ISSN No: 2348-4845
International Journal & Magazine of Engineering, Technology, Management and Research
A Peer Reviewed Open Access International Journal

Implementation of Novel BP Algorithm for LDPC Decoding on a General Purpose Mobile ARM11 CPU

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Abstract:

The design of future communication systems with high throughput demands will become a critical task, especially when sophisticated channel coding schemes have to be applied. Low-Density Parity-Check(LDPC) codes are among the most powerful forward error correcting codes, since they enable to get as close as a fraction of a dB from the Shannon limit.

As with all other channel coding schemes, LDPC codes add redundancy to the uncoded input data to make it more immune to channel impairments. A simplified decoding algorithm for decoding LDPC codes is proposed with a view to reduce the implementation complexity.

The algorithm is based on simple hard-decision decoding techniques while utilizing the advantages of soft channel information to improve decoder performance. This astonishing performance combined with their relatively simple decoding algorithm called Belief propagation algorithm which makes these codes very attractive for the next digital transmission system generations.

The parity check matrix used for the LDPC codes is sparse. A new technique for efficient encoding of LDPC codes based on the known concept of Lower triangular modification approach is introduced. This work deals with study and implementation of LDPC coding system over AWGN Channel.

Keywords:

LDPC Low-density parity-check, AWGN channel, Lower triangular modification approach, Belief propagation algorithm, Raspberry Pi, LCD Display

I.INTRODUCTION:

Digital wireless communications are omnipresent in our daily lives, with examples ranging from mobile phones and digital television via satellite or terrestrial links to wire- less Internet connections. In all those systems, coding schemes play an essential role in ensuring successful transmission of information, which is represented by a sequence of bits, from one point to another. In recent years, there has been an increasing demand for efficient and reliable data transmission with low power consumption over noisy channels. From the viewpoint of the receiver there are many ways to conflict with the disturbance caused by the channel. In short, data transmission permits two measures: error detection and correction. In information theory by adding redundancy bits to the transmission, it is possible to detect the presence of errors. This is called Error correcting codes (ECC)[2]. If the errors cannot be located, then the message is retransmitted until the error free message is received by the receiver. This method is called ARQ (automatic repeat and request)[2]. In forward error correction(FEC)[2] redundancy bits are added to information bits and used to reconstruct the original information without errors.

One of the most advanced classes of channel codes is the class of Low-density parity-check (LPDC) codes, which were first proposed by Gallager [4] in the early 1960s and rediscovered and generalized by MacKay et al. in the 1990s [4]. LDPC codes are a class of linear block LDPC codes. The name comes from the characteristic of their parity-check matrix which contains only a few 1's in comparison to the amount of 0's. Their main advantage is that they provide a performance which is very close to the capacity for a lot of different channels and linear time complex algorithms for decoding.

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Furthermore are they suited for implementations that make heavy use of parallelism. As strong competitors to Turbo Codes, LDPC codes are well known not only for their capacity-approaching performance but also for their manageable decoding complexity . More importantly, LDPC codes have some of the advantages of linear block codes, such as their simplicity and sparse (low-density) parity-check matrices which can be depicted as a graphical model called a Tanner graph[5]. Graphical approaches are often preferred because they provide a means of visualizing and analyzing complex mathematical relationships.

Nowadays, LDPC have made its way into some modern applications such as 10GBase-T Ethernet, Wi-Fi, WiMAX, Digital Video Broadcasting (DVB).The paper is laid out as follows. In section II we give a brief overview of Hamming codes. In section III we describe the proposed system setup while section IV gives the hardware implementation details. Section V is dedicated to software implementation. Finally, results in section VI and the paper is concluded in section VII.

II.HAMMING CODES:

Hamming codes[3] are a family of linear error-correcting codes and they are the earliest codes capable of actually correcting an error detected at the receiver. These codes can detect up to two-bit errors or correct one-bit errors without detection of uncorrected errors. A metric used to measure the "closeness" between two bit patterns is Hamming distance d. The Hamming distance between two bit patterns is the number of bits that are different.Consider (n, k, d) hamming code and we wish to correct single error using the fewest number of parity bits. Each parity bit gives the decoder a parity equation to validate the received code. With 3 parity bits, we have 3 parity equations, which can identify up to $2^3 = 8$ error conditions. One condition identifies "no error", so seven would be left to identify up to seven places of single error. Therefore, we can detect and correct any single error in a 7-bit word. With 3 parity bits, we have 4 bits left for information. Thus this is a (7, 4) block code. In a (7, 4) Hamming code, the parity equations are determined as follow[3]:

- The first parity equation checks bit 4, 5, 6, 7
- The second parity equation checks bit 2, 3, 6, 7
- The third parity equation checks bit 1, 3, 5, 7

This rule is easy to remember. The parity equations use the binary representation of the location of the error bit. For example, location 5 has the binary representation of 101, thus appears in equation 1 and 3. By applying this rule, we can tell which bit is wrong by reading the value of the binary combination of the result of the parity equations, with 1 being incorrect and 0 being correct. For example, if equation 1 and 2 are incorrect and equation 3 is correct, we can tell that the bit at location 6 (110) is wrong.

