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A Review on Polar Coded Modem

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Abstract: Turbo Codes are used currently for voice and data transmission in real world. Prior to them, Polar Codes were used for same purpose. Polar Codes are the first capacity achieving codes that are used for better error performance and power utilization. Due to the fact that Polar Codes has low complexity, high transmission rates can be achieved. This project proposes Polar Code based Modem to improve the Bit-Error-Rate (BER) performance and power consumption at receiver end. The experimentation will be carried on BPSK/QPSK modulated signal. The communication will be through Wi-Fi transmission Technique. It uses principle of channel polarization for encoding and Successive Cancellation (SC) Decoder for decoding. We are using raspberry pi as processor and ADC that will support the Voice/Data conversion rate of 200 KSPS speed. The range of communication is equal to Wi-Fi range of raspberry pi module respectively. This will enhance and encourage the Hot-Spot applications.

Keywords: BER, BPSK, QPSK, SC, polar codes, polar coded modem.

I. INTRODUCTION

Modem is abbreviation for Modulator – Demodulator. Modems are used for data transfer from one computer network to another computer network through, initially via telephone lines and currently via wireless channel. The computer network works in digital mode. Modulator converts information from digital mode to analog mode at the transmitting end and demodulator converts the same from analog to digital at receiving end. The process of converting analog signals of one computer network into digital signals of another computer network so they can be processed by a receiving computer is referred to as digitizing. Now a day, in order to access the Internet from any device, a modem, or hotspot, is required. Most broadband and mobile modems operate on a "4G" or fourth generation network system. The term "modem" here is used because it modulates carrier signals to encode digital information for transmission and then demodulates them in order to decode and use that information.

Data networks with high speed are the intensively important requirement of worlds. People are coming closer to facts of internet as part of digital world. If we try to explore any field, internet is a vital element. We know, in order to increase the data rate, we have to utilize the capacity of the channel through which we are sending the data. This concept is thoroughly explained by Shannon in Shannon's Capacity Theorem. Shannon demonstrated that the capacity of channel is very good if we provide that with high Signal-to-Noise ratio. But it was a theoretical calculation. Coming to practical, the capacity achieved by the researchers without compromising error rate is still less than Shannon's proposed capacity calculation. Here we are proposing Polar Coded Modem that basically uses the Polar Coding as a technique for encoding the data. It is very famous technique to achieve the great capacity of the channel. Polar coding also helps us to get desired performance.

Polar Coded Modem is proposed mainly for high speed data rates of data transmission. Also, we aimed at the good battery consumption at receiver. Due to better encoding method, the capacity of the channel will be utilized at maximum level. This will definitely help in overcoming the error performance so that decoding becomes less complex. This leads to increase decoding rate respectively. Currently complexity is very important factor as it is responsible for data rates.

II. LITERATURE SURVEY

Polar Codes have very great series of research for various factors. The researchers have proposed efficient encoding algorithm that will also help to save the memory bits. However, the performance will increase at the cost of increased complexity. Algorithm for greater throughput, complexity for Systematic Polar Codes (SPC) and Non-systematic Polar Codes (NSPC) were introduced. [5] Simulation based result to estimate the Signal-to-Noise Ratio (SNR) of the signal is done. The mapping of Bit Error Rate (BER) is done for better performance without losing the Complexity factor. [6]

One of the proposed algorithms is Reduced Latency List Decoding (RLLD) algorithm hat will indeed reduce the latency and also contributes to increase the throughput. Importance of the list decoding technique to enhance the error-correction performance of polar codes was discovered that yields high throughput with small as well as large list size. [11] [12] [13] The families of newly proposed architectures that have capabilities of high throughput, reduced decoding complexity were introduced by the researchers. However, they will have some amount of implementation complexity. The results show that various architectures come up with different levels of throughput respectively. [9]

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Proposal for an Approximate ML (AML) decoding unit for SCL decoders designed to take advantage of the distribution to reduce the complexity of the AML decoding unit, improving the throughput-area efficiency of the SCL decoders. [14] The controlled splitting of unfrozen bits helps to reduce the decoding complexity in polar codes. [15] A parallel concatenated structure is proposed to improve the performance of polar codes of finite length. The error performance of the proposed scheme is evaluated via simulations. The results show that, the scheme almost outperforms all the existed concatenation based polar codes, making the codes more practical. [16]
The above work was truly excellent. Polar code research is going on today also for better prospect ahead. We will see in later parts of the paper about technique which we are proposing along with each and every aspect and block explained properly.

