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Performance Analysis of Data Negation Codes for Cognitive Radio

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Abstract
Error Correcting Codes play an important role in maintaining a reliable link in the communication system. Error correcting codes are used to protect the system against errors introduced due to various reasons in the transmission media. These Codes enable the communication systems to have a reliable transmission over noisy channels. Cognitive Radio is a creative technology proposed to increase spectrum usage by allowing cognitive users to use the unused spectrum in changing environments. The Cognitive Radio (CR) technology will allow a group of potential users to identify and access available spectrum resources provided that the interference to the users for whom the band has been licensed is kept below a prescribed level. During the spectrum allocation for Primary user and cognitive user, lot of information may be lost due to random and burst errors and power issues. A secondary user (SU) can improve its data rate by increasing its transmission bandwidth while operating at low power and without creating destructive interference to the primary users (PUs).To achieve the acceptable error rate Forward error correction (FEC)control is done where received error rate is Controlled via Forward Transmission only. In this paper, a new Systematic Double Error Correcting Linear Block Code is proposed called the Data Negation codes. The performance of Data Negation codes for cognitive Radio is described in terms of Probability of undetected errors and also comparison of the proposed code is done with the existing Systematic Double error correcting Linear Block Code..

Keywords—Cognitive Radios, Software Defined Radios, Primary User, Cognitive User and Spectrum Sensing.

I. INTRODUCTION

Cognitive radio is a software-defined radio that

incorporates applications, interfaces, and cognition functions [1]. Recent studies show that most of the assigned spectrum is underutilized while the increasing number of wireless applications leads to a spectrum scarcity. In this context, Cognitive Radios (CRs) have been presented as the new communication paradigm for wireless systems utilizing the existing spectrum opportunistically [1], [2].Cognitive Radio is able to sense the spectrum to find the free spectrum, which can be optimally used by Cognitive Radio without causing interference to the licensed user. The challenge of the CR is that a large chunk of data is manipulated when it is changing the various parameters to adapt to the environment. The Primary user (PU) is the licensed user who can access the spectrum at any time. The CR uses the spectrum when it is idle and not used by PU. When the PU intends to access the channel the secondary user (SU) must vacate .In this process large amount of data is lost. Other reason for the loss of data is the sudden appearance of the PU. Therefore, the SU needs powerful error correction codes to mitigate the interference created by the PUs. The objective is to use the Data Negation Codes (DN codes) in Cognitive Radio. These are the new type of codes with simple Encoding and Decoding principles and suitable for cognitive radio.

II COGNITIVE RADIO

In Cognitive Radio, spectrum sensing is done to locate unused spectrum segments and optimally use these segments without harmful interference to the licensed user [3]. In order to properly adapt to the present needs, a cognitive radio must be capable of adapting in many directions, altering the waveforms and protocols of the radios without constraint [5]. Cognitive radios that are employed in a network with dynamic frequency assignments must operate efficiently in the presence of uncertainties and variations in the propagation characteristics of the network's communication links. Cognitive radios are ideally suited for use in dynamic spectrum access networks in which there may be large variations in channel conditions from one session to the next. Such variations are common in networks that operate in a fixed frequency band, but the variations are more severe if the frequency band is changed for consecutive sessions. Each radio in a dynamic spectrum access network must be aware of its communication environment, and it must provide the information that other radios need in order to communicate with it efficiently [8]. Typically, in CRNs, an SU senses the PU activity of the channel and adjusts its communication parameters accordingly. Conversely, whenever a PU stops transmission and another PU joins the network over a different frequency band, the SU needs to re-sense the channel and adapt its transmission parameters. Hence, continuous spectrum sensing and reformation of wireless links may result in substantial performance degradation of the SUs.

A reconfigurable radio with sensing means, in addition to its multiple communication parts, the CR system indeed features sensing means, adapting means and a smart sub-system dedicated to analyzing stimuli and making decisions as shown in Fig.1. Sensing means refer to all the possible methods the CR system has at its disposal for observing its environment, which can be categorized in four main families described below:

-Electromagnetic environment: spectrum occupancy, Signal to Noise Ratio (SNR), multi-path propagation, etc.

-Hardware environment: battery level, power consumption, computational resources load, etc.

-Network environment: telecommunication standards (GSM, UMTS, WiFi, etc.), operators and services available in the vicinity, traffic load on a link, etc.

-User-related environment: position, speed, and time of Day, user preferences, user profile (access rights, Contract…), video and audio sensor.

