

Implementation of Incremental Redundancy (IR) and Adaptive FEC Scheme For Cognitive Radio

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Abstract—Cognitive radio offers the promise of intelligent radios that can learn from and adapt to their environment. The most generally accepted definition is a radio that can sense and adapt to its environment. Data over wireless networks presents challenges associated with high packet loss rate characteristics. The lost transmission packets limit throughput. The Forward Error Correction (FEC) mechanism has been proposed to recover error packets/data. However, the FEC mechanism has to inject redundancy data. Fixed FEC mechanism injects fixed redundancy independent of dynamic changes in the channel conditions. In this paper two schemes have been proposed 1. Incremental redundancy (IR) with Hybrid Automatic Repeat reQuest (ARQ) 2. Adaptive Forward Error Correction schemes for Cognitive Radio (AFEC for CR) mechanism to solve this problem. These schemes utilize a mathematical analytical model from which the appropriate FEC redundancy is determined. The architecture for implementing the device to perform IR and A FEC for CR has been proposed.

Index Terms— *Cognitive radio, Incremental redundancy (IR), Adaptive Forward Error Correction (AFEC), Reed-Solomon (RS) codes.*

I. INTRODUCTION

Cognitive Radio has been proposed as a promising technology to solve today's spectrum scarcity problem. CR is able to sense the spectrum to find the free spectrum, which can be optimally used by Networking and primary system nodes to form a cognitive radio network (CRN) can use cooperative relay to greatly enhance network efficiency given a fixed bandwidth. An adaptive error control is thus necessary to facilitate reliable packet transmission effective utilization of bandwidth in the CRN [1].

Cognitive Radio without causing interference to the licensed (primary) user. Facing the increasing demands of wireless services and the underutilization of licensed spectrum, Cognitive Radio to sense the

spectrum and to opportunistically access the spectrum holes of primary systems has emerged as a technology to enhance spectrum utilization.

Typical mechanisms fall in one of two classes. ARQ mechanisms are closed-loop mechanisms based on the retransmission of the packets that were not received at the destination. Forward Error Correction (FEC) mechanisms are open-loop mechanisms based on the transmission of redundant information along with the original information so that (at least some of) the lost original data can be recovered from the redundant information. ARQ mechanisms are typically not acceptable for live audio applications over the Internet because they dramatically increase end to end latency [2].

ARQ is efficient when the channel condition is good or moderately good, but as the channel condition gets deteriorated, ARQ's throughput performance becomes unacceptably poor. This paper describes the Incremental redundancy Adaptive of FEC (AFEC) using Reed-Solomon (RS) codes. RS codes are known to provide optimal error-correction capability given fixed redundancy, and also excellent burst error-suppression capability. The RS code rate and frame length are chosen adaptively based on the estimated channel condition to maximize the throughput performance.

II. INTRODUCTION REED SOLOMON CODES

Reed-Solomon (RS) codes are non-binary cyclic error-correcting codes. They described a systematic way of building codes that could detect and correct multiple random symbol errors. By adding t check symbols to the data, an RS code can detect any combination of up to t erroneous symbols, or correct up to $t/2$ symbols. As an erasure code, it can correct up to t known erasures, or it can detect and correct combinations of errors and erasures. Furthermore, RS codes are suitable as multiple-burst bit-error correcting codes [3][4].

The Reed-Solomon code is actually a family of codes: For every choice of parameters m , n , and k , there is a Reed-Solomon code that has a symbol of size m , a block length $n < 2m$, and a message length $k < n$. Moreover, the

alphabet is interpreted as the finite field of order q , and thus, q has to be a prime power. In the most useful parameterizations of the Reed–Solomon code, the block length is usually some constant multiple of the message length, that is, the rate $R=k/n$ is some constant, and furthermore, the block length is equal to or one less than the alphabet size, that is, $n=q$ or $n=q-1$.

$$0 < k < n < 2^m + 2$$

Here k is the number of message bits to be encoded, n is the size of code word in an encoded block and m is the number of bits per symbol. Thus RS (n,k) can be written as follows:-

$$(n, k) = (2^{(m-1)}, 2^{(m-1)} - 1 - 2t)$$

Number of parity bits added to the message bits is calculated by $(n-k) = 2t$ where t is the number of errors corrected by RS code. The distance of the RS code is given by: $d_{\min} = n-k+1$

The main reason that Reed-Solomon are still frequently used is that in many applications and in particular in storage device applications errors often occur in bursts. Reed Solomon codes have the nice property that bursts of consecutive errors an effect bits that correspond to a much smaller number of elements in the field on which the Reed-Solomon code is defined.