III. POLAR CODED MODEM

1. Introduction:
In our project, we are going to use polar coding and decoding in order to achieve our goal. We will be using simple modulation technique with effective devices. We are focusing on the mainly two factors, among which first is BER i.e. Bit Error Rate performance and secondly, we are focusing on the power performance also. In this power plays a bit greater role when it comes to the receivers. When we consider mobile phone as a receiver end in communication link, it is, for sure, becomes a concerned fact about power utilization of the device. As we already know that mobile device is having a very limited battery. On contrary, connectivity to internet has become mandatory now a day. Hence power performance has gained sudden importance when it comes to battery limited device. We will be concentrating on the above fact and that's why chosen Polar codes as the encoding and decoding algorithm. Polar codes are not only famous for its capacity achieving characteristic but also famous for low power consuming error detecting code characteristic. Presently, it is very much effective compared to other coding technique. Following we will be seeing its transmitter and receiver details and their block diagrams respectively.

2. Transmitter:
Transmitter is quite a bit similar to the regular communication system model only there are some differences in the blocks or techniques used for achieving the goals of the project.

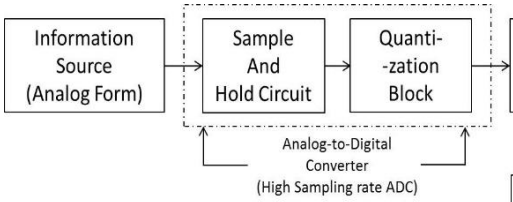

Fig.-1: Transmitter Block Diagram

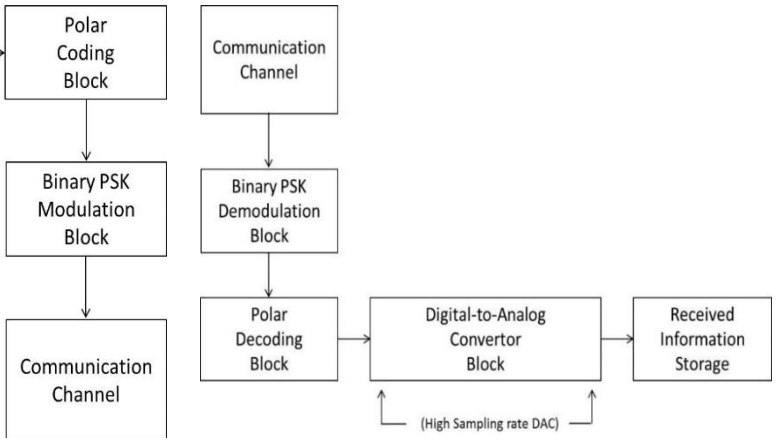

Fig.-2: Receiver Block Diagram

As per fig-1 diagram, the transmitter block diagram is shown with internal block as well. Here we are talking about high data rates so we will be implementing it with some high-end devices. Here we are dealing with High speed analog-to-digital converters that will have good resolution and good output rate. Probably we will be using several mega samples per second ADCs here. Another important block is of Encoder. Polar codes, as stated earlier, will be used as encoding technique for the data coming out from ADC. In polar codes, we are going to check the performance on the basis of various list size. Gere at transmitter, power is not an issue as we have considered data center as transmitter.

Coming to last block before we transmit the actual signal into the channel is modulator block. As we know very well, modulator technique is important from decoding perspective. Here our goal is not towards modulation direction hence we are just keeping is sober by implementing simple BPSK (Binary Phase Shift Keying) technology to modulate the data. From this block, the data will be sending over the communication channel successfully.

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3. Receiver:
Receiver of proposed Polar Coded Modem is also simple with Polar decoding as decoder block. The block diagram is shown in the following fig-2. The implementation is somewhat vice-versa of that of transmitter itself. As shown in fig-2, the receiver block explains the modification of proposed work from the conventional communication receiver block diagram. After reception of the data, the relevant error detecting and correcting algorithm used is Polar decoding one.
Polar decoding is characteristic by the property of good BER (bit-error-rate) performance. Binary Phase Shift Keying (BPSK) is basic Demodulation scheme used. Here again our focus is more on the error detection and correction rather than demodulation method. Further, we have used the High-speed Digital-to-Analog Convertors to achieve enough or expected data rates at receiver side. Decoding is very important because the data rate totally depend on how fast decoding is and how well you decode the received data without errors or with minimum error.

