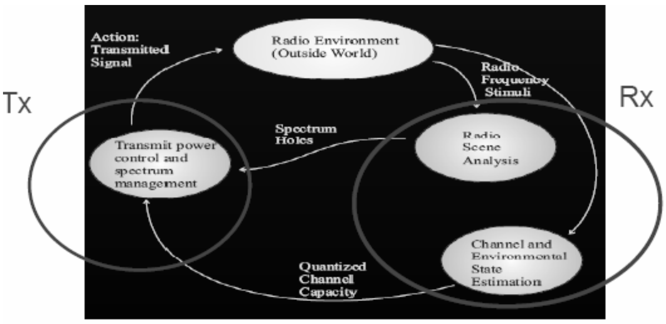

Fig. 2 Cognitive Cycle

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 this every possible parameter observable by a wireless node or network is taken into account.

2.2 Spectrum Sensing Cognitive Radio:

In this only the radio frequency spectrum is considered.

Besides the above types, based on the Spectrum Bands available for communication Cognitive radio can be further categorised into the following two categories,:

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 bands 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.

4. Spectrum Sharing- Spectrum Scheduling method takes care of sharing the available spectrum.

Work presented here is for the Spectrum Sensing Cognitive Radios. If the spectrum sensed is with higher bandwidth than 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).

Work presented 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 modeling 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. 3.A a complex convolutional encoder with a constraint length of 7 (see Figure 4)was designed.

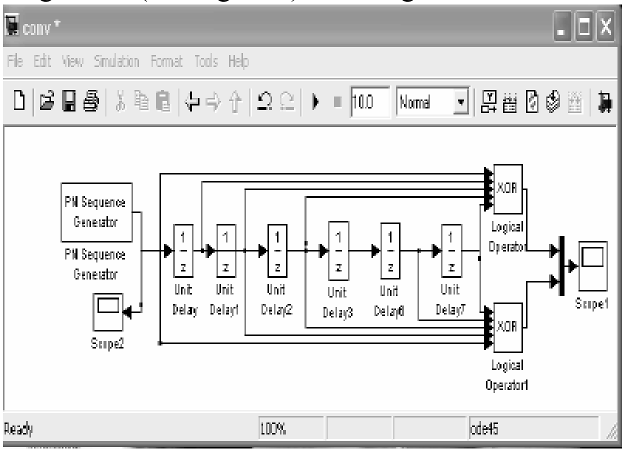

Fig 4. MATLAB Simulation of Convolution Encoder

The generator polynomials for this encoder are g0 = 171oct

and g1 =133oct.

The encoder can easily be implemented in hardware shift registers.

The first step is to represent the input bit string as a polynomial. Any sequence of 0's and 1's can be represented as a binary number or a polynomial.

The convolutional encoder for WiMAX (g0 = 171oct and g1 = 133oct) can be represented as follows:

- $g0 = 1 + D + D2 + D3 + D6$
- $g1 = 1 + D2 + D3 + D5 + D6$

The convolutional encoder basically multiplies the generator polynomials by the input bit string, as follows:

- $A(x) = g0(x) * I(x) = a\ b\ c \ldots g$
- $B(x) = g1(x) * I(x) = P\ Q\ R \ldots V$

Interleaving the two outputs from the convolutional encoder yields $E(x) = aPbQcR \ldots gV$, which can also be written as:

$E(x) = (a0\ b0\ c0 \ldots g0) + (0P0Q0R \ldots 0V) = A(x2) + x*B(x2)$

Therefore, $E(x) = A(x2) + x * B(x2)$ and $A(x2) = g0(x2) * I(x2)$

and $B(x2) = g1(x2) * I(x2)$, with the following:

$E(x) = g0(x2) * I(x2) + x * g1(x2) * I(x2)$

$= I(x2) * (g0(x2) + x * g1(x2))$

$= I(x2) * G(x)$ where

$G(x) = g0(x2) + x * g1(x2)$

i.e. $G(x) = 1 + x + x2 + x4 + x5 + x6 + x7 + x11 + x12 + x13$.

If the BER performance need to further Improved a Turbo codec replaces the normal convolutional codec.

TURBO ENCODER

It 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. Simulation model of Turbo encoder –decoder is shown in fig 5.

