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BER Performance Maintenance in TURBO coded OFDM in Cognitive Radio

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ABSTRACT

Spectrum measurements show that wide ranges of the spectrum are rarely used most of the time while other bands are heavily used. However, those unused portions of the spectrum are licensed and thus cannot be utilized by users other than the license owners. Hence, there is a need for a novel technology that can benefit from these opportunities. Cognitive radio is a promising concept that offers solution to spectral crowding problem by introducing the opportunistic usage of frequency bands that are not heavily occupied by licensed users. As the spectrum is underutilized by the primary license holders ,there exists 'spectrum holes, that can be used by secondary users, yielding efficient utilization of the spectrum and eliminating the apparent spectrum scarcity. Sensing the higher bandwidth in a Cognitive System, the circuits in the System must be tuned for transferring data at higher data rates. At such increased data rates the BER (Bit Error Rate) performance may degrade. So it is a must for the Cognitive Radio to accordingly add processing circuits to maintain the BER. Orthogonal frequency division multiplexing (OFDM)-based transmission is a promising candidate for a flexible spectrum pooling system in DSA environment, where the implementation achieves high data rates via collective usage of a large number of subcarrier bands. This paper discusses on forward error correction by using turbo codes. The combination of OFDM and turbo coding and recursive decoding allows these codes to achieve near Shannon's limit performance in the turbo cliff region.

I. INTRODUCTION

Cognitive Radio can be defined as an intelligent wireless system that is aware of its surrounding environment through sensing and measurements; a system that uses its gained experience to plan future actions and adapt to improve the overall communication quality and meet user needs. Hence, cognitive radio should have ability to sense and be aware of its operational environment, and dynamically adjust its radio operating Parameters accordingly. For cognitive radio to achieve this objective, the physical layer(PHY)needs to be highly flexible and adaptable. A special case of multicarrier transmission known as orthogonal Frequency division multiplexing(OFDM) is one of the most widely used technologies in current wireless communications systems and it has the potential of fulfilling the aforementioned requirements of cognitive radios inherently or with minor changes. In OFDM, the entire channel is divided into many narrow sub channels that are utilized in parallel transmission [3], thereby increasing a symbol period to an OFDM period that is much larger than the channel delay spread and thus reducing the effect of Inter Block Interference (IBI) caused by the dispersive Rayleigh-fading environment [4]. Therefore, OFDM is an effective technique for combating multipath fading and for high-bit-rate transmission over mobile wireless channels. In addition, OFDM can achieve adaptive allocation of transmission load in different sub channels to achieve optimum entire transmission rate [5]. Furthermore, because of the long duration of the OFDM symbol, OFDM can alleviate the effect of impulse noise. When OFDM is designed such that there is neither Inter Channel Interference (ICI) nor Inter Block Interference (IBI), the computationally efficient Fast Fourier Transform (FFT) can be applied to decouple sub channels, and channel is equalized by normalizing with a complex scalar for each sub channel [3]. In a multipath fading channel, all subcarriers have different attenuations. Some subcarriers may even be completely lost because of deep fades. Therefore, the overall bit-error-rate (BER) may be largely dominated by a few subcarriers with the smallest amplitudes. To avoid this problem, channel coding and interleaving can be used. By using coding, errors can be corrected up to a certain level depending on the code rate and type, and the channel. Interleaving is applied to randomize the occurrence of bit errors. Section 2 introduces the concept of Cognitive Radio. Section 3 & 4 describe OFDM model and TURBO codes. Section 5 depicts the simulations to measure the performance of OFDM under AWGN channel and RAYLEIGH channel conditions, for different modulationschemes like BPSK, QPSK used in IEEE 802.11a wireless LAN standard. The BER performance of TCOFDM system

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is compared with uncoded OFDM system. Conclusions are given in section 6.

