Analysis of the Physical Layer in IEEE 802.16(e) Standard

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Abstract – **WiMAX (IEEE 802.16e) is a broadband wireless solution that enables convergence of mobile and fixed broadband networks through a common wide area broadband radio access technology and flexible network architecture. In this paper we explains the steps in channel coding stage and make comparative analysis of the forward error correction codes implemented in IEEE 802.16e standard. The main function of the channel coding is to prevent and to correct the transmission errors of wireless systems and they must have a very good performance in order to maintain high data rates.**

Keywords **–WiMAX, channel coding, turbo codes**

I. INTRODUCTION

Worldwide Interoperability for Microwave Access (*WiMAX*) is a standards-based wireless technology for providing high-speed, last-mile broadband connectivity to homes and businesses and for mobile wireless networks. WiMAX is similar to Wi-Fi but offers larger bandwidth, stronger encryption, and improved performance over longer distances by connecting between receiving stations that are not in the line of sight. WiMAX uses Orthogonal Frequency Division Modulation (*OFDM*) technology, which has a lower power consumption rate. WiMAX can be used for a number of applications, including last-mile broadband connections, hotspots and cellular backhaul, and high-speed enterprise connectivity for business. It supports broadband services such as VoIP or video [1], [2].

WiMAX is essentially a next-generation wireless technology that enhances broadband wireless access. WiMAX comes in two varieties, fixed wireless and mobile. The fixed version, known as 802.16d, was designed to be a replacement or supplement for broadband cable access or DSL. A recently ratified version, 802.16e, also can support fixed wireless applications, but it allows for roaming among base stations as well. Thus, the two standards are generally known as fixed WiMAX and mobile WiMAX. The 802.16 standard is beneficial to every link in the broadband wireless chain, such as consumers, operators, and component makers.

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II. WIMAX PHYSICAL LAYER

The WiMAX physical layer is based on orthogonal frequency division multiplexing. OFDM is the transmission scheme of choice to enable high-speed data, video, and multimedia communications and is used by a variety of commercial broadband systems, including DSL, Wi-Fi, Digital Video Broadcast-Handheld (*DVB-H*), and MediaFLO, besides WiMAX. OFDM is an elegant and efficient scheme for high data rate transmission in a non-line-of-sight or multipath radio environment.

Apart from the usual functions such as randomization, forward error correction (*FEC*), interleaving, and mapping to QPSK and QAM symbols, the standard also specifies optional multiple antenna techniques. This includes space time coding (*STC*), beamforming using adaptive antennas schemes, and multiple input multiple output (*MIMO*) techniques which achieve higher data rates. The OFDM modulation/demodulation is usually implemented by performing fast fourier transform (*FFT*) and inverse FFT on the data signal. Although not specified in the standards, other advanced signal processing techniques such as crest factor reduction (*CFR*) and digital predistortion (*DPD*) are also usually implemented in the forward path, to improve the efficiency of the power amplifiers used in the base stations. The uplink receive processing functions include time, frequency and power synchronization (ranging), and frequency domain equalization, along with rest of the decoding/demodulation operations necessary to recover the transmitted signal [3].

One of the ambitious design goals of future wireless systems, including 4G, IEEE 802.11n/802.16 standards, is to reliably provide very high data rate transmission in hostile environments: hundreds of Mb/s or more for downlink transmission with a low frame error rate (*FER*), typically less than 5.10^{-4}. Therefore, efficient equalizers and decoders are required in order to mitigate inter-symbol interference (*ISI*) and residual interference, respectively. OFDM modulation is particularly suited for transmissions over multipath channels. An OFDM system transforms the frequency selective channel into a set of narrowband Gaussian orthogonal subchannels. Since the frequency selectivity implies that some subbands are strongly weakened, a powerful receiver is needed. Several methods such as power allocation or channel coding have been used [4], [5].

Like all other standards, only the components of the transmitter are specified; the components of the receiver are left up to the equipment manufacturer to implement.