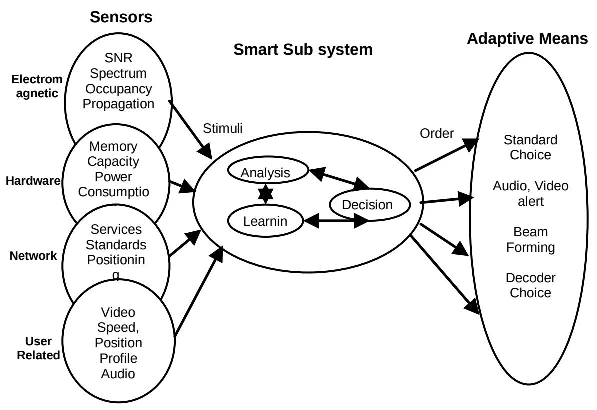

Fig.1: Schematic Functional View of Cognitive Radio System

The cognition cycle in CR is shown in Fig.2

Spectrum sensing: detecting the unused spectrum and sharing it without harmful interference with other users, it is an important requirement of the Cognitive Radio network to sense spectrum holes, detecting primary users is the most efficient way to detect spectrum holes. Cognitive radios must have the capability to determine if a signal from a primary transmitter is locally present in a certain spectrum.

Spectrum management: Capturing the best available spectrum to meet user communication requirements. Cognitive radios should decide on the best spectrum band to meet the quality of service requirements over all available spectrum bands.

Spectrum mobility: It is defined as the process when a cognitive radio user exchanges its frequency of operation. Cognitive radio networks target to use the spectrum in a dynamic manner by allowing the radio terminals to operate in the best available frequency band, maintaining seamless communication requirements during the transition to better spectrum.

Spectrum sharing: Providing a fair spectrum scheduling method among coexisting users.

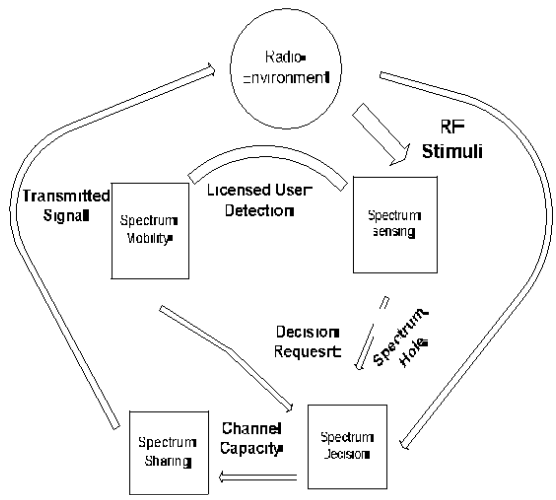

Fig 2: Cognition Cycle in Cognitive Radio Networks

III. ERROR CORRECTING CODES

Error correcting codes are algorithms for expressing a sequence of numbers such that any errors which are introduced can be detected and corrected based on the remaining numbers. Data Negation Codes are the codes which are intended to use in CR because of their simplicity and robustness. These codes are Forward Error Correction codes where the error rate is controlled via forward transmission only. Design techniques for DN codes exist which enable the construction of codes which approach the Shannon's capacity to within hundredths of a decibel.

These codes are weight based codes represented as (n,k) codes with coding efficiency of 50%. The encoding procedure depends on weight of the message. The weight of the message is the number of 1's present. In Systematic Block Codes the parity bits are the linear combination of message bits. In Data Negation codes the parity bit

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structure is not the same for all the codes because the weight is not same for all messages. These codes are also referred as Systematic Codes with unequal Parity Bit Structure.

The general form of the (n,k) Data Negation Code word is given by $M_1M_2.....M_kP_1P_2..........P_k$ where $M_1M_2.....M_k$ are the k message bits and $P_1P_2..........P_k$ are (n-k) parity bits where n=2k.

The Polynomial description of the Codeword is given as C(x)=M(x).P+Q(x), where M(x) is the message polynomial and P is the Primary matrix of order [kx2K] and Q(x) is the secondary polynomial. The Primary Matrix is same for the message with Zero/Even weight and odd weight. It is given as the first row of 'P' is $1+x^{k+1}$, second row is $x+ x^{k+1}$, third row is $x^k+ x^{k+3}$ and the k^{th} row is $x^k+ x^{2k}$.

The Secondary Polynomial is Q(x) and for message with Zero/Even weight is given by Q(x)= 0 which is written as $0.x^0+0.x^1+.......0.x^k+0.x^{k+1} +0.x^{k+2}+0.x^{k+3}+.........+0.x^{2k}$.