At the encoder[3], if location 3, 5, 6, 7 contain the original information and location 1, 2, 4 contain the parity bits (locations which are power of 2) then using the first parity equation and bits at location 5, 6, 7, we can calculate the value of the parity bit at location 4 and so on.The main disadvantages of Hamming codes is the fixed Hamming distance due to this these codes allows the detection of two error bits and the ability to correct only a single error bit and the problem of implementing coders for large blocks. Another disadvantage of Hamming codes are that they are very ineffective for low SNR, where the received signal level is very low.

III.PROPOSED SYSTEM:

The proposed system overcomes the drawbacks of the Hamming codes by using LDPC[4] channel coding. LDPC code is a forward error correcting codes used in noisy communication channel to reduce the probability of loss of information. Their main advantage is that they provide a performance which is very close to the capacity for a lot of different channels and linear time complex algorithms for decoding. Furthermore are they suited for implementations that make heavy use of parallelism. LDPC codes are a class of linear block codes corresponding to the parity check matrix H. Parity check matrix consists of only zeros and ones and is very sparse which means that the density of ones in this matrix is very low. For given K information bits, a valid codeword c of length n bits of an LCPD codes satisfies the constraint $c*H^T=0$ [5] . Let each column of the parity check matrix H has $W_c$ones and each row has W_r ones. An LDPC code is said to be regular if W_c is constant for every column, W_r is constant for every row and $W_r= W_c \ N/(N-k)$. An LDPC which is not regular is called irregular.

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An important advance in the theory of LDPC codes is made possible by Tanner's[5] method of using bipartite graphs to provide a graphical representation of the parity check matrix. As a consequence, the bipartite graph of a LDPC code is sometimes referred to as a Tanner graph. In graphs edge is the connection between the two nodes. A bipartite graph is a graph in which the nodes may be partitioned into two subsets such that there are no edges connecting nodes within a subset. In the context of LDPC codes, the two subsets of nodes are referred to as variable nodes and check nodes. There is one variable node for each of the n bits in the code and there is one check node for each of the m rows of H. An edge exists between the i^th variable node and the j^th check node if and only if H_ij = 1. Here, H_ij is an element in the H matrix at the i^th row and j^th column[6].

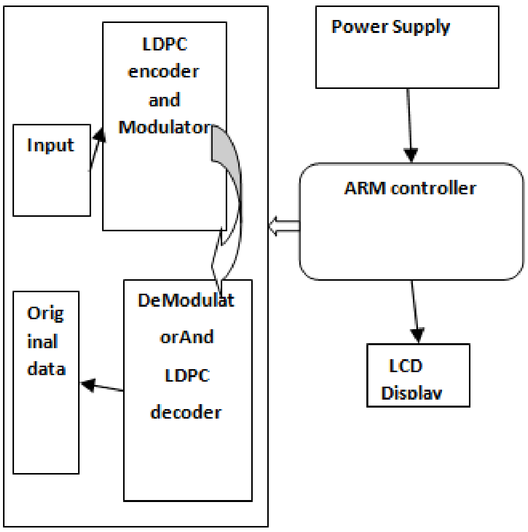

Fig1. Block Diagram

ENCODER:

If the generator matrix G of a linear block code is known then encoding can be done using c=m.G. The cost of this method depends on the Hamming weights of the basis vectors of G. If the vectors are dense, the cost of encoding using this method is proportional to n^2. This cost becomes linear with n if G is sparse. However, LDPC is given by the null space of a sparse parity-check matrix H. It is unlikely that the generator matrix G will also be sparse. Therefore the straightforward method of encoding LDPC would require number of operations proportional to n^2. This is too slow for most practical applications. Therefore it is desirable to have encoding algorithms that run in linear time[5].