II. COGNITIVE RADIO

OFDM is a good fit for Cognitive Radio as the underlying sensing and spectrum shaping capabilities together with flexibility and adaptiveness make OFDM probably the best candidate for cognitive radio systems.[13]. 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 as regards use of RS encoder for presence of Burst Errors has already been carried out [8]), finally establishes connection with proper initial handshake with receiver. The main functions of the Cognitive radio are

1. Spectrum Sensing- This involves Primary Transmitter detection. 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.

Once the band is sensed bulk data at higher data rate to be transmitted e.g. real time applications like Mobile Services and to transmit small packets of data with high accuracy, required in Emergency Services where 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.

III. OFDM SYSTEM MODEL

A. Transmitter Architecture

In OFDM, the incoming bit stream enters into a serial-to-parallel converter, which outputs N lower rate data streams. These data streams are then simultaneously sent over N orthogonal carriers. Hence the bandwidth per carrier is only $(1/N)^{th}$ of the overall system bandwidth and, as a result, each carrier experiences a flat fade (upon transmission over the channel) [11]. Utilizing this strategy, OFDM drastically reduces Inter-Symbol Interference (ISI) and effectively avoids multipath in frequency selective channels [12].

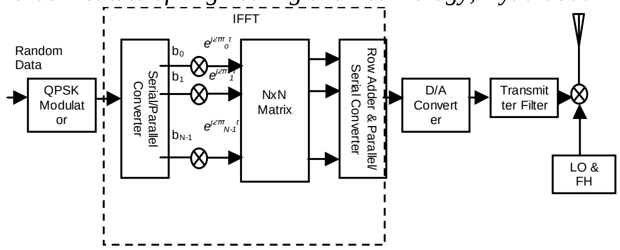

Fig.1 Transmitter Architecture of

Fig.1 shows the architecture of the OFDM transmitter [7]. It needs two steps to implement the spectrum spreading:

1. The first step is the Inverse Fast Fourier Transform (IFFT) which is used to modulate multiple sub carriers and multiplex them to form wideband signals.
2. The second step is the frequency hopping which is employed to move the signal to different frequency bands to realize Ultra-Wide Band (UWB) communications.

The Quadrature Phase Shift Keying (QPSK) symbols modulate the orthogonal sinusoidal sub carriers using the IFFT to form the OFDM symbol in the time domain. These modulated signal samples for different sub carriers are summed together to form the OFDM symbol. If we denote QPSK symbols by b_k, the number of the sub carriers by N, and the corresponding sub carrier frequency by f_k, where $0 \le k \le N-1$, OFDM signal has the following expression[10].

$$x(n) = \frac{1}{N}\sum_{k=0}^{N-1} b_k e^{j2\pi f_k n}$$

$$= \frac{1}{N}\sum_{k=0}^{N-1} b_k e^{j2\pi \frac{k}{N} n} \qquad 0 \le n \le N-1 \qquad (1)$$

Letting W_N denote $e^{-j2\pi/N}$, W_N^{-nk} means the k^{th} sub carrier at n^{th} time instant. After the IFFT operation, N OFDM symbol samples are generated. For the convenience, we ignore the factor 1/N thereafter. These N samples can be expressed in the matrix form

$$\begin{bmatrix} X(0) \\ X(1) \\ \dots \\ X(n-1) \end{bmatrix} = \begin{bmatrix} b_0 W_N^{0} + b_1 W_N^{0*1} + \dots + b_k W_N^{0*(N-1)} \\ b_0 W_N^{-1*0} + b_1 W_N^{\frac{N}{N}1*1} + \dots + b_k W_N^{-1*(N-1)} \\ \dots\dots \\ b_0 W_N^{-(N-1)*0} + b_1 W_N^{-(N-1)*1} + \dots + b_k W_N^{-(N-1)*(N-1)} \end{bmatrix} \qquad (5)$$