The Secondary Polynomial for message with Odd weight is given by

$Q(x)= 0.x^0+0.x^1+...0.x^k+1.x^{k+1} +1.x^{k+2}+1.x^{k+3}+......+1.x^{2k}$.

For an (n,k) Code the message polynomial is

$M(x)= M_1.x^0+ M_2.x^1+... M_k.x^k$.

The Code polynomial is given as

$C(x)= M_1.x^0+ M_2.x^1+... M_k.x^k+ P_1.x^{k+1}+ P_2.x^{k+2}+... P_k.x2^k$.

In the Matrix form, the code word of 'n' bits length is given by C=M.P+Q, where M is the message word, 'P' is the Primary Matrix of order (kx2k) and Q is the Secondary Matrix of order (1x2k).

For the message words of zero/even weight,

$P= [I_{kxk}\ \ I_{kxk}]_{kx2k}$ and $Q=[\{00....\}_{1xk}\ \{00....\}_{1xk}]_{1x2k}$

For the message word of odd weight, Primary Matrix being the same and $Q=[\{00....\}_{1xk}\ \{11....\}_{1xk}]_{1x2k}$

The code word is obtained as $[M_1M_2.....M_kP_1P_2...P_k]$.

The Parity bits are obtained from the relation

- For the message word of zero/even weight,$P_1=M_1+0;P_2=M_2+0;..P_k=M_k+0$.
- For the message word with odd weight,$P_1=M_1+1,P_2=M_2+1;..P_k=M_k+1$.

Thus, the encoding rule is , for the message words with

- Zero/even weight, the parity bits of the corresponding code word are same as the message bits.
- Odd weight, the parity bits of the corresponding code word is the complement of the message bits.

Hence the name is Data Negation codes.

All the code words with even Message word length will satisfy the relation $C.P^T=P.C^T=[0\ 0\ 0..0]_{1xk}$ .All the code words of with odd Message word length will satisfy the relation $C.P^T=P.C^T=[1\ 1\ 1..1]_{1xk}$,where C^T and P^T are the transposed versions of the primary Matrix and the code vector C.

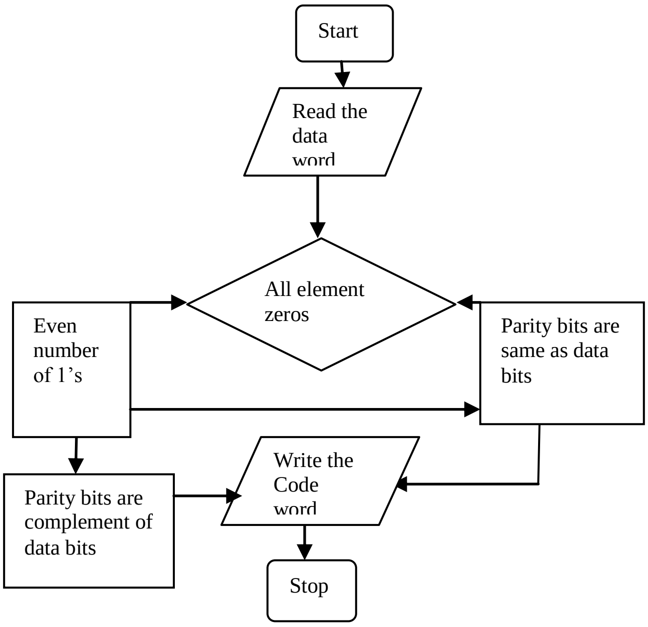

Fig 3: Flow Chart to generate Weight based Data Negation codes

The length of the message bits is 6 and 6 parity bits are added according to the weight of the message word.

Undetected errors occur when the Decoder fails to detect the presence of errors. If the coding scheme is used for error detection on a Binary Symmetric Channel, the Probability of an undetected Error $\mathbf{P_{ud}}$ **(E)** is obtained from the weight enumerator of the code {Ai}. If the code 'C' contains Ai number of code words of weight 'i' the weight Enumerator A(z) of the code is defined as

$$A(z)= \sum_{i=0}^{n} Ai.z^i$$

Using Mac Williams identity, the probability of undetected error is computed from A(z) and is given as

$$P_{ud}\ (E)=(1-p)^n.\sum_{i=1}^{n} [A[p/(1-p)]-1] \quad \text{where } z=p/1-p$$

Where p is the Transition probability. It is the probability that a transmitted '0' is received as '1' and vice-versa.

N is the number of code bits in the Code word.