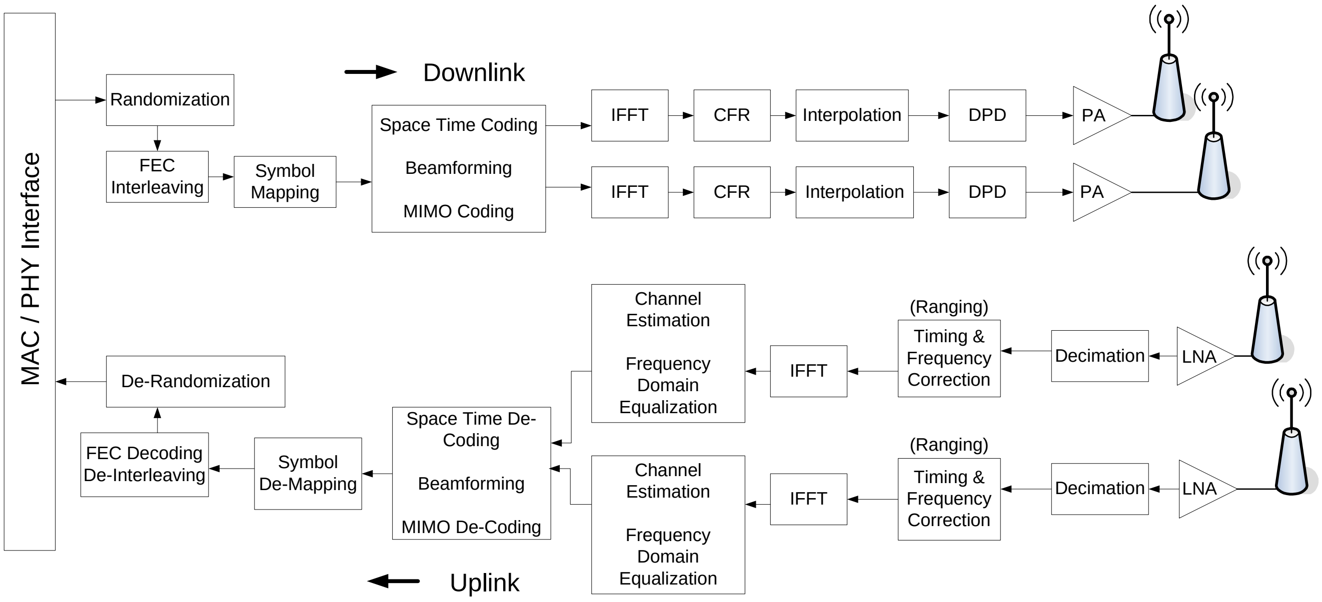

Fig.1 PHY Layer functions in a typical WiMAX base station

III. CHANNEL CODING

In IEEE 802.16e-2005, the channel coding stage consists of the following steps: data randomization, channel coding, rate matching, HARQ, if used, and interleaving. Data randomization is performed in the uplink and the downlink, using the output of a maximum-length shift-register sequence that is initialized at the beginning of every FEC block. This shift-register sequence is modulo 2, added with the data sequence to create the randomized data. The purpose of the randomization stage is to provide layer 1 encryption and to prevent a rogue receiver from decoding the data. When HARQ is used, the initial seed of the shift-register sequence for each HARQ transmission is kept constant in order to enable joint decoding of the same FEC block over multiple transmissions.

Channel coding is performed on each FEC block, which consists of an integer number of subchannels. A subchannel is the basic unit of resource allocation in the PHY layer and comprises several data and pilot subcarriers. The exact number of data and pilot subcarriers in a subchannel depends on the subcarrier permutation scheme. The maximum number of subchannels in an FEC block is dependent on the channel coding scheme and the modulation constellation. If the number of subchannels required for the FEC block is larger than this maximum limit, the block is first segmented into multiple FEC subblocks. These subblocks are encoded and rate matched separately and then concatenated sequentially, to form a single coded data block. Code block segmentation is performed for larger FEC blocks in order to prevent excessive complexity and memory requirement of the decoding algorithm at the receiver. [3]