III. INTRODUCTION TO IR

Incremental redundancy (IR) is used to get maximum performance out of the available narrow bandwidth. By using Read Solomon coding the system can add protection to the data. However, this coding adds redundancy to the original data. This has the effect of reducing data throughput or user bandwidth.

IR with HARQ it is possible to increase the throughput based on the channel conditions. Functional state diagram (Figure 1) shows the How incremental redundancy works. It illustrates Different states of incremental redundancy. A data block is sent to the receiver. If there are no errors then the block will be passed up to the next layer of protocol for processing. However, if the block is received in error then the mobile will send an ARQ to the base station. The transmitter will then retransmit the block using a different coding scheme. This block will be recombined with the first block increasing the amount of redundancy and giving the receiver/transmitter a better chance of being able to recover from the errors[5][6].

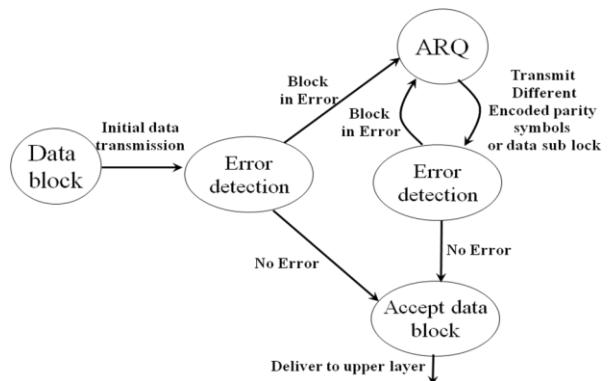


Figure 1. State diagram of Incremental redundancy.

IV. INTRODUCTION TO COGNITIVE RADIO

The main functions of cognitive radios are

A. Adaptive Frequency /Spectrum sensing:

Detecting unused spectrum and sharing it, without harmful interference to other users; an important requirement of the cognitive-radio network to sense empty spectrum. Detecting primary users is the most efficient way to detect empty spectrum. Spectrum-sensing techniques may be grouped into three categories [7][8] [9] [10][11]:

- 1) Transmitter detection: Cognitive radios have the capability to determine if a signal from a primary transmitter is locally present in a certain spectrum. There are several proposed approaches to transmitter detection:
- 2) Matched filter detection
- 3) Energy detection
- 4) Cooperative detection: Refers to spectrum-sensing methods where information from multiple cognitive-radio users is incorporated for primary-user detection
- 5) Interference-based detection

B. Power Control:

Power control is used for both opportunistic spectrum access and spectrum sharing CR systems for finding the cut-off level in SNR supporting the channel allocation and imposing interference power constraints for the primary user's protection respectively. In a joint power control and spectrum sensing is proposed for capacity maximization.

C. Spectrum management:

Capturing the best available spectrum to meet user communication requirements, while not creating undue interference to other (primary) users. Cognitive radios should decide on the best spectrum band (of all bands available) to meet quality of service requirements; therefore, spectrum-management functions are required for cognitive radios. Spectrum-management functions are classified as:

- 1) Spectrum analysis
- 2) Spectrum decision

D. Adaptive TDMA

If we look upon the users behaviour in an FDMA/TDMA system over the time/frequency plane in Figure 1, we may find out that a considerable part of the area remains unused spectrum holes. This unused area marks the pool from which frequencies can be allocated to secondary users (SUs), for example, in a hotspot. In the following we denote the FDMA/TDMA users as primary users (PUs). In order to make the implementation of the SUs' system into the PUs' system feasible, two main assumptions should be fulfilled.

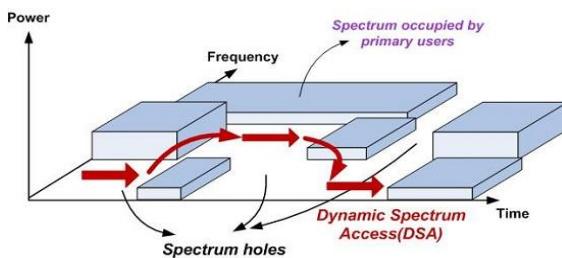


Figure 2. FDMA/TDMA systems over the time/frequency plane

E. Adaptive digital modulation

Adaptive modulation in opportunistic spectrum access, Spectrum Sharing (SS) and sensing based SS CRNs in order to assess the achievable performance in terms of spectral efficiency and to derive the optimal power allocation for each implementation. For adaptive modulation we consider several constellation numbers and bit error rate (BER) target values. Closed form expressions regarding the average spectral efficiency over fading channels and the corresponding required optimal power allocation that maximizes the average spectral efficiency are derived. A Rayleigh fading channel model is considered for characterizing the fading effects on digital transmissions in urban wireless mobile communications