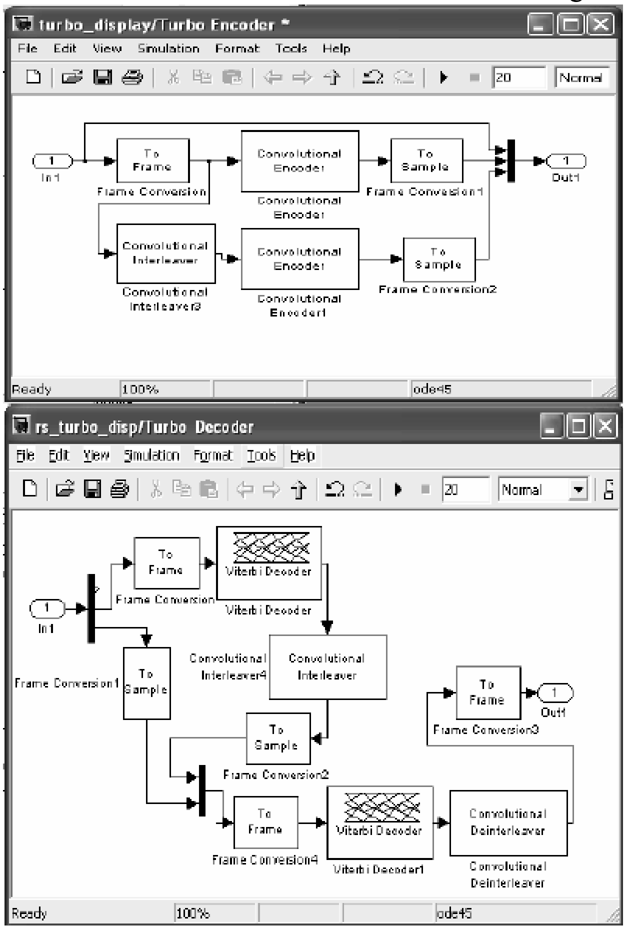

Fig. 5 SIMULINK Model of Turbo Encoder-Decoder

TURBO DECODER

Turbo decoder shown above in Fig. 5 uses iterative decoding. The turbo code decoder is based on a modified Viterbi algorithm that incorporates reliability values to improve decoding performance. The turbo decoder consists of M elementary decoders - one for each encoder in turbo encoding part. Each elementary decoder uses the Soft Decision Viterbi Decoding to produce a soft decision for each received bit. After an iteration of the decoding process, every elementary decoder shares its soft decision output with the other M - 1 elementary decoders.

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. 6. These steps were carried out to test the hardware implementation possibility of the codec.

As seen in fig. 2 the Cognitive Cycle begins with Radio Scene Analysis, Scanning for Spectrum Holes(Unoccupied spectrum spaces). 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 has 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 user defined parameters as 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. 8.

An adaptive physical layer schemes is the transmitter action in response to time varying channel quality which is related to many factors. A reliable estimation of the channel transfer quality is required for the next active transmit time slot so the transmitter has to select appropriate modulation and channel modes [8].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.

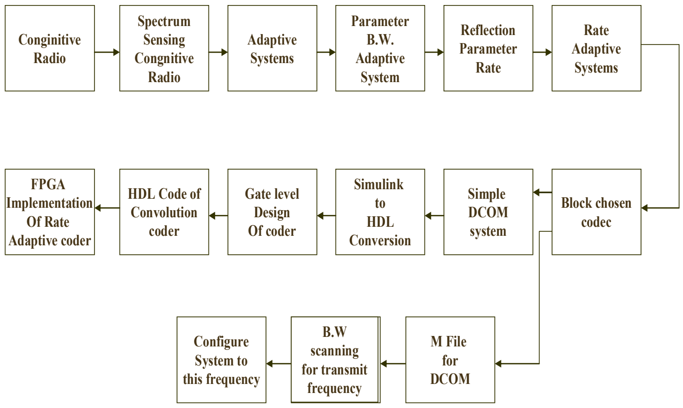

Fig. 7 Work Flow

TABLE I
BITS PER FRAME VS COMPUTATIONAL TIME & CORRESPONDING BER

Sr. No	Bits per Frame	Computation Time	BER
1	5	3 min	0.1340 E -2
2	7	7 min	0.1184 E-2
3	10	15 min 10 sec	0.1071 E-2
4	15	1 hour 36 min	0.0750 E-2

The reduction in BER with adaptive coder is plotted and the corresponding graph is shown in fig.9. The convolution encoder in Matlab was HDL coded and the code was downloaded in FPGA [9], [10]. 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.7.

