

Adaptive RS Coding with LDPC-STBC Scheme in OFDM Systems

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Abstract— THE SEARCH for a good coding algorithm is motivated by the fact that various communication channels require their optimal performance. The computer simulation results show improved error-correction capability of LDPC codes with increase in number of iterations in decoding algorithm. The decoding algorithm of LDPC codes has less complexity than that of turbo codes. The capacity-approaching LDPC codes are adopted to achieve lower transmission power and more reliable communication. As high throughput LDPC decoders are becoming more ubiquitous for upcoming communication standards, energy efficient low power decoder algorithms and architectures are a design priority. The paper proposed hybrid LDPC and STBC scheme with adaptive RS coding and proved its good bit error performance.

Index Terms— AMC, Low-Density Parity Check (LDPC), OFDM, RS codes, STBC.

I. INTRODUCTION

OFDM is transmission scheme of choice to enable high-speed data, video, and multimedia communications and is used by a variety of commercial broadband systems [1]. Signal bandwidth is divided into many narrow sub-channels which are transmitted in parallel. Each sub-channel is typically chosen narrow enough to eliminate the effect of delay spread. For mobile or wireless applications, the channel is often described as a set of independent multipath components. Among the most important parameters when choosing the modulation scheme are the delay and the expected received power for different delays. One has to introduce an equalizer to mitigate the effects of Inter-symbol interference (ISI). Another alternative is to use many parallel channels so that the symbol time on each of the channels is long. This means that only a small part of the symbol is affected by ISI and this is the idea behind orthogonal frequency division multiplexing.

We live in the information age, the high-speed development of the human society both from daily work, learning activities or political, economic, military and scientific activities are inseparable from the reliable information transmission, while the error correcting code is a kind of important technology which is able to increase the reliability of information. Error correcting code can be applied to not only communication but also bar code. Through the interference of the external environment (e.g. fouling) the information which is recorded by two-dimensional

bar code will make a lot of mistakes, which need to use error-correcting codes to correct errors and restore the original information. Long term evolution (LTE) addresses the emerging trend for the mass provision of rich multimedia services, such as Mobile TV, in a more powerful and spectral efficient way than its predecessors. The Evolved-Multimedia Broadcast/Multicast Service (E-MBMS) framework is envisaged to play an essential role for the LTE-A proliferation in mobile environments. 3GPP Long term evolution (LTE) wireless broadband is intended to provide higher data rates and throughput with less latency. Due to the channel impairments of the radio channel and higher order modulation techniques, the probabilities of errors are high. Presently compared with the number of error-correcting codes LDPC code and RS code are studied much more, LDPC code has a low computational complexity, which has a linear relationship with the code length and sets a few requests on the hardware at the same time, while for RS codes there is a exponential relationship between computational complexity and code length, and the maximum error correction capacity is only 30%. LDPC codes have been demonstrated to perform very close to the Shannon limit when decoded iteratively using message-passing algorithms [2]. Using belief propagation algorithm both irregular and regular Low Density Parity Codes (LDPC) achieve rates close to the capacity on the other channels like Binary Symmetric channel (BSC) and Additive White Gaussian Noise Channel (AWGNC) with channel state information (CSI) available at both transmitter and receiver [26].

Adaptive modulation for wireless communications has received significant interest in the past five years. It has long been recognized that adaptive modulation provides more efficient use of the channel than fixed modulation schemes. It is currently implemented in a packet data CDMA standard and in wireless LAN standards such as IEEE 802.11. However, the challenge associated with adaptive modulation is that the mobile channel change with time. Thus, the feedback of channel information becomes the limiting factor in adaptive modulation. Adaptive modulation and coding is beneficial in terms of spectral efficiency and probability of bit error. AMC technique allows the system to overcome time selective fading. The key element of adaptive modulation is that it enhances the range that a higher modulation scheme can be used over, because the system can bend to the actual fading circumstances, as opposed to having a fixed scheme that is planned for the worst case situations. In AMC, not only the modulation order but also the forward error correction (FEC) schemes are varied by adjusting their code rate to communication channel variations. An example of utilization of the cited AMC scheme is illustrated in Fig.1.