F. Adaptive Forward Error Correcting (FEC) scheme

Adaptive Forward Error Correcting codes are used in cognitive technology to utilise the bandwidth effectively based on the channel conditions, bandwidth and frequency selection. Cognitive Radio is used in various frequency spectrums, configurable bandwidth, and various applications. Fixed FEC schemes are not suitable for such a system, based on the all the above paramours Radio should select FEC schemes which is suitable for that particular condition.

V. SYSTEM ARCHITECTURE OF PROPOSED COGNITIVE RADIO

This paper proposes architecture for the Cognitive radio and the implementation of IR and AFEC for CR for effective utilization of bandwidth. System is divided in to three parts (Figure 3), FR front end interface, Data Processing Unit and User and application interface.

RF front end interface, allow dynamically reconfigurable software and hardware implementations of multiple wireless links supporting individual data rates controlled by monitoring and control engine.

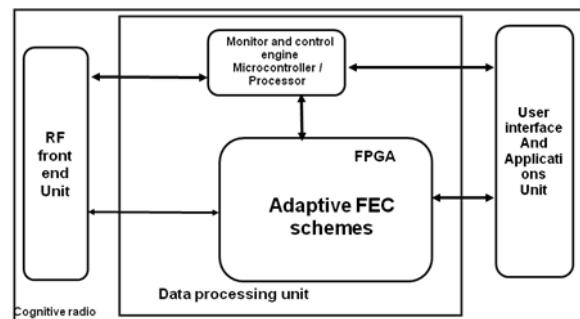


Figure 3. Proposed architecture of CR

Data Processing Unit FPGA-based design, it is also exploring the architectural benefits of custom integrated circuitry all the monitoring/controlling and base band signal/data processing is performed in this block. Proposed work of this project i.e “Implementation of Incremental Redundancy (IR) and adaptive FEC schemes for cognitive radio” is used in this stage. User interface block interface the user interfaces or applications like voice, data, etc.

Main focus of this paper is to describe the Implementation of Incremental Redundancy (IR) and Adaptive FEC schemes to be used in CR which is dynamically configured by controlling unit. Proposed architecture of the AFEC for CR is single chip solution implemented in FPGA. Chip is configurable by configuring register bank. RS code is used as a error correcting codes in this implementation. It is block codes so the block synchronization is required, it is self synchronizing device, includes frame generator and frame detector to find the start of the encoded block.

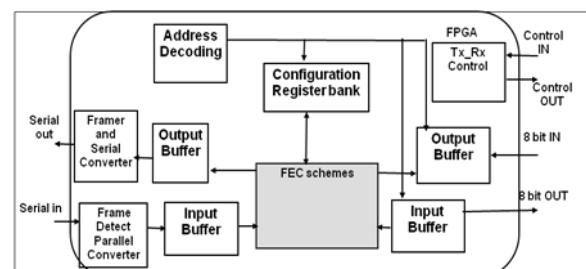


Figure 4. Internal block diagram of AFEC

The data to be transmitted is written into buffer and transmit command is asserted. Based on the configuration register the appropriate encoder and decoder is selected by the AFEC unit and encodes data, generates the frame by inserting the sync bytes. At receive end the sync bytes are detected and encoded block is decoded.

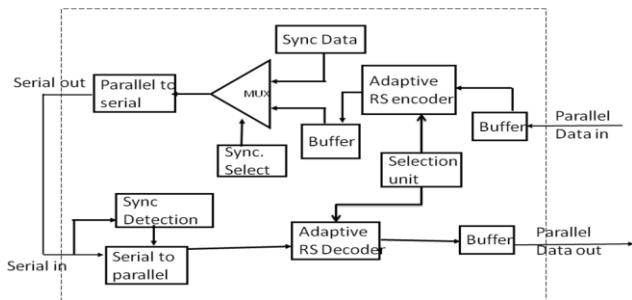


Figure 5. Implementation block diagram

In IR scheme the message length K is fixed and based on the channel condition initial parity symbols q is fixed. As illustrated in the Figure 6, in first transmission both data and parity symbols are transmitted, if receiver detects error after decoding retains the data and send Negative ACK(NACK) to transmitter else transmits ACK. If transmitter Receives NACK, encodes same data with $2q$ parity symbols and retransmits only parity symbols to receiver else send new data block. Receiver appends received parity symbols with previously received data symbols and decoded. If data is error free ACK is sent.