4 Results

The software chosen for modeling was Matlab 7.4. The Computer used had a Pentium processor with 2.4 GHz processing speed & 512 Mb RAM. 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. Therefore 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 too. 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 8.

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.

The graph in fig. 9 shows that the adaptive codec reduces the BER with increase in frame size that has resulted from increase in bandwidth.

The simulation output of the FPGA implemented HDL code of convolution encoder is shown in fig.10 & fig.11

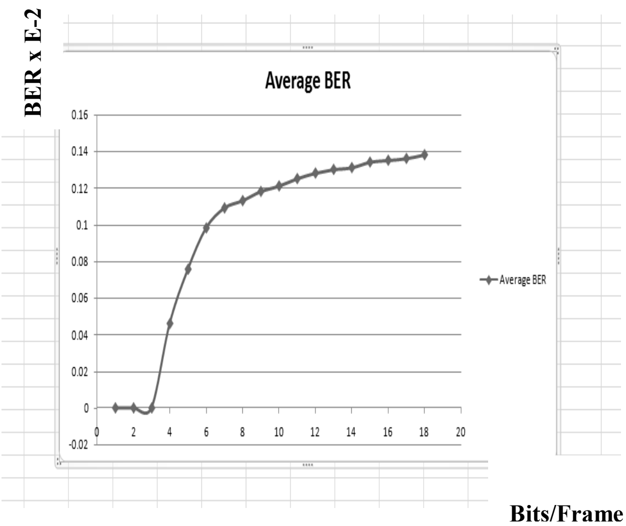

Fig. 8. BER on Y-Axis vs. Bits per frame on X- Axis for non adaptive Codec

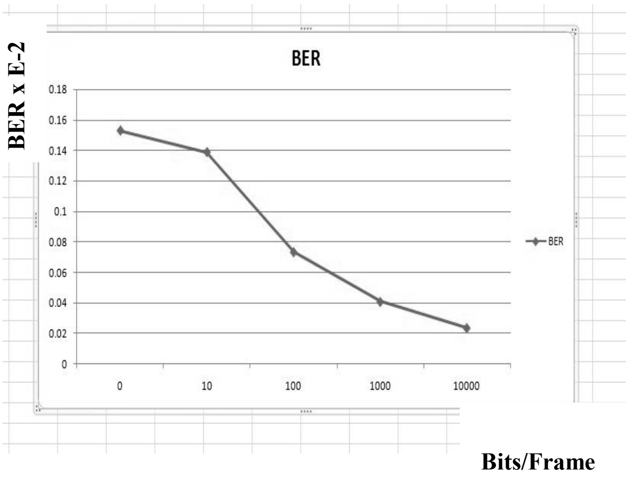

Fig 9. BER on Y-Axis Vs. Bits per frame on X-Axis for adaptive Codec

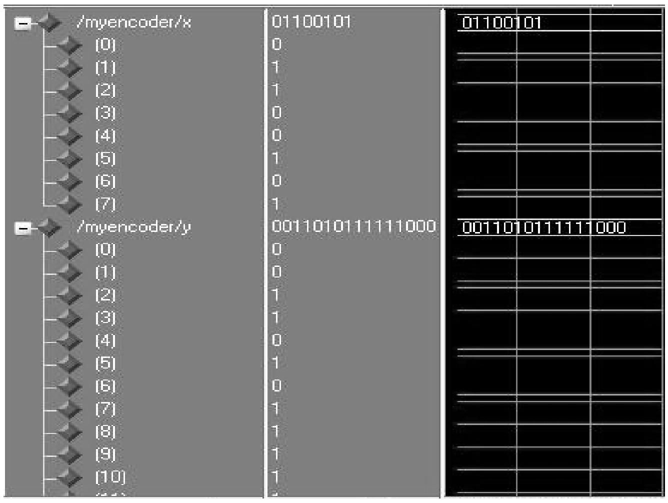

Fig 10. 0 to 7 input bits & 0to 10 output coded bits waveform

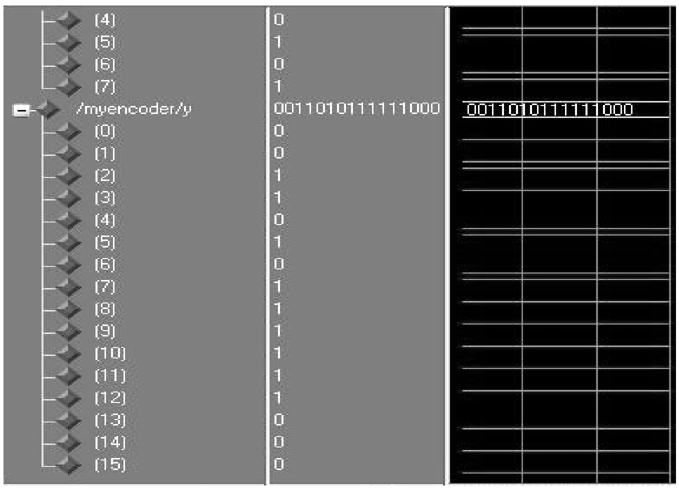

Fig 11. 4 to 7 input bits & 0to 15 complete coded bits waveform.

The Simulation models in case of WiMax were prepared for following four systems [4]:
1. WiMax using RS+ Convolutional Codec and OQPSK [11]
2. Existing WiMax system(RS + Convolutional) and QPSK
3. WiMax using RS+ Turbo Codec and QPSK
4. WiMax using Turbo Codec and QPSK
Each of them was observed for bit error rate at different values of S/N (signal to noise ratio). Graphs of S/N versus BER(bit error rate) were plotted and are as shown in fig 12.

The SDR chooses the system design based on the following observation, as is observed in fig 12.
1. The turbo concatenation with RS gives desired performance of decreasing the bit error rate with increasing S/N.