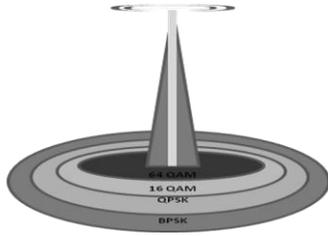


Fig.1 Scheme for the utilization of AMC

The Fig.1 shows that as the range increases, the system steps down to a lower modulation, but as closer to the base station, higher order modulations can be used for increased throughput. The LDPC codes have recently attracted tremendous research interest because of their excellent error-correcting performance and highly parallel decoding scheme. A wide array of the latest communication and storage systems have chosen LDPC codes for forward error correction in applications including digital video broadcasting (DVB-S2), 10 Gigabit Ethernet (10GBASE-T), broadband wireless access (WiMax), wireless local area network (WiFi), deep-space communications, and magnetic storage in hard disk drives [2]. In nano scale CMOS processes, digital LDPC decoders with their low-power architectures appear to be the best solution for future communication applications that demand performance near the limits of channel capacity.

The Space-Time coding of Multiple-input Multiple-output (MIMO) antenna technology make channel encoding and diversity techniques together, to take the fullest advantage of the reliability of diversity techniques and the hidden channel capacity, while ensuring a diversity gain and encoding gain. Among them, STBC is a kind of full diversity gain and the more practical encoding scheme but it cannot achieve coding gain. The simulation results proved that hybrid LDPC with STBC gives better results than individual STBC in flat Rayleigh fading channel especially at low SNR i.e. poor channel conditions.

This paper is organized as follows. First, Section 1 gives an introduction then Section 2 introduces the proposed idea of using LDPC and STBC with adaptive RS coding to achieve good error rate performance with multiple transmit antennas and also techniques for lowering transmission power and error floor of LDPC. Section 3 gives the results and discussion. Finally, conclusion is presented in Section 4.

II. LDPC-STBC SCHEME

In this paper, a parity-check matrix is divided into three sub matrices, each containing a single 1 in each column to construct LDPC code. The first of these sub matrices contains 1's in descending order; i.e., the i^{th} row contains 1's. The other sub matrices are merely column permutations of the first sub matrix. The permutations of the second sub matrix and the third sub matrix are independently selected with keeping the column weight and the row weight constant. After constructing the parity-check codes like this, we remove the four-cycle from the parity-check matrix by extracting the corresponding columns. Low-density parity-check codes using the belief propagation decoding algorithm tend to exhibit a high error floor in the bit error rate curves, when some problematic graphical structures, such as the so-called trapping sets, exist in the corresponding

Tanner graph. This paper also presents a joint row-column decoding algorithm to lower the error floor, in which the column processing is combined with the processing of each row. By gradually updating the pseudo-posterior probabilities of all bit nodes, this algorithm minimizes the propagation of erroneous information from trapping sets into the whole graph. Though the BER of LDPC codes decreases steeply with increasing signal-to-noise ratio (SNR) for low SNR, the BER tends to exhibit a sudden saturation for medium to high SNR, i.e. the so-called error floor. It is accepted now that the error floor of LDPC codes using the Belief-Propagation (BP) decoding algorithm is mainly due to some problematic graphical structures in the code's Tanner graph, such as trapping sets [6]-[8]. The concept of a trapping set, initially referred to as a near codeword, was first described in the analysis of error floors in [6] and was further described in [7]. Some near code words which do not constitute valid code words but cause failures in the BP decoder in an AWGN channel or in a binary symmetric channel are typically referred to as trapping sets. To lower the error floor, LDPC codes have carefully been constructed with some constraints in the design of the parity-check matrix [9]-[12]. For practical application in industrial standards, LDPC codes have to be designed to satisfy the specifications of various standards. For example, the LDPC codes specified in the IEEE 802.16e standard for fixed and mobile broadband wireless access systems flexibly support different frame lengths through the use of an expansion factor which is the size of each sub matrix [13]. Since the same set of parity-check matrices is used for various frame lengths, it is difficult to avoid all the problematic trapping sets in the code construction. Thus, robust decoders which minimize the negative influence of trapping sets on the BER performance are favored to lower the error floor.

The second approach for controlling the error floor in LDPC is as follows. The error floor of LDPC is revisited as an effect of dynamic message behavior in the so-called absorption sets of the code. If the signal growth in the absorption sets is properly balanced by the growth of set-external messages, the error floor can be lowered to essentially arbitrarily low levels. However, when utilizing sub-optimal $O(n)$ iterative decoding algorithm, such as message passing (MP) or linear programming, a marked increase of error rates at high SNRs tends to appear with respect to optimal decoding [14]. The error curve assumes the shape of an error floor with a very slow decrease with SNR. This error floor is caused by inherent structural weaknesses in the code's interconnect network, which cause long latencies in the iterative decoder or outright lock-up in error patterns associated with these weaknesses.