Richardson and Urbanke[8] proposed an encoding algorithm called Lower Triangular Modification Approach that has effectively linear running time for any code with a sparse parity-check matrix. The algorithm consists of two phases: Preprocessing [8]and Encoding[8] In the preprocessing phase[9], H is converted into the form shown below by row and column permutations.H = (A&B&T@C&D&E)Where T has a lower triangular form and it is done by row and column permutations of H. Since H is sparse, A, B, C, D, E, T are also sparse. g, the gap, measures how close H can be made, by row and column permutations, to a lower triangular matrix. keep the matrices A, B, T unchanged and transform the matrix E into an all-zero matrix and the matrix D into an identity matrix, both by Gaussian elimination.

In encoding phase[8]. Let c = (s , p_1, p_2) where s is the information bit, p_1 and p_2 are parity bits, p_1 has length g and p_2 has length k - g . Consider $Hc^T = 0$ and multiple $\begin{bmatrix} I & 0 \\ -ET^{-1} & I \end{bmatrix}$ on both sides

$$\begin{bmatrix} A & B & T \\ -ET^{-1}A + C & -ET^{-1}B + D & 0 \end{bmatrix}\begin{bmatrix} s \\ p_1 \\ p_2 \end{bmatrix} = 0$$

Therefore we get,

$$As^T + Bp_1^T + Tp_2^T = 0$$

$$(-ET^{-1}A + C)s^T + (-ET^{-1}B + D)p_1^T = 0$$

Hence

$$p_1^T = -\varphi(-ET^{-1}A + C)s^T$$

Where $\varphi = (-ET^{-1}B + D)$ also φ is non-singular

$$p_1^T = -T^{-1}(As^T + Bp_1^T)$$

Thus by this Lower triangular modification approach the encoding of LDPC codes is linear to n.

B.ADDITIVE WHITE GAUSSIAN NOISE CHANNEL:

Additive white Gaussian noise (AWGN)[10] is a basic noise model used in Information theory to mimic the effect of many random processes that occur in nature. The modifiers denote specific characteristics:

• 'Additive' because it is added to any noise that might be intrinsic to the information system.

• 'White' refers to idea that it has uniform power across the frequency band for the information system. It is an analogy to the color white which has uniform emissions at all frequencies in the visible spectrum.

• 'Gaussian' because it has a normal distribution in the time domain with an average time domain value of zero.

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The encoded code word is transmitted through the AWGN channel. In the channel, the binary vector c is first mapped into transmitted signal vector t. The binary phase-shift keyed (BPSK)[10] signal constellation is employed, so that the signal a = E_s represents the bit 1 and the signal – a represents the bit 0 i.e. -E_s . The energy per bit E_b is related to transmitted code bit E_s by E_s=rE_b. The Probability of bit error rate (BER) of BPSK in AWGN can be calculated as

$$P_b = Q\left(\sqrt{\frac{E_b}{N_0}}\right)$$

C.DECODER:

The decoder receives the code from the channel which contains errors. It uses the parity bits information and H matrix to correct the errors in the code word. The decoder can be implemented by using Hard Decision Decoding[6] and Soft Decision Decoding methods[5].

The soft-decision decoder operates with the same-principle as the hard-decision decoder, except that the messages are the A Posterior probability that the received bit is a 1 or a 0 given the received vector y.Let us define some notations as follows[5]:

$r(i)\backslash j$: The set of all variable nodes connected to check

$c(i)\backslash j$: The set of all check nodes connected to variable node with check node excluded.

$l(P_i)$: The log-likelihood ratio (LLR) of bit which is Derived from the received value y_i.

$l(r_{ji})$: The LLR of bit which is sent from check node to variable node i.

$l(q_{ij})$: The LLR of bit which is sent from variable node to check node j.

$l(Q_i)$: The posteriori LLR of bit i computed at each iteration.

The following are the steps of Belief Propagation algorithm [5]

1. Initialization:
   Compute the log likelihood ratio (LLR) l_i for n = 1,2,…, N using the following equation, where σ^2 is variance of the noise generated by the AWGN Channel.

$$l(P_i) = ln\left(\frac{P_r(c_i = 0 \mid y_i)}{P_r(c_i = 1 \mid y_i)}\right) = \frac{2}{\sigma^2} y_i$$

2. Iterative Processes :
   a. Check node updating is given as

$$l(r_{ji}) = 2\tanh^{-1}\left(\prod_{i' \in r(i)\backslash j} \tanh\left(\frac{1}{2} l(q_{i'j})\right)\right)$$

   b. Variable node updating is given as

$$l(q_{ij}) = l(P_i) + \sum_{j' \in c(i)\backslash j} l(r_{ji})$$

3. A Posterior probability update operation :

$$l(Q_i) = l(P_i) + \sum_{j' \in c(i)} l(r_{ji})$$

4. Parity check operation :

$$c^\wedge_i = \begin{cases} 1 & l(Q_i) > 0 \\ 0 & l(Q_i) \le 0 \end{cases}$$

5. If $c^\wedge H^T = 0$, c^ is considered as a valid decoded word; if the number of iterations exceeds the maximum one and c^ is not a valid codeword, the decoding processing terminates and a failure is declared; otherwise the processing procedure returns to the check node updating of 2