2. Using only Turbo codes for the Codec design, works perfect as far as simulation is concerned. But real time systems will introduce Burst errors. To reduce burst errors RS coding is a must.
3. More over, it was observed that every system requires different signal power for the receiver to interpret the data. The Turbo concatenated system works fine with low power signals as compared to only RS codec system.
4. Also the OQPSK system can respond to much low level signals in comparison with the existing QPSK systems and produce a much lower BER.

4 Conclusion

Cognitive radio is an innovative technology proposed to increase spectrum usage by allowing dynamic allocation of the unused spectrum in changing environments. By exploiting the existing wireless spectrum opportunistically, Cognitive Radio Networks are being developed to solve current network problems resulting from the limited available spectrum usage. Cognitive Network 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. The hardware encoder had been realized by downloading the HDL code into FPGA. An increase in bandwidth is utilized for reducing the BER.

5 Work in Progress

Authors of the paper are actively involved in performance improvement of BER. More precisely when the channel is in Cognitive Network, adaption to the available Bandwidth without deterioration of the performance parameters is a must. Present work focused on improving the BER performance with availability of higher Bandwidth. The available BW can be utilized to increase the data rates. In such situations maintaining the BER performance seems to be difficulty. A probable solution is use of Multicarrier modulation, as suggested by Haitham J. Taha & M. F. M. Salleh [12]. This has given me an idea to carry out future work with Spread Spectrum Techniques.