These decoding failures are very important for low-error-rate applications such as cable modems and optical transmission systems. They were initially studied in [15]-[17], and called trapping sets in [18]. Such trapping sets are dependent not only on the code but also on the channel where the code is used, as well as the specific decoding algorithm. For example, trapping sets on the binary erasure channel are known as stopping sets [19], whereas the dominant trapping sets of LDPC codes on the Gaussian channel are the absorption sets [20]. Absorption sets are also the sets implicated in the failure mechanism of message-passing decoder for binary symmetric channels.

Due to the importance of error floors in low-BER applications, recent efforts have focused on understanding the dynamics of

absorption sets [18] and several modifications of the decoding algorithm have been studied to lower the error floor, specifically targeting the absorption sets. The onset of the error floor on Gaussian channels is very strongly related to the behavior of the algorithm on binary symmetric channels, and that the dynamics of the absorption sets fully explain why and when the error floor becomes dominant in a given code. The growth rate of the error patterns in the absorption set can be balanced by the growth of the LLRs external to the set, if a sufficient dynamic range for these messages is available.

Space-time transmit diversity (STTD) and space time block coding (STBC) are the attractive techniques for high bit-rate and high capacity transmission. It is the simple space-time transmit diversity technique using multiple antennas in wireless communication. STBC with two transmit antennas was first proposed by Alamouti and generalized to more than two transmit antennas by Tarokh et al. STBC requires the orthogonality between two transmit antennas and the channel state information (CSI) at the receiver. In these schemes, the information symbols can be decoded without a reduction of the transmission rate and the complex signal processing by using the orthogonality and the CSI. Since the STBC can obtain not the coding gain but the diversity gain, the concatenation scheme of turbo codes and STBC (Turbo-STBC) was proposed to improve the error rate performance of the STBC. It has been shown that the Turbo-STBC can achieve the good error rate performance in a flat Rayleigh fading channel [21]. It has been shown in [22] that when the block length is relatively large, the error rate performance of the LDPC codes is better than that of the turbo codes with almost the same block length and code rate. Furthermore, the decoding algorithm of LDPC codes has less complexity than that of turbo codes. LDPC codes have been applied to wireless communications and code division multiple access (CDMA). There is a challenge in implementing high-throughput LDPC decoders with a low area and power on a silicon chip for practical applications. The increased parallelism coupled with a reduced supply voltage is particularly effective technique to reduce the power consumption of LDPC decoders due to their inherent parallelism. Also, there is an efficient method to detect early convergence of the iterative decoder and terminate the computations as soon as a valid code word is detected, thereby reducing dynamic power consumption [25]. A bit-serial fully-parallel LDPC decoder is fabricated in a 0.13 μm CMOS process and its effect on the power consumption is analyzed. With early termination, the prototype is capable of decoding with 10.4 pJ/bit/iteration, while performing within 3 dB of the Shannon limit at a BER of 10^{-5} and with 3.3 Gb/s total throughput. If operated from a 0.6 V supply, the energy consumption can be further reduced to 2.7 pJ/bit/iteration while maintaining a total throughput of 648 Mb/s, due to the highly-parallel architecture. The high energy efficiency can be attributed to its high level of parallelism as predicted in this paper. It can also be explained with that even though the decoder performs 64 iterations on each block, the vast majority of blocks converge in the first few iterations, resulting in minimal switching activity for the remaining iterations. This is in contrast with the bit-serial block-interlaced decoder where the switching activity does not scale down with decoder convergence unless an early termination method is applied.