The set of weight distributions for an (12,6) DN code is $\{A_0,A_1,A_2,A_3,A_4,A_5,A_6,A_7,A_8,A_9A_{10}A_{11}A_{12}\}=$ {1,0,0,0,15,0,32,0,15,0,0,0,1} i.e. the No. of Code words

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of zero weight =1,No.of code words of weight four = 15,No.of code words of weight Six=32, No. of code words of weight Eight=15, No. of code words of weight Twelve=1.

The weight Enumerator of the code is $A(z)=1+15z^4+32z^6+15z^8+z^{12}$.

The Probability of the undetected error is

$$\mathbf{P_{ud}(E) = (1-p)^{12}\,[1+14(p/1-p)^4+32(p/1-p)^6+15(p/1-p)^8+(p/1-p)^{12}-1]}$$

IV. ROLE OF DATA NEGATION CODES IN COGNITIVE RADIO AND PROPOSED METHOLODGY

Data Negation codes can play an important role in cognitive radio networks to achieve seamless, always- best-connected wireless services. Cognitive Radio networks will be capable to adjust parameters for the transmission on the fly without any change on the hardware components.

In this section, the DN codes are explored to be used for solving the dynamic spectrum access problem and hence performance is analyzed. It is assumed that there are only two cognitive users: a transmitter Tx who wants to convey a message to a receiver Rx. The available bandwidth *B* is divided into sub carriers. The primary user and secondary users are represented by '1' and '0' respectively. The sub carriers can be used by both the primary and cognitive users, although the cognitive users are not allowed to transmit in a sub carrier used by a primary user. After the spectrum sensing the primary and cognitive user can be represented as [0 0 1 1 1]. Any of the spectrum sensing techniques like energy detector and matched filter can be used. The performance of DN code is analyzed, when spectrum hole is detected and the frequency is assigned to cognitive user, as shown in Fig.4

In a Cognitive Radio Network the CR detects the PU using any of the spectrum sensing methods like Energy detection, Matched Filter, Cyclostationary detection etc. If the spectrum is not used by the Primary then that channel is assigned to the Cognitive user. The transmission of data between the two SU's is done using the Data Negation coding scheme using Antipodal signalling. The performance of Data Negation (DN) codes combined with their relatively simple decoding algorithm makes these codes very attractive for cognitive Radio networks.

By using the data Error correction Codes in the transmission by the Cognitive user, any errors occurring due to the sudden appearance of the legacy user can be corrected .This way the reliable link between the CU's can be maintained.

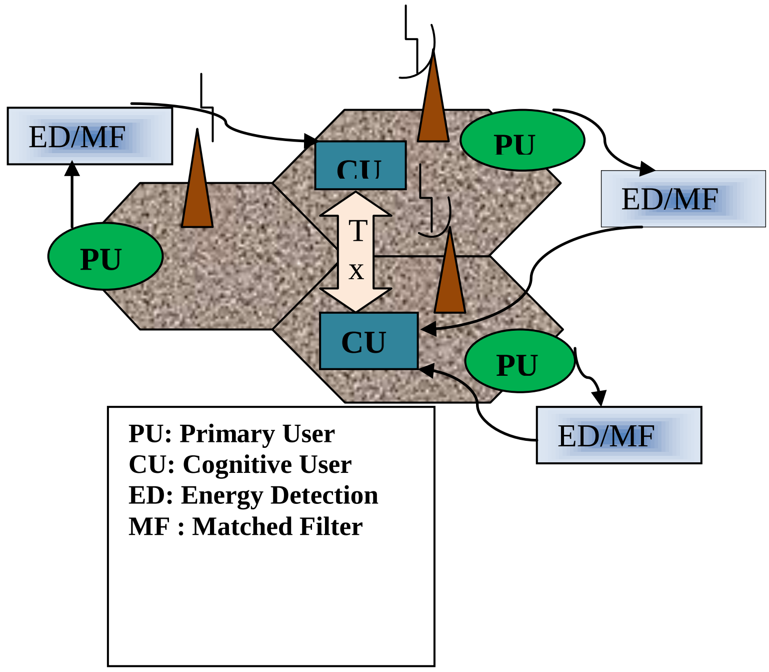

Fig 4: Cognitive Radio Networks

V. RESULTS & COMPARISONS

To analyze the performance of DN codes for Cognitive radio networks the Code was generated using Matlab and the Probability of undetected error was computed for (12,6) Data Negation code. The proposed code is compared with (10,4) Systematic Linear Double Error Correcting Block Code in terms of $\mathbf{P_{ud}(E)}$.