4. Hardware
The hardware we are willing to use is very simple. We want our concept to be of minimal cost and easily implementable. Hence, we have used Raspberry Pi as our main processing block. We will be implementing all the algorithms in it. Modulation, demodulation, encoding, decoding algorithms will be implemented in raspberry pi module respectively. Analog-to-Digital Convertors will be interfacing with module and will send data to ADC for processing. Similarly, Digital-to-Analog Convertor is used at receiver end. In this way, Hardware is so simple and very cheaper in costing also.

5. Polar Encoding Block:
Rather sending the data straight away without encoding, send same data by doing some operations on them making it intelligent way of information exchange is called as Coding. In other words, coding is taking k-bits, convert them to n-bits and the transmit it and vice a versa at receiver. This was firstly proposed by the researcher named Shannon. He had proved that we can improve the rate of transmission by using more intelligent processing and will improve the quality of channel. Polar Codes are initially introduced and described by Erdal Arikan in his published paper. According to Arikan, Polar Coding shows that when considered asymptotically, in mathematical terms, helps to achieve the Shannon's Capacity respectively. He defined Polar Codes initially for Binary Discrete Memoryless Channels (B-DMS). It is called as First Capacity Achieving Codes in coding history.

— Channel Polarization:
Polar Encoding is totally derived from polarization of the channel. Basically polarization, in polar coding terms, is splitting noisy polarizing channel into two extremes. Here polarize is in terms of the quality of the channel. That is its dividing channel into complete noiseless or complete noisy. If we consider N copies of channel, then the iteration will be in order of n. Here, $N = 2^n$ and is the block length of information's bits. By saying that the channel is completely noiseless, its means C=1 or completely noisy means C=0 where C is Shannon's Capacity and It should be satisfying this condition as $0 < C < 1$. So according to the theory, by applying channel polarization, we will get total N no. of channels form which C fraction of channels will be completely noiseless. Hence, we can use them to send information through that channels. The remaining channel which are noisy are therefore made frozen and will not be used in further communication processes.

For implementation of the above I am taking the values of different parameters as follows_
K = 64 bits (Information signal length), N = 128 bits (Block Length of encoded information signal),
K message bits are then converted into the N encoded vector. This conversion is done by taking pattern of modulo-2 operation on the message bits which are combination of frozen and noiseless bits. Mathematically it is expressed as_

$$N = K\,\text{bits} * \text{Generator Matrix}$$

Where G_N = Generator matrix is matrix formed by calculation having a base kernel as_

$$\text{kernel} = \begin{bmatrix} 1 & 1 \\ 0 & 1 \end{bmatrix}$$

The circuit is shown below which shows actually diagrammatic representation of conversion process (Encoding). It's also called as Butterfly Circuit respectively. This has $\left(\frac{N}{2}\log_2 N\right)$ Modulo-2 operations in one Butterfly Circuit and Complexity = $O(N \log_2 N)$. Every node includes (mod-2) the signs on every approaching edge from the left and sends the outcome out on all right edges. For generator matrix, denoted by G_N calculation, assume $N = 2^n$ for $n > 0$. Let I_k denote identity matrix of size (k x k). Here is the formula with which we will find out G_N as_

$$G_N = \left(I_{N/2} \otimes F\right) R_N \left(I_2 \otimes G_{N/2}\right), \text{ for } N \geq 2$$
$$\text{with } G_1 = I_1$$

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6. Code & Channel Construction:
Code construction is the process which is used especially in polar codes to send the data through pre-defined fixed bits. Here we are considering the Additive White Gaussian Noise (AWGN) channel. We are setting different channel parameters as follows_
Channel = AWGN, range of the varying the SNR values n dBs, initially, considering the frozen bits position equals to zeros respectively.

In this we have to choose k bits from the N bits available for data transfer. Let us take $N = 2^n$ as {0, …, N-1} – N indices and as mentioned above we have to choose k bits from that N indices. There are various algorithms for selection of k-bits.