IV.HARDWARE IMPLEMENTATION:

A.RASPBERRY PI BOARD:

The Raspberry Pi[11] is a credit-card-sized single-board computer developed in the UK by the Raspberry Pi Foundation with the intention of promoting the teaching of basic computer science in schools.

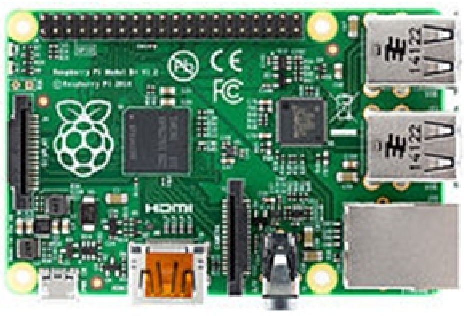

Fig2. Raspberry Pi Board[11]

The Raspberry Pi has a Broadcom BCM2835 system on a chip (SoC), which includes an ARM1176JZF-S 700 MHz processor, Video Core IV GPU, and was originally shipped with 256 megabytes of RAM, later upgraded to 512 MB. It does not include a built-in hard disk or solid-state drive, but uses an SD card for booting and persistent storage.

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The Raspberry Pi board contains a processor and graphics chip, program memory (RAM) and various interfaces and connectors for external devices. It operates in the same way as a standard PC, requiring a keyboard for command entry, a display unit and a power supply. Since Raspberry Pi board operates like PC it requires 'mass-storage', but a hard disk drive of the type found in a typical PC is not really in keeping with the miniature size of Raspberry Pi. Instead we will use an SD Flash memory card normally used in digital cameras, configured in such a way to 'look like' a hard drive to Raspberry Pi's processor.

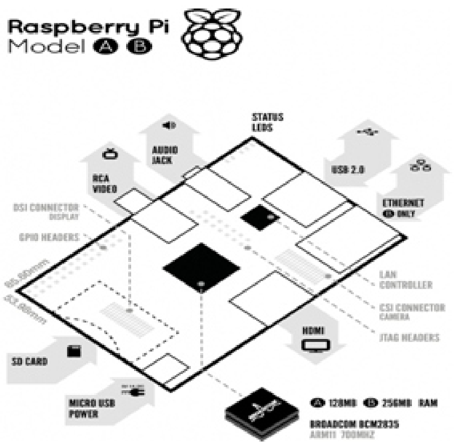

Fig3. Board features[11]

Raspberry Pi will 'boot' (load the Operating System into RAM) from this card in the same way as a PC 'boots up' into Windows from its hard disk. The following are essential to get started:

1.SD card containing Linux Operating system
2.USB keyboard
3.Monitor (with HDMI, DVI, Composite or SCART input)
4.Power supply
5.Video cable to suit the monitor used

Fig4. Hardware setup

B.INPUT DATABASE:

Mackey codes Database: This is a database of sparse graph codes. Properties recorded include the codes' parity check matrices, their rates and minimum distances, their empirical performance on the binary input Gaussian noise channel, and histograms of decoding times.

V.SOFTWARE IMPLEMENTATION

Linux Operating System:

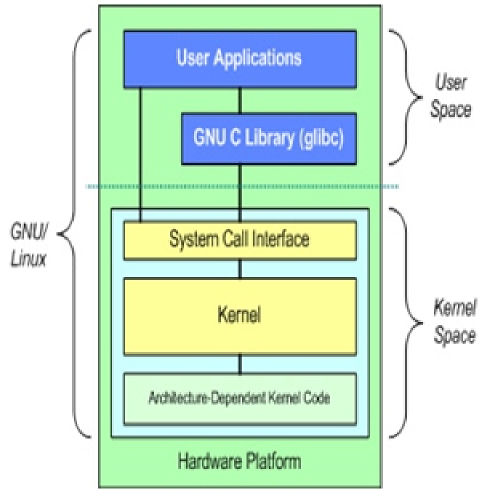

Fig5. Architecture of Linux Operating System

Linux or GNU/Linux is a free and open source software operating system for computers. Free and open source software (FOSS) means that everyone has the freedom to use it, see how it works, and changes it. Since Linux is free software it means that none of the software will put any license restrictions on users. This is one of the reasons why many people use Linux. The Linux kernel, handles process control, networking, and peripheral and file system access. Device drivers are either integrated directly with the kernel or added as modules loaded while the system is running. The Raspberry Pi primarily uses Linux-kernel-based operating systems. The ARM11 chip at the heart of the Pi is based on version 6 of the ARM. The current releases of several popular versions of Linux, including Ubuntu, will not run on the ARM11. Raspbian is an operating system which is one of the flavor of Linux-kernel recommended for Raspberry Pi.