A. Convolutional Coding

The mandatory channel coding scheme in IEEE 802.16e is based on binary nonrecursive convolutional coding (CC). The convolutional encoder uses a constituent encoder with a constraint length 7 and a native code rate 1/2. The output of the data randomizer is encoded using this constituent encoder. In order to initialize the encoder to the 0 state, each FEC block is padded with a byte of 0x00 at the end in the OFDM mode. In the OFDMA mode, tailbiting is used to initialize the encoder, as shown in Fig. 2. The 6 bits from the end of the data block are appended to the beginning, to be used as flush bits. These appended bits flush out the bits left in the encoder by the previous FEC block. The first 12 parity bits that are generated by the convolutional encoder which depend on the 6 bits left in the encoder by the previous FEC block are discarded. Tailbiting is slightly more bandwidth efficient than using flush bits since the FEC blocks are not padded unneccessarily. However, tailbiting requires a more complex decoding algorithm, since the starting and finishing states of the decoder are no longer known. In order to achieve code rates higher than 1/2, the output of the encoder is punctured, using the puncturing pattern.

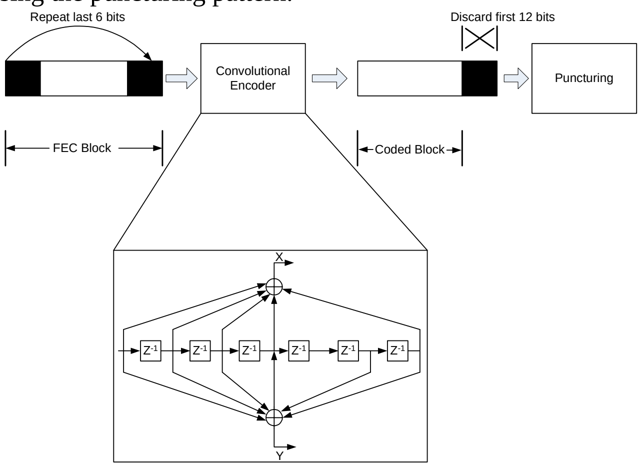

Fig.2 Convolutional encoder and tailbiting in IEEE 802.16e

B. Turbo Codes

WiMAX uses duobinary turbo codes with a constituent recursive encoder of constraint length 4. In duo binary turbo codes two consecutive bits from the uncoded bit sequence are sent to the encoder simultaneously. Unlike the binary turbo encoder used in HSDPA and 1xEV-DO, which has a single generating polynomial for one party bit, the duobinary convolution encoder has two generating polynomials, $1+D^2+D^3$ and $1+D^3$ for two parity bits. Since two consecutive bits are used as simultaneous inputs, this encoder has four possible state transitions compared to two possible state transitions for a binary turbo encoder. [6]

Duobinary turbo codes are a special case of nonbinary turbo codes, which have many advantages over conventional binary turbo codes:

✓***Better convergence***: The better convergence of the bidimensional iterative process is explained by a lower density of the erroneous paths in each dimension, reducing the correlation effects between the component decoders;

✓***Larger minimum distances***: The nonbinary nature of the code adds one more degree of freedom in the design of permutations (interleaver)-intrasymbol permutation-which results in a larger minimum distance between codewords;

✓***Less sensitivity to puncturing patterns***: In order to achieve code rates higher than 1/3 less redundancy, bits need to be punctured for nonbinary turbo codes, thus resulting in better performance of punctured codes;

✓***Robustness of the decoder***: The performance gap between the optimal MAP decoder and simplified suboptimal decoders, such as log-MAP and the soft input soft output (SOVA) algorithm, is much less in the case of duobinary turbo codes than in binary turbo codes.