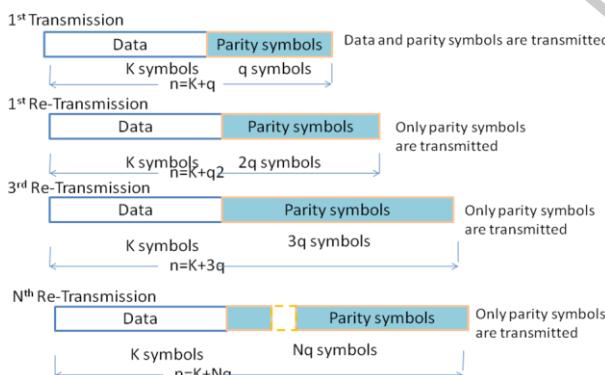


Figure 6. Illustration of IR schemes

In AFEC mode, the n value is fixed and message length and parity symbol length is varied based on the configuration which is intend depends on the channel condition as shown in Figure 7.

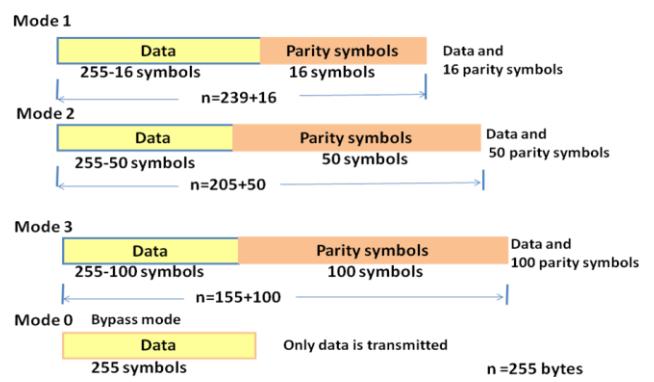


Figure 7. Illustration of Adaptive FEC

In Cognitive radio data communication, two types of packets 1) data packet 2) control packet. Control packet can be packet from application end or from remote end radio.

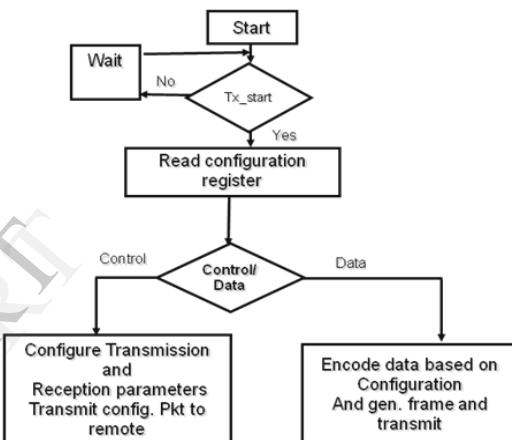


Figure 8. Functional flow diagram

Data packet is actual data to be transmitted to the remote end; control packet is to configuration packet to configure the radio configuration parameters. Figure 8 shows the packet flow chart. If transmit command is interrupt from the application card, it enables the AFEC unit to Read the configuration register act accordingly, based on the configuration register the data in the input buffer can be data packet to be transmitted or control packet to configure. If the received packet is data packet then perform RS encode the based on the predefined configuration, generate frame and transmits. If the received packet is control packet then the updates the configuration based on the configuration data. Same configuration is transmitted to remote end to configure.

VI. SIMULATION RESULTS

All the functional modules are implemented using Verilog HDL and Xilinx ISE development tools. Simulated and verified the results of individual module. Integrated the all the module and verified the result by looping back serial data at the output. Xilinx ISim

simulator is used for functional verification Xilinx IP core is used for RS encoder and decoder.

Wave forms shows the behavioral simulation outputs, RS encodes and integration of all the modules with Frame generator, Frame sync detector and RS decoder.

Test data is generated using test-bench, start encode signal is generated, Figure 9 to 13 shows the integrated system simulated wave forms, data and encode start signal is generated, Sync is added to the out of encoder and converted in to serial. Serial data is looped back to serial in line and sync is detected and converted into parallel and given to RS decoder, RS decoder takes latency depends on number of parity symbols($r=n-k$) added. The end to end simulation of different modes output is shown in figures.