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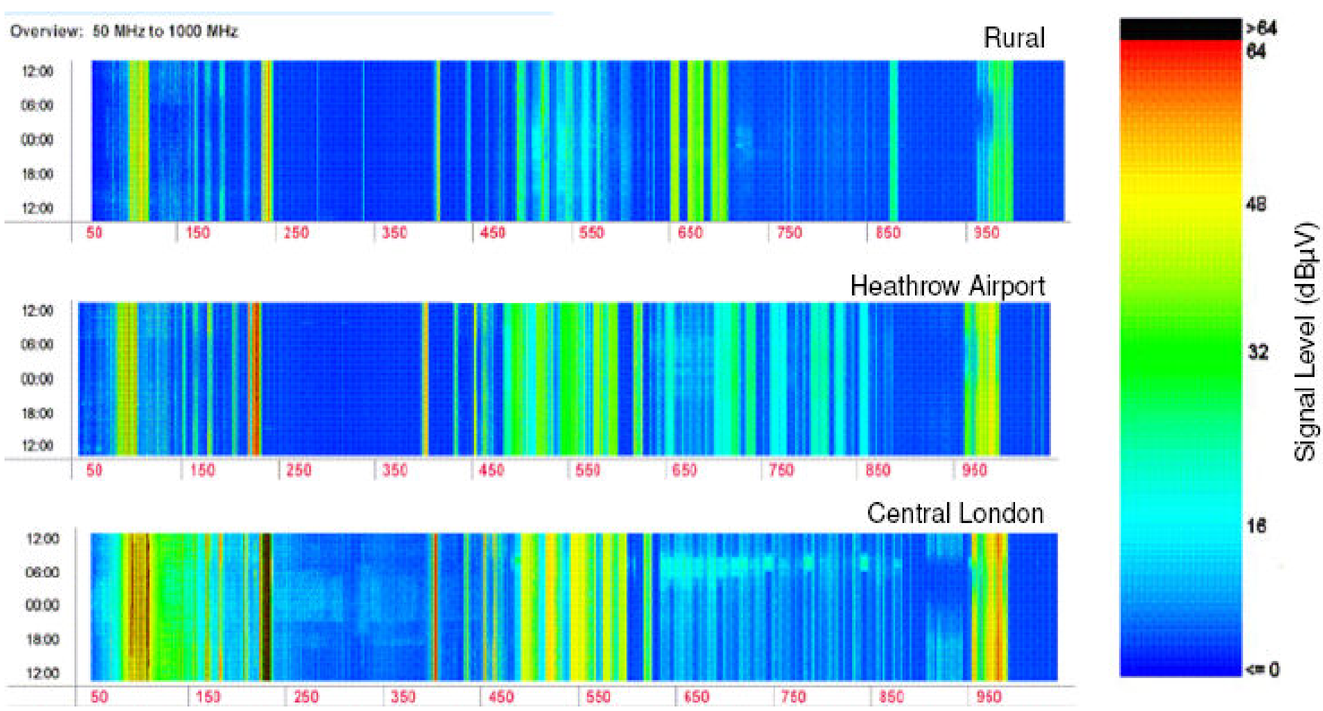

Fig.1. Spectral Occupancy Measurements From Ofcom Web Site- http://www.ofcom.org.uk/research/technology/research/emer_tech/cograd/