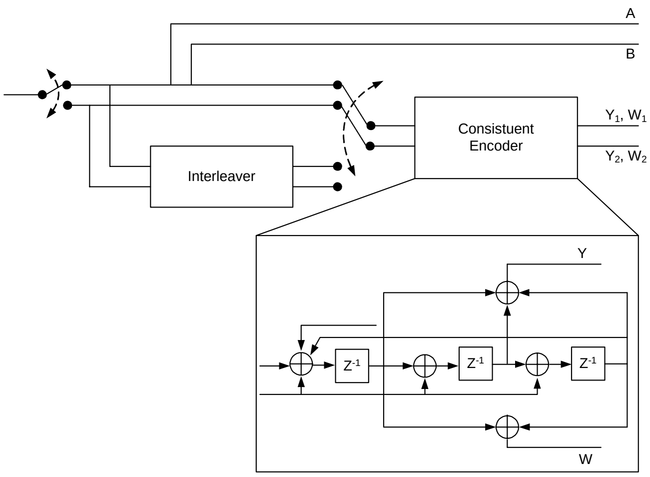

Fig.3 Turbo Encoder in IEEE 802.16e

C. Block Turbo Codes and LDPC Codes

Other channel coding schemes, such as block turbo codes and LDPC codes, have been defined in WIMAX as optional channel coding schemes. The block turbo codes consist of two binary extended Hamming codes that are applied on natural and interleaved information bit sequences, respectively. A BTC codeword is a simple product code, usually formed by a serial concatenation of two block encoders separated by a block interleaver. Let (n_i, k_i, δ_i), i={1, 2}, be the length, dimension, and minimum distance of the constituent codes, respectively. Then the parameters for the product code are $n_p=n_1 \bullet n_2$, $k_p=k_1 \bullet k_2$, $\delta_p=\delta_1 \bullet \delta_2$. The IEEE 802.16 standard offers several different options for encoding, but the longest constituent block code is a (64, 57, 4) extended Hamming code.

Low-density parity-check (*LDPC*) codes have recently attracted tremendous research interest because of their excellent error correction performance. LDPC codes have been adopted in many standards such as DVB-S2, 10GBase-T, 802.16e (*WiMAX*) and 802.11n. However, designing an LDPC code that has superior performance and can be mapped efficiently into hardware, is still a challenge. [7]

LDPC codes have a large degree of freedom in both code and decoder design. The datapath of the decoder is generally simple, and the operations can be easily parallelized. However, because of the interconnection complexity, the fully parallel LDPC decoder is huge for large block sizes. The partial parallel decoder which makes use of small block matrices with ordered structure is highly preferred. Several LDPC codes with ordered structures based on algebraic constructions have been proposed. These codes make use of algebraic properties that achieve good bit error rate (*BER*) performance. [8], [9]

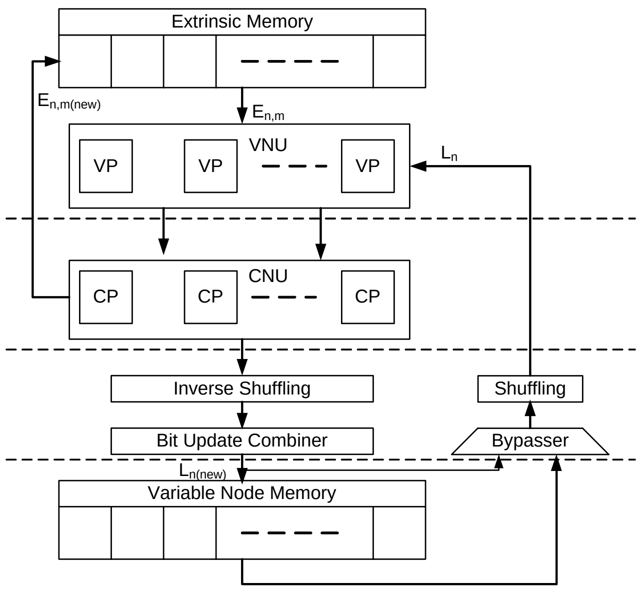

Fig.4 LDPC decoder architecture

The conventional TPMP SPA (the standard two-phase message passing Sum-Product algorithm) is commonly regarded as the standard LDPC decoding algorithm and is generally implemented in log domain. The check-to-variable messages R_{cv} are computed as Eqs. (1) and (2).