The computations for different $\mathbf{P_{ud}(E)}$ for (12,6) DN Code are tabulated as:

p	**10^{-1}**	**10^{-2}**	**10^{-3}**	10^{-4}
$P_{ud}(E)$	**$6.62X10^{-1}$**	**$0.138X10^{-4}$**	**$1.488X10^{-8}$**	**$1.55X10^{-12}$**

The weight Enumerator of the (10,.4) Systematic Linear Double Error Correcting Block Code is $A(z)=1+z^3+z^4+5z^6+6z^6+z^7$.

The computations for different $\mathbf{P_{ud}(E)}$ for (10,4) Systematic Code are tabulated as:

p	**10^{-1}**	**10^{-2}**	**10^{-3}**	10^{-4}
$P_{ud}(E)$	**$5.7X10^{-1}$**	**$9.42X10^{-4}$**	**$9.94X10^{-7}$**	**$9.99X10^{-10}$**

The comparison of Double Error Correcting codes is shown in fig 5.The codes compared are (10,4) code and (12,6) Data Negation Codes. The Coding Efficiency for (10,4) code is 40% whereas it is 50% for DN codes indicating its enhanced performance.

It is seen that for a transition probability of 10^{-4} over a BSC, the **P_{ud}(E)** tells that ,out of 10^{12} code digits, there are on average 2 erroneous digits that pass through the decoder undetected when (12,6) DN code is used. It is seen that for a transition probability of 10^{-4} over a BSC, the **P_{ud}(E)** tells that ,out of 10^{10} code digits, there are on average 10 erroneous digits that pass through the decoder undetected when (10,4) code is used.

The Data Negation code is applied when spectrum hole is detected and the cognitive user is allotted the frequency. When the unused channel is assigned to the Cognitive User the Probability of undetected error is analyzed.

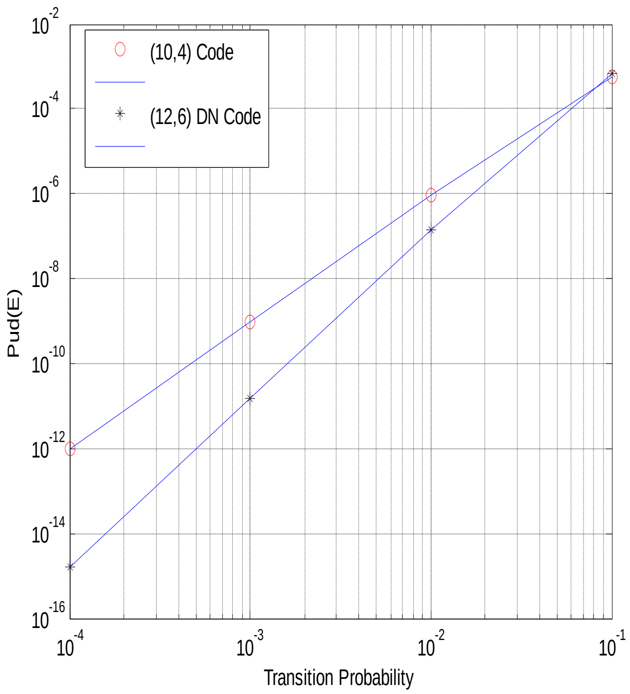

Fig 5:**P_{ud}(E)** for (10,4) and (12,6) Systematic Linear Block Double Error Correcting Code.

VI. CONCLUSION

In this paper the performance of Data Negation Codes is analyzed for Cognitive Radio in terms of Probability of error detection. In implementing the DN codes, complex mathematical rules are not required. Only Negation operation is used in generating the parity bits required for detection and correction. During frequency shifting from primary user to secondary user a lot of data is lost. Random Errors also occur when the PU suddenly appears during the transmission between the CU's. For reliable transfer of data and spectrum allocation in Cognitive Radio networks performance of DN code is checked in terms of P_{ud}(E) Vs transition probability. It is observed that good DN code can work with good performance for spectrum allocation in Cognitive Radio networks. Improved DN codes can work more efficiently. Sensing of the spectrum is important in Cognitive radio networks. Once the frequency is obtained by CU, maximum utilization of the spectrum is done by transmitting the data and Error rate is controlled using FEC. At the receiving end errors can be detected and corrected if proper decoding scheme is designed with minimum operations. The increasing demand of improved data rate and reliability in modern wireless communication systems is pushing next-generation standards toward error correction techniques with good performance.

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