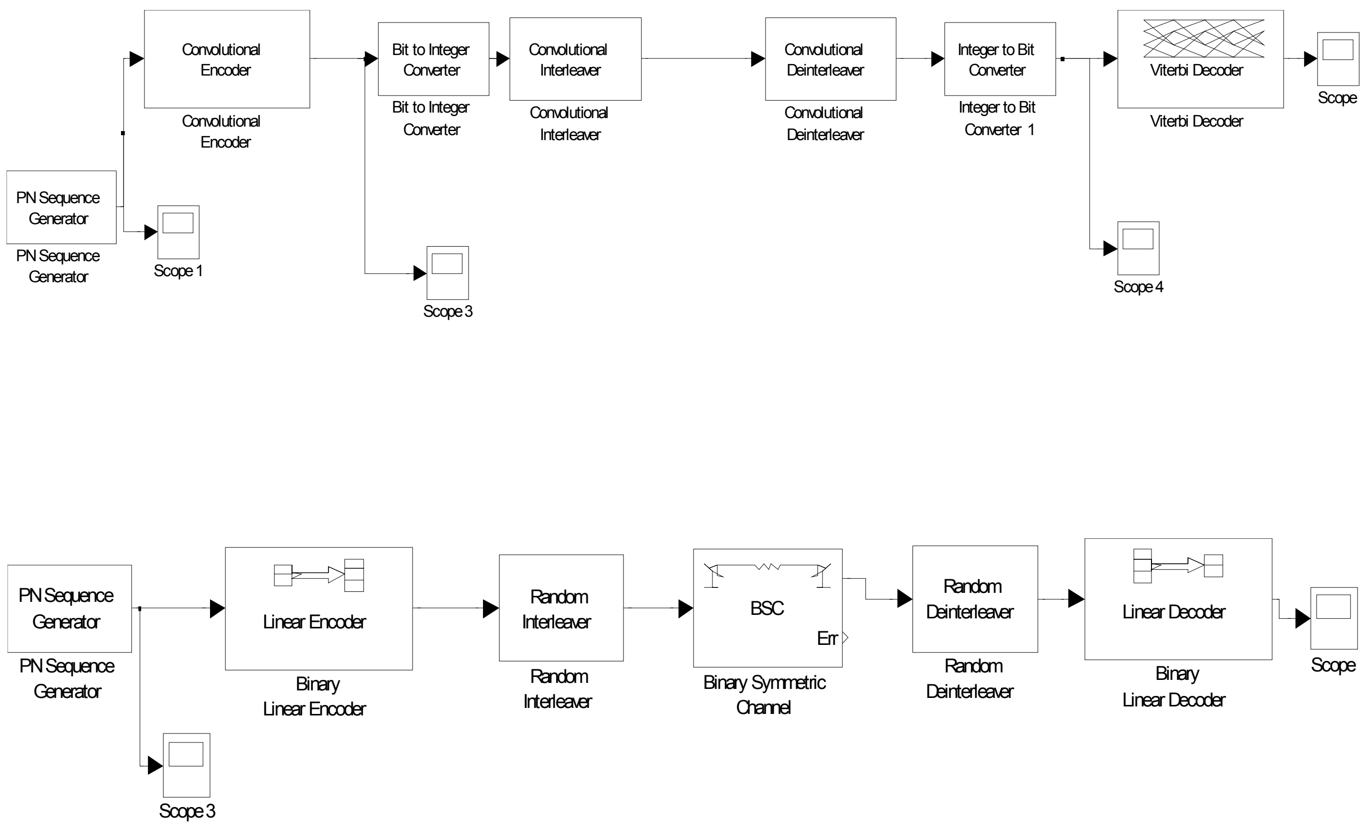

Fig. 3 Simulation Model of Simple Digital Communication System, prepared in Matlab Simulink

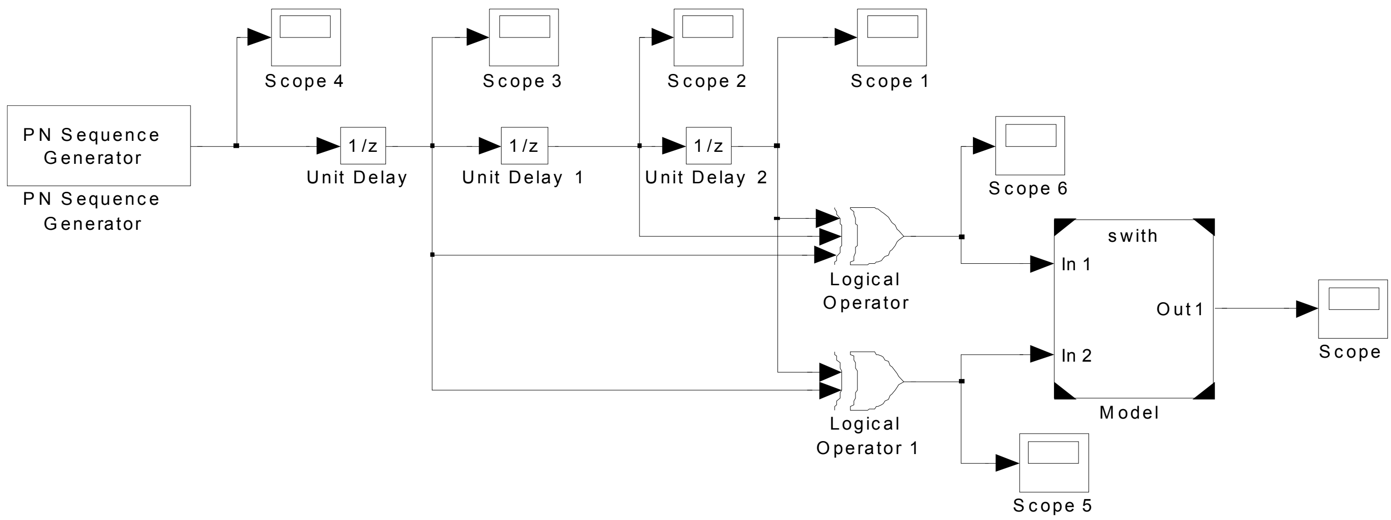

Fig. 6 Gate Level Design of the Convolution Encoder for Simulink to HDL Conversion