An energy efficient low-density parity-check (LDPC) decoder using an adaptive wordwidth datapath is investigated. The decoder switches between a Normal Mode and a reduced wordwidth Low Power Mode. Signal toggling is reduced as variable node processing inputs change in fewer bits. The duration of time that the decoder stays in a given mode is optimized for power and BER requirements and the received SNR. The paper explores different Low Power Mode algorithms to reduce the wordwidth and their implementations. Analysis of the BER performance and power consumption from fixed-point numerical and post-layout power simulations, respectively, is presented for a full parallel 10GBASE-T LDPC decoder in 65nmCMOS. A 5.10mm² low power decoder implementation achieves 85.7Gbps while operating at 185MHz and dissipates 16.4 pJ/bit at 1.3V with early termination. At 0.6V the decoder throughput is 9.3Gbps (greater than 6.4 Gbps required for 10GBASE-T) while dissipating an average power of 31mW. This is 4.6 lower than the state of the art reported power with an SNR loss of 0.35 dB at BER = 10^{-7} . A low power adaptive wordwidth LDPC decoder algorithm and architecture based on the input patterns during the decoding process [27]. Depending on the SNR and decoding iteration, different low power settings were determined to find the best tradeoff between bit error performance and energy consumption. Out of the low power wordwidth adaptive methods explored one implementation had a post-layout decoder area of 5.10mm², while attaining a 85.7Gbps throughput with early termination while dissipating 16.4 pJ/bit at 1.3V. Compared to another 10GBASE-T design with similar areas in 65 nm and operating at 0.7V, this work achieves nearly 2 \times improvement in throughput, thus meeting the 6.4Gbps required by the standard. Energy efficiency was over 3.5 \times better with only 0.2 dB loss in coding gain. This loss compares favorably with the non uniform quantization bit reduction technique.

The hybrid LDPC-STBC system is considered with multiple transmit antennas (Tx) and one receive antenna (Rx). Information bits are encoded and modulated in BPSK. Transmit sequences are generated at the space-time block encoder and transmitted from multiple transmit antennas. At the receiver, the maximal ratio combining is implemented by using the orthogonality of the transmit signals and the estimated channel impulse responses. The combined signals are demodulated and decoded, and the data bits are restored [5]. By changing the number of iterations at the same code length and code rate computer simulations are made for LDPC decoding algorithm. The receiver performance of E-MBMS is expected to be improved compared to earlier accesses. Orthogonal Frequency Division Multiple Access (OFDMA) significantly reduces intracell interference compared to MBMS based on CDMA technology. Two receiver antennas are expected to be mandatory in the User Equipment (UE) to mitigate intercell interference. We consider Orthogonal Frequency-Division Multiplexing/Orthogonal Frequency Division Multiple Access (OFDM/OFDMA) where the use of LDPC codes in combination with multiple input multiple output (MIMO) and signal space diversity is exploited to achieve several gains in band-limited wireless communication systems [28]. To explore their potential as capacity achieving codes for more realistic wireless channels, we combine them with the use of complex rotation matrices (CRM) and real rotation matrices (RRM) specific to obtain multi resolution with MIMO. RMs

provides signal space diversity which can improve the robustness against fading.

WiMAX simulator is used in this paper. The Random bits are generated, and then, coded by a concatenated Reed Solomon (RS) and Convolutional encoder. The systematic outer RS code uses a codeword length of 255 bytes, a data length of 239 bytes, and a parity length of 16 bytes. Depending on the currently selected AMC value, the RS code is shortened, to allow for smaller block sizes, and punctured. The outer convolution code of rate $R = 1/2$ is generated by the polynomials 1710CT and 1330CT. This code belongs to the class of the so-called maximum free distance codes with constraint length equal to seven.

TABLE I

WIMAX Modulation and Coding Schemes

AMC	Modulation	RS code	CC code rate	Overall Code rate
1	BPSK	(12,12,0)	1/2	1/2
2	QPSK	(32,24,4)	2/3	1/2
3	QPSK	(40,36,2)	5/6	3/4
4	16-QAM	(64,48,4)	2/3	1/2
5	16-QAM	(80,72,4)	5/6	3/4
6	64-QAM	(108,96,6)	3/4	2/3
7	64-QAM	(120,108,6)	5/6	3/4

However, after puncturing the maximum free distance is reduced to $d_{free} = 6$ for $R = 2/3$, $d_{free} = 5$ for $R = 3/4$, $d_{free} = 4$ for $R = 5/6$, and $d_{free} = 10$ for $R=1/2$, respectively. After coding, an interleaver is implemented to avoid long runs of low reliable bits at the decoder input. The interleaved bits are mapped adaptively to a symbol alphabet [3]. The coding, interleaving, and symbol mapping are the same as defined in the WiMAX IEEE 802.16d specification [3], [4]. Depending on the feedback information from the receiver, the mapping and the coding rate are adjusted. The seven possibilities for the AMC schemes are summarized in Table I.