Following are the parameters for Adaptive FEC scheme:

- 1) Mode 3: data is encoded by adding 16 parity symbols($r=16$), $t=8$.
- 2) Mode 2: data is encoded by adding 50 parity symbols($r=50$), $t=25$.
- 3) Mode 1: data is encoded by adding 100 parity symbols($r=100$), $t=50$.
- 4) Mode 0 is bypass mode where the input data is bypassed to output.

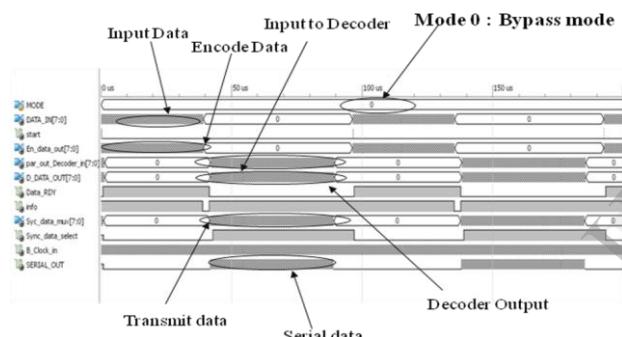


Figure 9 Simulation output wave forms of AFEC (Mode 0)

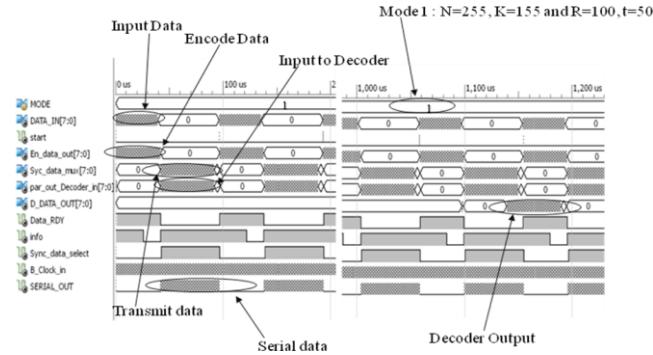


Figure 10 Simulation output wave forms of AFEC (Mode 1)

In simulation output shows the generated data, encoded data. Frame generation, detection of sync pattern to find the start of frame and decoded of data. In bypass mode the encoding and decoding is bypassed. In subsequent modes

the redundancy symbols are added. Based on the length of the redundancy symbols the decoding time is varied.

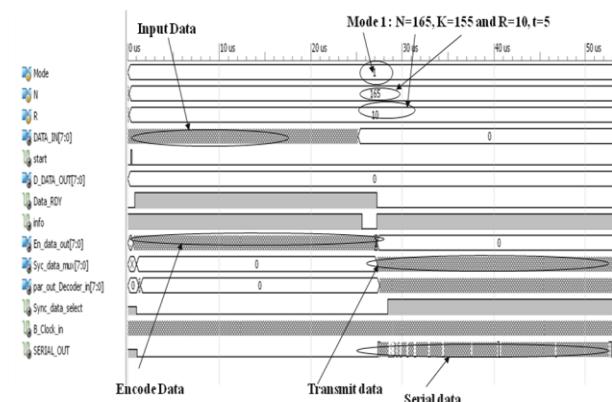


Figure 11 Simulation output wave forms IR both data and parity are transmitted (Mode 1).

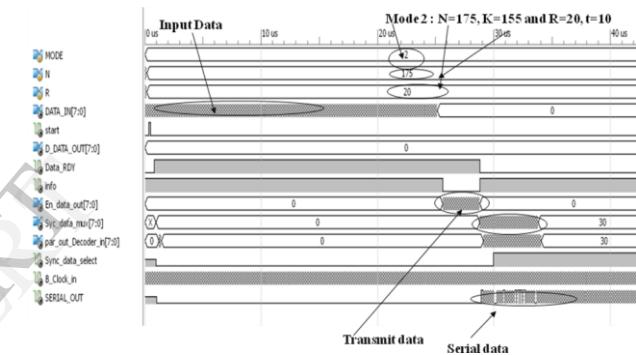


Figure 12 Simulation output wave forms IR only parity symbols are transmitted (Mode 2)