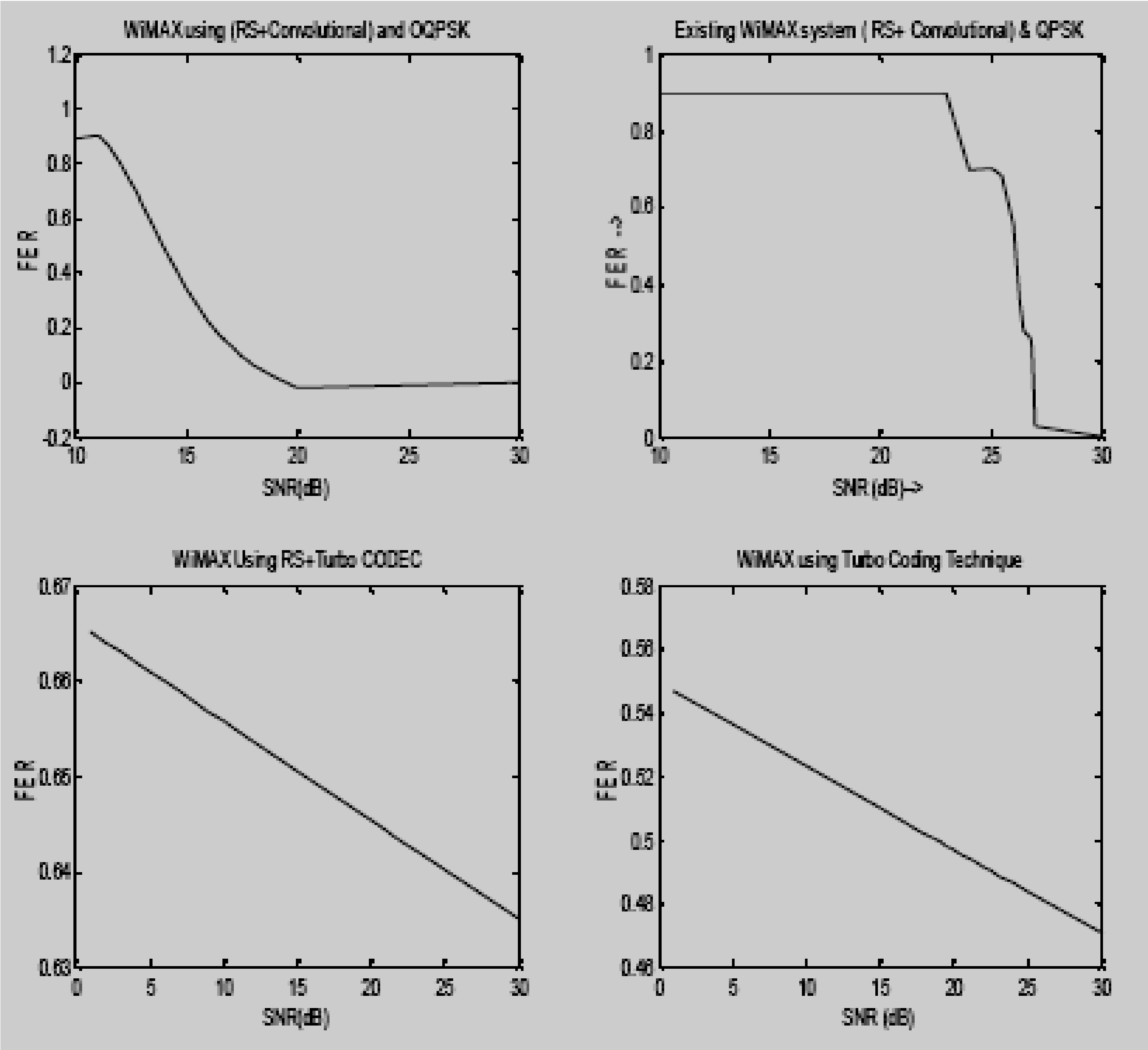

Fig 12 Plots of S/N vs. Frame Error Rate (FER) for different models of WiMax System

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Prof. Rajeshree D. Rraut, born on Aug. 2nd, 1976, completed her bachelor's degree in Electronics & Telecommunication Engineering, from Government College of Engineering, Amravati, M.S., India. She Completed her Masters in Electronics from the same institute in 2002. She is submitting her Ph. D in Error Control Coding for performance improvement in Bit Error Rate in January 2010. Having an experience of 11 years, she currently associated as an Assistant Professor, with Electronics & Communication Engineering Department of Shri Ramdeobaba Kamla Nehru engineering College, Nagpur, M.S., India. She has 04 International Journal Papers, 05 International Conference, and over 10 National Conference papers on accord. She has worked as a Reviewer for IEEE TENCON, Singapore. She delivered expert talks in the field. She is the member of professional bodies like ISTE, IETE & WSEAS. She believes "Work is Worship".