The sequence [x(0), x(1), ..., x(N -1)] is an OFDM symbol after IFFT operation. After the D/A converter and transmitter filter, the analog baseband signal is generated. Then the system shifts the baseband signal to a particular frequency band for a short time interval using frequency hopping. The signal hops between different frequency bands, so that it spans a range of spectrum over a period of time, and the bandwidth reaches 1.584GHz. Each OFDM symbol consists of

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many non-zero sub carriers within the symbol interval. Its spectrum can be regarded as the convolution of the spectrum of a window pulse with a group of sub carriers. The spectra of the respectively modulated data symbols are overlapped. At the centre of each sub carrier, all the spectrum values of other sub carriers are zero. In this way, the spectrum efficiency can be increased. However, with the carrier frequency hopping in different sub bands, the signal power is not evenly distributed across the sub bands, which leads to some problems with power allocation. The symbol rate and the shape of power spectral density of the modulated signal depend on the rate at which the symbols enter the D/A converter and the transmitter filter. The signal transmission is not performed continuously on the 3 sub bands. Instead, it is time multiplexed using frequency hopping between different sub bands. Therefore, the system has some challenging issues regarding system performance.

B.Receiver Architecture

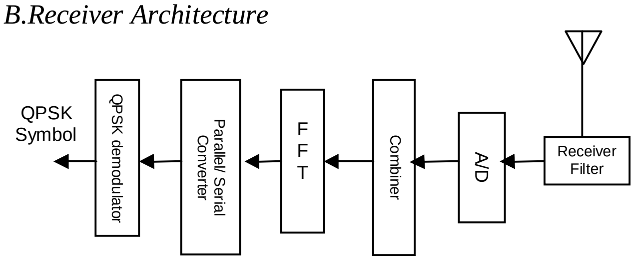

Fig.2 Receiver Structure of OFDM System

In order to recover the transmitted data information, inverse operations are performed at the receiver. Assuming an AWGN channel, Fig.2 illustrates the receiver architecture of the OFDM system. It consists of receiver filter, A/D converter, combiner, FFT module, parallel/ serial converter and QPSK de-modulator. The receiver filter can be designed to match the transmitter filter.

IV TURBO CODES

Parallel concatenated codes, as they are also known, can be implemented by using either block codes (PCBC) or convolutional codes (PCCC). PCCC resulted from the combination of three ideas that were known to all in the coding community:

- The transforming of commonly used non-systematic convolutional codes into systematic convolutional codes.
- The utilization of soft input soft output decoding. Instead of using hard decisions, the decoder uses the probabilities of the received data to generate soft output which also contain information about the degree of certainty of the output bits.
- This is achieved by using an interleaver. Encoders and decoders working on permuted versions of the same information. An iterative decoding algorithm centered around the last two concept would refine its output with each pass, thus resembling the turbo engine used in airplanes. Hence, the name Turbo was used to refer to the process.

In the encoder binary input data sequence is represented by dk=(d1….dn).It is passed through Convolutional Encoder and a coded bit stream is generated. The data sequence is then interleaved. The interleaved data sequence is passed to a second convolutional encoder , and a second coded bit stream, is generated. The code sequence that is passed to the modulator for transmission is a multiplexed (and possibly punctured) stream consisting of systematic code bits and parity bits from both the first encoder ENC1 and the second encoder ENC2.They are Recursive Systematic Convolutional (RSC) codes that is, convolutional codes which use feedback and in which the un coded data bits appear in the transmitted code bit sequence. RSC encoders will tend to generate high weight code sequences for groups of data bits spread far apart in the input sequence. The infinite impulse response property of RSC codes is complemented in turbo codes by the interleaver between component encoders.