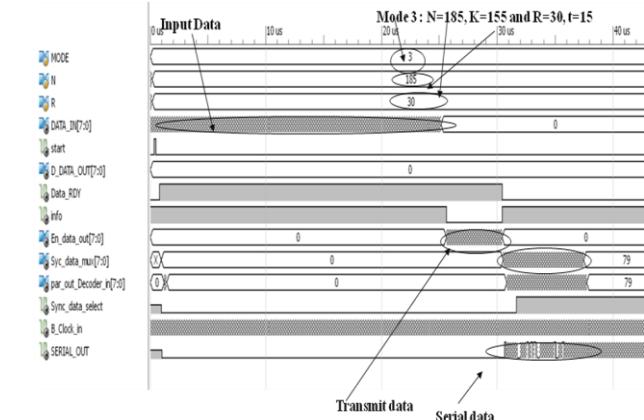


Figure 13 Simulation output wave forms IR only parity symbols are transmitted (Mode 3)

Following are the parameters for Incremental Redundancy (IR) scheme:

- 1) Mode 0: Bypass mode
- 2) Mode 1: $n=165$, $k=155$ and $r=10$, $t=5$
- 3) Mode 2: $n=175$, $k=155$ and $r=20$, $t=10$
- 4) Mode 3: $n=185$, $k=155$ and $r=30$, $t=15$

In this scheme the data symbols length is fixed and redundancy symbols length is variable. At initial

transition (Mode 1) both data and parity symbols are transmitted. Subsequent mode 2, mode 3 only parity symbols are transmitted higher length are transmitted. At receiving end previously received information and retransmitted parity symbols are used to decode.

VII. CONCLUSION

Implemented and simulated the proposed AFEC and IR schemes. In AFEC scheme configuration of encoding and decoding with frame detection is verified. Functionality for designed modes like 0,1,2,3 of operation is tested performance by introducing errors .

As a future work evaluation of these schemes with dynamic configuration mode, with hardware. Integration of higher layer protocols . Configuration protocol between FEC schemes unit and control and monitoring unit.

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REFERENCES

- [1] Hsiung-Yu Huang, Tzu-Chi Huang ; Chilankurti, N. ; Rung-Shiang Cheng, "Adaptive Forward Error Correction with cognitive Technology Mechanism for video streaming over wireless Networks" *IEEE 2010 International Symposium on Computer Communication Control and Automation*, 5-7 May 2010
- [2] Sunghyun Choi and Kang G. Shin, "Cost-Effective Adaptive Error Control Using a Hybrid of FEC and ARQ in Wireless Networks" *Technical Report CSE-TR-402-99, University of Michigan*, June, 1999,
- [3] Faisal Rasheed, Arjun Puri ,Sudesh Kumar. "Performance Comparison of Reed Solomon Code and BCH Code over Rayleigh Fading Channel", *International Journal of Computer Applications* (0975 – 8887) Volume 71– No.20, June 2013.
- [4] Faisal Rasheed, Arjun Puri ,Sudesh Kumar. "Performance Comparison of Reed Solomon Code and BCH Code over Rayleigh Fading Channel", *International Journal of Computer Applications* (0975 – 8887) Volume 71– No.20, June 2013.
- [5] Application note, "Agilent Incremental Redundancy in EGPRS", *Agilent technologies*.
- [6] Tumula V. K. Chaitanya and Erik G. Larsson, "Outage-Optimal Power Allocation for Hybrid ARQ with Incremental Redundancy", *IEEE TRANSACTIONS ON WIRELESS COMMUNICATIONS*, VOL. 10, NO. 7, JULY 2011 2069
- [7] Przemyslaw Pawelczak et al. "Cognitive radio emergency networks requirements and design". Proc. of the *IEEE Symposium on New Frontiers in Dynamic Spectrum Access*, Nov. 2005
- [8] Qiwei Zhang, Andre B.J. Kokkeler and Gerard J.M. Smit,"A Reconfigurable Radio Architecture for Cognitive Radio in Emergency Networks", *Proceedings of the 9th European Conference on Wireless Technology*, September 2006,

- [9] N. Shribala, Dr.P.Srihari, Dr.B.C.Jinaga, "Performance Analysis of Data Negation Codes for Cognitive Radio", *International Journal of Scientific Engineering and Technology* (ISSN : 2277-1581)Volume No.2, Issue No.4, pp : 233-238 1 April 2013.
- [10]. Jean Bolot ,Adaptive FEC-Based Error Control for Interactive Audio in the Internet "Computer Science Department Faculty Publication Series" 1998
- [11] Friedrich K. Jondral, "Software-Defined Radio—Basics and Evolution to Cognitive Radio", *EURASIP Journal on Wireless Communications and Networking* 2005:3, 275–283_c 2005



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