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VI.RESULTS:

The tool required for simulating is the GNU g++ compiler. The GNU Compiler Collection (GCC) is a compiler system produced by the GNU project supporting various programming languages. GNU g++ compiler supports C++ programming language.

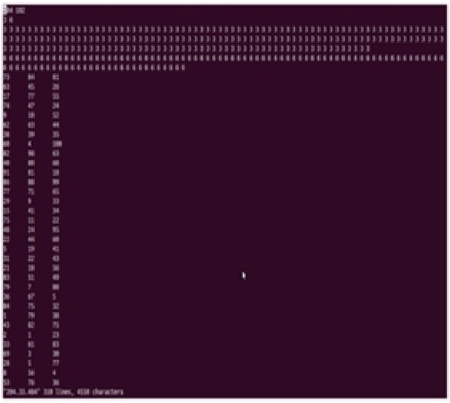

Fig6. Standard input Mackey Database given to the LDPC encoder

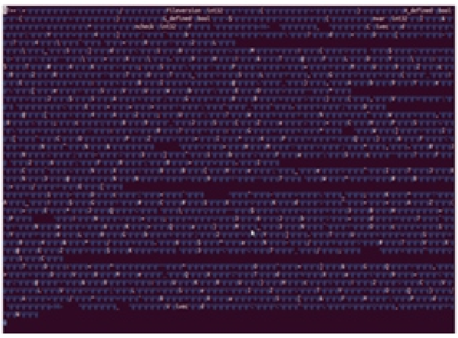

Fig7. Mackey Database Corrupted with noise when pass through AWGN channel

The figure 10, the graph between number of frames and error detected, which gives the information that as each iteration increases, number of frames increase and number of errors are decreased. Thus errors are detected by using Belief Propagation algorithm.

Fig8. LDPC code generation

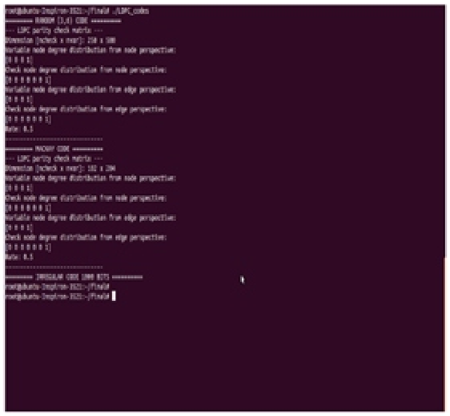

Fig9. LDPC code simulation

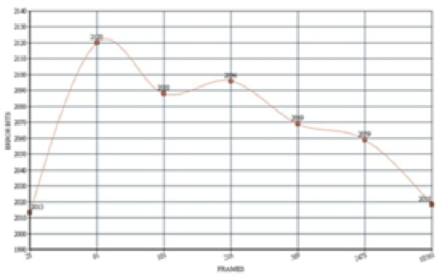

Fig10. Graph between number of frames and error detected.

VII.CONCLUSION:

The project "Implementation of Novel BP Algorithm for LDPC Decoding on a General Purpose Mobile ARM11 CPU" has been successfully designed and tested. This paper presents an implementation of a channel coding scheme. It contains encoder, channel and a decoder. Encoder is implemented using standard encoding method and lower triangular modification approach as well. Parity check matrix is constructed and generator matrix is implemented from parity check matrix. Additive white Gaussian noise channel model is implemented. Decoder is implemented using both soft decision and hard decision decoding algorithms of Belief Propagation algorithm. It has been developed by integrating features of all the hardware components and software used. Presence of every module has been reasoned out and placed carefully thus contributing to the best working of the unit. Secondly, using highly advanced Raspberry pi board and with the help of growing technology the project has been successfully implemented.

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In the future, we hope to implement and test the algorithm on a mobile GPU as well, since that could allow for higher throughputs, while also allowing the CPU to perform other tasks in parallel. This work will however serve as a baseline against which other accelerated implementations will be compared.

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