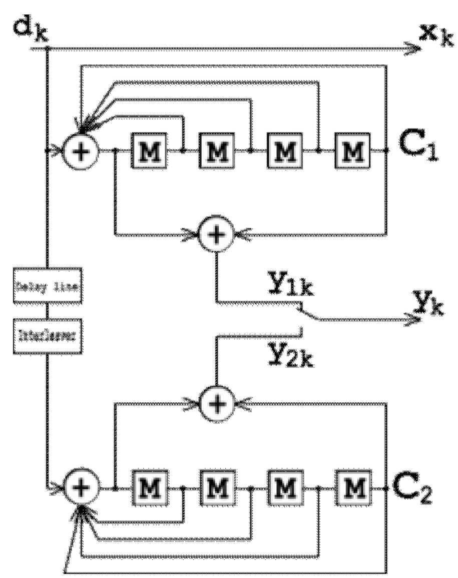

Fig.3 Turbo Encoder

In the figure, *M* is a memory register. The delay line and interleaver force input bits d_k to appear in different sequences. At first iteration, the input sequence d_k appears at both outputs of the encoder, x_k and y_{1k} or y_{2k} due to the encoder's systematic nature. If the encoders C_1 and C_2 are used respectively in n_1 and n_2 iterations, their rates are respectively equal to

$$R_1 = \frac{n_1 + n_2}{2n_1 + n_2},$$
$$R_2 = \frac{n_1 + n_2}{2n_2 + n_1}$$

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An interleaver is a device for permuting a sequence ofbits (or symbols) at its input into an alternate sequence with a different ordering at the output. Turbo codes tend to make use of pseudo-random interleavers, whose role is to ensure that most groups of data bits which are close together when entering one RSC encoder are spread far apart before entering the other RSC encoder. The result is a composite codeword which will often have a high code weight. Different code rates are achieved by puncturing the parity bit sequences to form 1/3, 1/2 ,3/4 rate codes. Turbo codes, however, do have a fixed block length, determined by the length of the interleaver. Tail bits are usually appended to each block of data bits entering one or other of the component encoders, to return it to the all-zeroes state at the end of the trellis. This process is called termination, and allows the MAP algorithm to make assumptions about the start and end trellis states. This yields better BER performance. Termination of both component encoders is more difficult, because the terminating sequence for the first encoder is interleaved and may well not, by itself, terminate the second encoder.

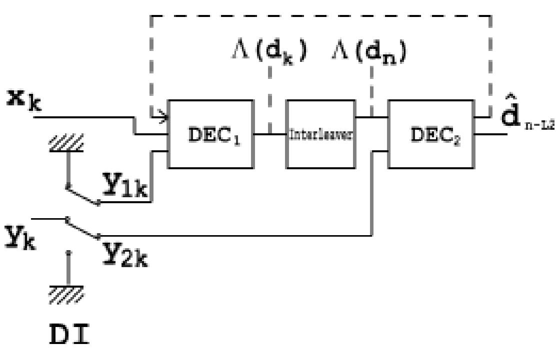

Fig.4 Turbo Decoder

An interleaver installed between the two decoders is used here to scatter error bursts coming from DEC1output. *DI* block is a demultiplexing and insertion module. It works as a switch, redirecting input bits to DEC1at one moment and to DEC2 at another. In OFF state, it feeds both $y_{1k}$and y_{2k}inputs with padding bits (zeros).Consider a memory less channel, and assume that at *k*-th iteration, the decoder receives a pair of random variables:

$$x_k = (2d_k - 1) + a_k,$$
$$y_k = 2(Y_k - 1) + b_k$$

where $a_k$and $b_k$are independent noise components having the same variance σ^2. $Y_k$is a *k*-th bit from y_k encoder output.

Redundant information is demultiplexed and sent through *DI* to DEC1 (when $y_k = y_{1k}$) and to DEC2 (when $y_k = y_{2k}$). DEC1 yields a soft decision, i.e.:

$$\Lambda(d_k) = \log \frac{p(d_k = 1)}{p(d_k = 0)}$$

and delivers it to DEC2. $\Lambda(d_k)$ is called the *logarithm of the likelihood ratio* (LLR). $p(d_k = i), i \in \{0, 1\}$is the *a posteriori probability* (APP) of the $d_k$data bit which shows the probability of interpreting a received $d_k$bit as i. Taking the *LLR* into account, DEC2 yields a hard decision, i.e. a decoded bit.