III. SIMULATION SET-UP AND ANALYSIS

The simulink model is shown in Fig.2. The system is operating with a bandwidth of 500 kHz divided into 64 tones. The total symbol period is 138 μ s, of which 10 μ s is a cyclic prefix. Sampling is performed with 500 kHz rate. A symbol thus consists of 69 samples, five of which are contained in the cyclic prefix (i.e. $L = 5$). 50,000 channels are randomized per average SNR, each consist of five pulses, of which four have uniformly distributed delays over the interval 0-10 μ s, while one tap is always assumed to have a zero delay, corresponding to a perfect time synchronization of the sampling instants.

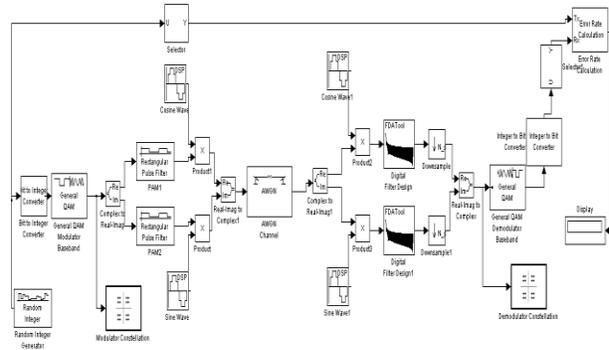


Fig.2 Simulink model of communication system

Computer Simulation was carried out both in MATLAB and SIMULINK using different signals like BPSK, ASK, BFSK, QAM, QPSK in a Rayleigh fading and AWGN channel. BER vs. SNR graph was plotted to compare the performance of different systems.

In Quadrature Phase Shift Keying (QPSK) two sinusoids (Sine and Cosine) are taken as basis functions for modulation. Modulation is achieved by varying the phase of the basis functions depending on the message symbols. In QPSK, modulation is symbol based, where one symbol contains 2 bits. In a communication system, the receiver side BER may be affected by transmission, channel noise, interference, distortion, bit synchronization problems, attenuation, wireless multipath fading, etc. It is easily verify from the Scatter plots in Fig.3 that as the SNR decreases the Constellation of QPSK are more crowded and hence BER increases. Scatter graphs were plotted varying SNR from 1db to 10db to encounter the results.

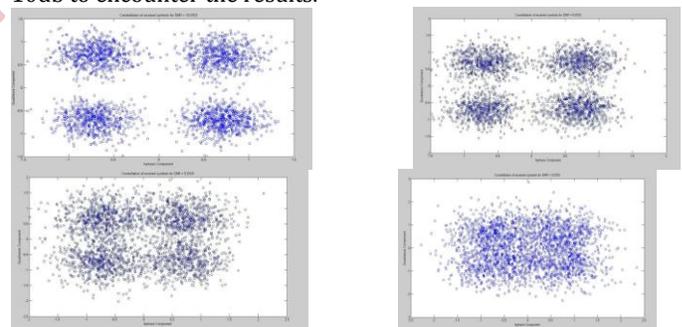


Fig.3 QPSK signal constellation with SNR = 10dB, 8dB, 5dB and 3dB

The BER may be improved by choosing a strong signal strength (unless this causes cross-talk and more bit errors), by choosing a slow and robust modulation scheme or line coding scheme, and by applying channel coding schemes such as redundant forward error correction codes. Signal-to-noise ratio (often abbreviated SNR or S/N) is a measure used in science and engineering that compares the level of a desired signal to the level of background noise. The plot in Fig.4 is of SNR vs. BER for QPSK signals which again show that as the SNR increases there will be decrease in the BER.

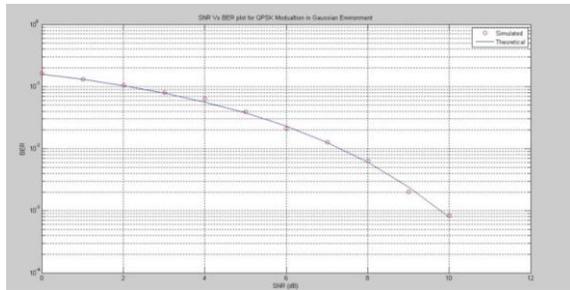


Fig.4 BER vs. SNR plot for QPSK signal

The plots show the improvement in performance of system with the use of different modulation and coding schemes in WiMAX system in order to instantaneously adapt spectral efficiency to the variations in the channel SNR while maintaining an acceptable BER. Adaptive modulation enables a WiMAX system to optimize the throughput based on the propagation conditions. Using adaptive modulation scheme, WiMAX system can choose the highest order modulation provided the channel conditions are good. AMC technique allows the system to overcome time selective fading. The supported modulations are BPSK, QPSK, 16-QAM and 64-QAM. MATLAB simulations can be used to understand the basic processing involved in this system.