$$R_{cv} = S_c \times sign(L_{cv}) \times \Psi\{\sum_{n \in N(c)} \Psi(L_{cn}) - \Psi(L_{cv})\} \quad (1)$$

$$S_c = \prod_{n \in N(c)} sign(L_{cn}) \quad (2)$$

where $N(c)$ denotes the set of variable nodes connected to the check node c, and $\Psi(x) = -\log(\tanh(|x|/2))$ is a nonlinear function. The variable-to-check message L_{cv} is computed as Eqs. (3) and (4).

$$L_{cv} = L_v - R_{cv} \quad (3)$$

$$L_v = \sum_{m \in M(v)} R_{mv} + I_v \quad (4)$$

where L_v is the LLR message of variable node v and $M(v)$ denotes the set of check nodes connected to the variable node v. The intrinsic message corresponding to variable node v is $I_v = 2r_v / \sigma^2$, for binary input (mapping 0 to +1 and 1 to -1) and AWGN channel, where r_v and σ are the received soft value and the standard deviation of noise, respectively. The sign of L_v is taken as the estimated codeword bit c_v (mapping +1 to 0 and -1 to 1). The check-sum P_c of parity equation corresponding to check node c is computed by Eq. (5). [10]

$$P_c = \oplus_{v \in N(c)} c_v \quad (5)$$

where $\oplus$ represents binary addition. If $P_c = 0$ for any check node c, a valid code is found and the decoding process can be terminated.

IV. Simulation and Results

We have simulated and compared LDPC codes and convolutional turbo codes intended for the WiMAX (*IEEE 802.16e*) forward error correcting schemes. For the CTC, iterative decoding was stopped after 10 iterations. Concerning the LDPC decoder, the maximum number of iterations of belief propagation decoding was limited to 100. The simulations were carried out for different code rates, lengths and modulation schemes in additive white Gaussian noise (*AWGN*) channel. Simulations were run to determine the performance of CTC and LDPC in AWGN channel with BPSK modulation [6]. For each simulation, a curve showing the bit-error rate (*BER*) versus E_b/N_0 was computed. The E_b stands for energy per bit and the N_0 stands for the noise power spectral density ratio.

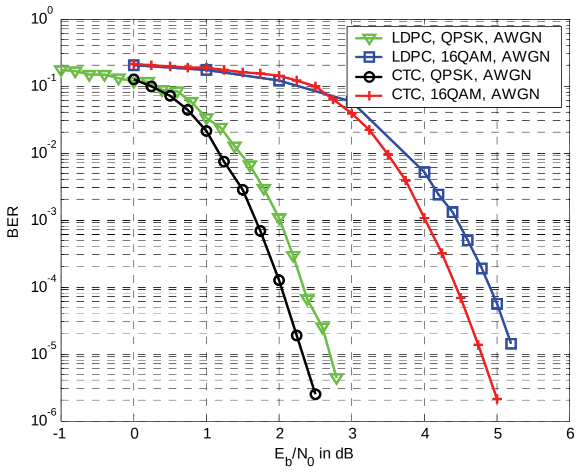

Fig.5 Comparison between LDPC and CTC with code rate R=1/2

On Fig. 5 we shows the comparison between LDPC codes and CTC codes with code rate R=1/2, two modulation schemes (QPSK and 16QAM) and N=576 bits.

V. Conclusion

The contribution of this paper has been a study into WiMAX forward error correcting codes. It presents a validation and a discussion of these types of codes. Secondly, this paper presents an implementation of convolutional turbo codes and LDPC codes developed in Matlab. The performance gain using advanced coding techniques like CTC and LDPC is quite small for rate 1/2 codes. One reason for this is that the standard only provides short to moderate code lengths (N≤2304) which is the most crucial parameter for this class of codes. The performance of CTC and LDPC is about the same and by changing some decoding parameters the small advantage of one of them can be interchanged. Nevertheless, LDPC decoding is less complex than CTC decoding.

Acknowledgement

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