7. Polar Decoding Block:
— Successive Cancellation Decoder:
Coming to decoder side, we have to go through basic decoder that is used in Polar Codes i.e., Successive Cancellation (SC) Decoder respectively. As per explained above in encoding section, the received encoded vectors X will be gone through algorithm to extract N likelihoods into N likelihood of sent information k-bits sequentially. In this section, we consider the computational complexity of the Successive Cancellation (SC) decoding algorithm. Let $X_D(N)$ denotes the worst-case complexity of SC decoding overall G_N codes with block length of N. We will show that $X_D(N) = O(N \log N)$. we are /considering the AWGN channel with initially no frozen bits. Afterwards we will be assigning the different values to frozen bits also.

This method of detecting and extracting likelihoods call as Tree Search Method. N likelihoods are processed further to get the required single value and there will be N iteration for every k^{th} bit. It's called as computational tree. The tree will go from right hand side to left hand side while processing. After 1st iteration we will get the 1st bit. Now considering this bit as estimated one, this will definitely go in reverse direction. On that basis, there will be many modulo-2 operations based on estimated bit. Further it will step by step will estimate every k message bit accordingly.

IV. EXPERIMENTATION AND RESULTS

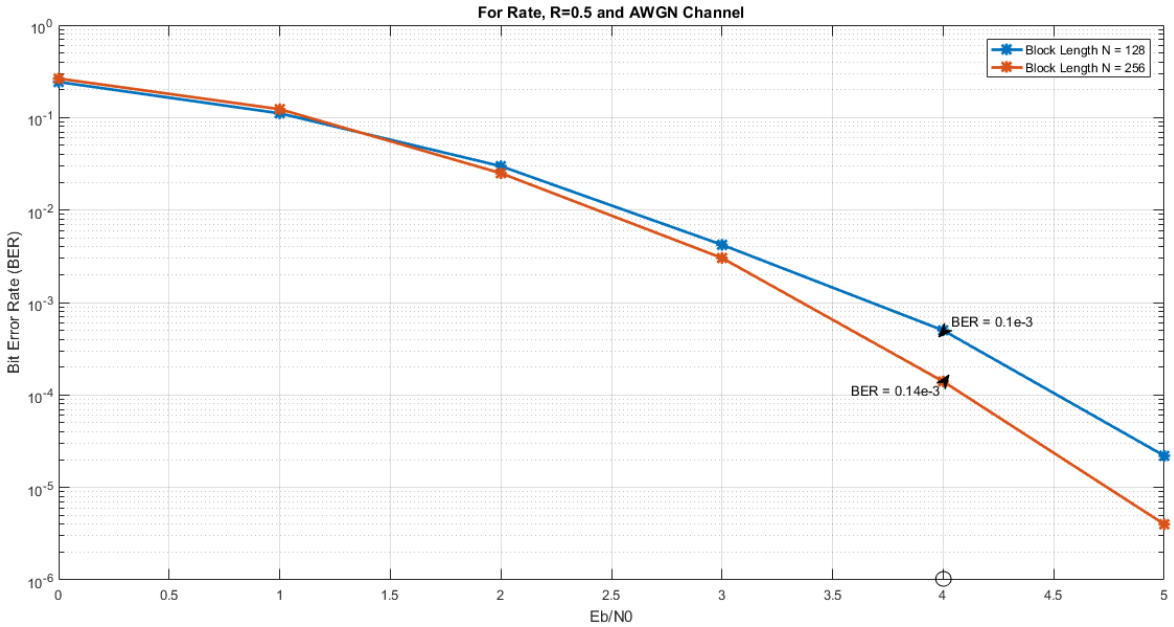

Fig.3 – Ideal Performance of Polar Codes (MATLAB Simulation)

V. CONCLUSION AND DISSCUSION

Polar Codes and its characteristics were studied. The work done by various researchers were considered in literature survey to find out how the basic parameters like complexity, throughput and latency research is going on currently. Also block diagram of the proposed work has been introduced with corresponding implementation technicalities. We will be considering two parameters for future references as Bit Error Rate performance and Power requirement. The BER performance plot has been simulated and plotted in MATLAB respectively.

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