The decoder is built in a similar way to the above encoder – two elementary decoders are interconnected to each other, but in serial way, not in parallel The decoding Algorithms are MAP algorithms implemented using the soft-input, soft-output processing. In the Forward and the Reverse pass the probabilities are calculated. These are used to provide the soft estimate of the transmitted symbol. The soft estimate is represented as a log likelihood ratio (LLR).The other simplified algorithms are Max Log Map and Log Map. As stated above, working in the logarithmic domain compacts the dynamic range of all the values we are working with. It also converts the multiplication operations to additions. The exponential terms obtained are computationally intensive but their maximum log value is taken which results in series of additions. The log-likelihood probability of each bit is divided into extrinsic, a priori and systematic components. The Log Map algorithm considers only the maximum exponential term. When implementing the Log-MAP algorithm, all maximizations are augmented by the correction function. The incorporation of the correction function increases the complexity slightly relative to the Max Log-MAP algorithm. However, this effect can be minimized by storing the correction values in a simple look-up table.

V MATLAB IMPLEMENTATION OF COFDM

Simulation model:

1. Generate the information bits randomly.
2. Encode the information bits using a turbo encoder with the specified generator matrix.
3. Use QPSK or different QAM modulation to convert the binary bits, 0 and 1, into complex signals (before these modulation use zero padding)
4. Perform serial to parallel conversion.
5. Use IFFT to generate OFDM signals, zero padding is being done before IFFT.
6. Use parallel to serial convertor to transmit signal serially.

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7. Introduce noise to simulate channel errors. We assume that the signals are transmitted over an AWGN (Additive White Gaussian Noise) and Rayleigh channel.
8. At the receiver side, perform reverse operations to decode the received sequence.
9. Count the number of erroneous bits by comparing the decoded bit sequence with the original one.
10. Calculate the BER and plot it.

Simulation parameters are
Digital Modulation : BPSK QPSK, QAM
Turbo code rates : 1/3
SISO Decoder :Log-MAP
Code Generator : {111, 101}
Interleaver : pseudo random interleaver

Bursty errors deteriorate the performance of the communications system. The burst errors can happen either by impulsive noise or by deep frequency fades. Fig 5.2 shows the performance of the uncoded OFDM system with AWGN.

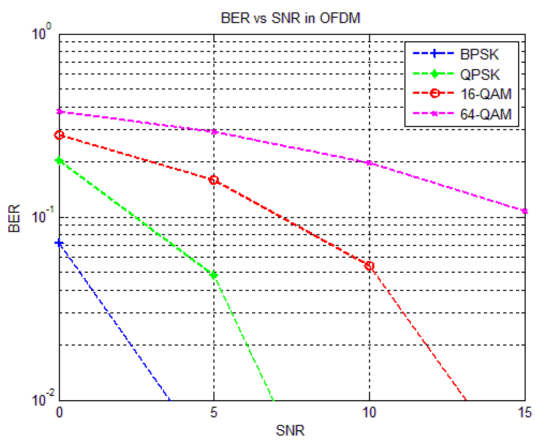

Fig.5 BER vs. SNR plot for OFDM using BPSK, QPSK, 16 QAM, 64 QAM

Convolution coding in OFDM can give performance improvement of some 5 db on AWGN channel over the uncoded OFDM system at required BER. Further improvement in the performance can be obtained by applying turbo coding instead of convolution code. Turbo code gives better performance at low SNR.

The BER performance of TCOFDM system is compared with the respective uncoded system under the fading AWGN channel and RAYLEIGH fading channel. Simulation is done with the turbo codes with polynomial generators, (1, 5 / 7,8) which are iteratively decoded by Log- MAP for a number of decoding iterations. The results are shown in Fig.6 to Fig.9. From the results, we observe that both turbo codes (1, 5/7)8 give considerably good BER performance. The overall performance is considered very well in operation under fading channel which is also efficient in terms of power consumption as compared to the uncoded system.