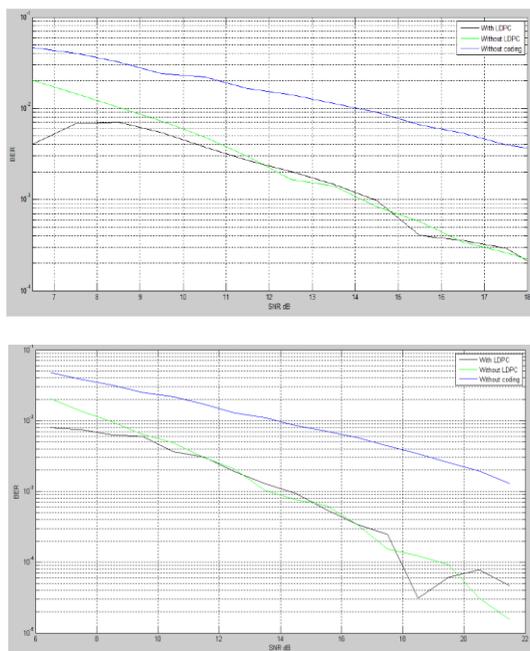


Fig.5 BER vs. SNR for 2X1 LDPC-STBC scheme with number of Iterations = 500, 100

The computation for LDPC decoding is of low complexity, which does not increase dramatically with the code length, and it has a rigorous theoretical analysis of testability. Usually a linear block code decoding complexity and code length is growing exponentially. However due to parity check matrix's sparse of LDPC code, the decoding complexity grows linearly with the code

length, consequently it overcomes the decoding complexity issues when the code is longer. LDPC code uses iterative decoding algorithm, and can operate in parallel with high-speed decoding ability. Its overall capacity is big, and the system transmission can be effectively improved. The most common LDPC decoding is belief propagation decoding algorithm (referred as BP algorithm), also known as Sum- Product (SP) algorithm or message passing (MP) algorithm [23]. The decoding algorithm of LDPC codes has less complexity than that of turbo codes. Furthermore, when the block length is relatively large, the error rate performance of the LDPC codes is better than that of the turbo codes with almost identical code rate and block length [22]. The results of concatenation scheme of LDPC and STBC has been shown in Fig.5 and proved to have achieved good error rate performance. From the plots, it is observed that system performance increases with the use of LDPC codes especially for lower SNR values. Hence results show that the BER of the LDPC-STBC is better than that of individual STBC in flat Rayleigh fading channel which finds application for high bit-rate mobile communications with multiple transmit antennas. From the simulation results, it can also be concluded that larger the number of iterations, LDPC decoding performance improves and the more errors can be rectified; based on the same code length and rate, but the number of iterations can not be unlimited, or the computing complexity will be increased [24].

IV. CONCLUSION

The simulation results show that an OFDM based WiMAX system can use optimization mechanism of AMC that employ multiple modulation and coding schemes in order to instantaneously adapt spectral efficiency to the variations in the channel SNR while maintaining an acceptable BER. According to this mechanism, as the range increases, the system steps down to a lower modulation, but as closer to the base station, higher order modulations can be used for increased throughput. The system performance further increases with the use of LDPC codes especially for lower SNR values. For the same SNR value LDPC-STBC coding scheme gives the best result as compared to individual STBC in flat Rayleigh fading channel. Hence LDPC codes in combination with multiple input multiple output (MIMO) and signal space diversity is exploited to achieve several gains in band-limited wireless communication applications such as in 3GPP LTE standard. The computer simulation results also proved improved error-correction capability of LDPC codes with increase in number of iterations in decoding algorithm. LDPC decoders with their reduced complexity and inherent parallel mechanism find abundance application in low-power wireless transmission. A low power adaptive wordwidth LDPC decoder algorithm and architecture based on the input patterns during the decoding process is investigated. Depending on the SNR and decoding iteration, different low power settings can be determined to find the best tradeoff between bit error performance and energy consumption. To attack trapping sets which cause error floor in the error curve of LDPC codes, various schemes like joint row-column decoding algorithm and a proper choice of message representation inside the iterative message-passing decoder have been suggested to improve the

performance in both the waterfall region and the error floor region.

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