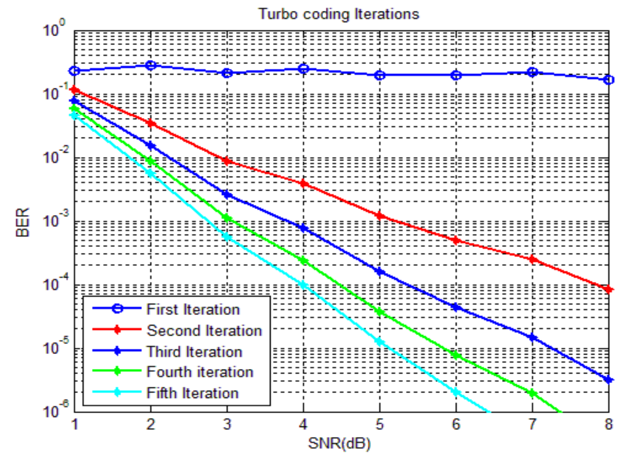

Fig.6 BER vs. SNR plot for turbo codes for different iterations

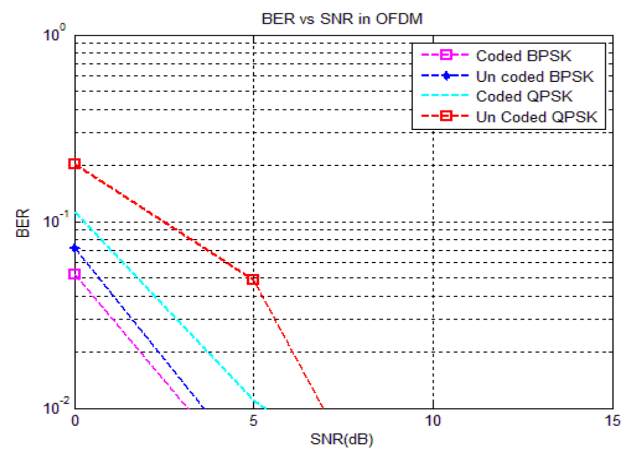

Fig.7 BER vs. SNR plot for uncoded and turbo coded OFDM using BPSK and QPSK

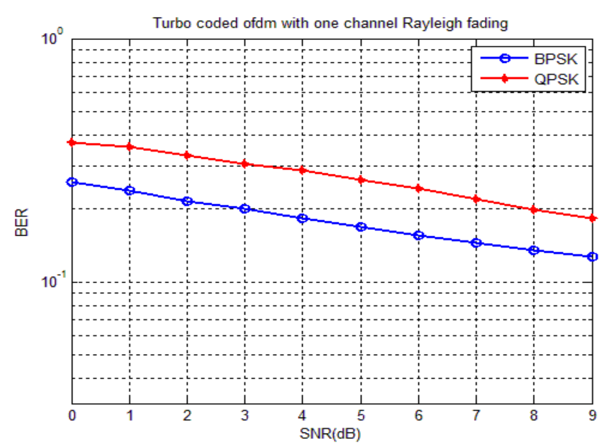

Fig.8 BER vs. SNR plot for turbo coded OFDM under one path Rayleigh channel.

VI 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

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and are allowed to use it as long as it does not interfere with primary users to whom it has been licensed. On the other hand, OFDM technique is used in many wireless systems and proven as a reliable and effective transmission method. OFDM can be used for realizing cognitive radio concept because of its inherent capabilities. By employing OFDM transmission in cognitive radio systems; adaptive, aware and flexible systems that can interoperate with current technologies can be realized. OFDM with Turbo codes is implemented in Matlab to be utilized to maintain the BER at high data rates.

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