MINISTRY OF EDUCATION AND SCIENCE OF UKRAINE
NATIONAL AVIATION UNIVERSITY
FACULTY OF AERONAVIGATIONS, ELECTRONICS AND TELECOMMUNICATIONS
DEPARTMENT OF TELECOMMUNICATION AND RADIO ENGINEERING SYSTEMS

ADMIT TO DEFENCE
Head of the Department

____________ R. Odarchenko
“_____”____________2022

DIPLOMA WORK

(EXPLANATORY NOTE)

BACHELOR’S DEGREE GRADUATE
BY SPECIALITY "TELECOMMUNICATIONS AND RADIO ENGINEERING"

Topic: «Error correcting codes for present generations of mobile communication systems»

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Kyiv 2022

NATIONAL AVIATION UNIVERSITY

Faculty of aeronavigations, electronics and telecommunications
Department of telecommunication and radio engineering systems
Speciality: 172 "Telecommunications and radio engineering"
Educational professional program: Telecommunication systems and networks

ADMIT TO DEFENCE
Head of the Department

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"_____" ____________2022

TASK
for execution of bachelor diploma work

Lomachevska Anzhela
(full name)

1.Topic of diploma work: «Error correcting codes for present generations of mobile communication systems»

approved by the order of the rector from «25» April 2022 №433/ст.

2. The term of the work: from 25 April 2022 to 12 June 2022.

3.Initial work data: theoretical and methodological data for error correcting codes in mobile communication systems.

4. Explanatory note content:

- Information transmission via low noise immunity channels of telecommunication systems
- Error correcting codes in modern mobile systems
- A Low-density parity check code in 4G telecommunication systems
- \- To draw the appropriate conclusions

5. List of required illustrative material: Scheme of LDPC encoder, scheme of LDPC decoder.

6. Work schedule

№ n/p	Task	Term implementation	Performance note
1.	Developing a detailed content of sections of diploma work	23.05.2022-25.05.2022	Done
2.	Introduction	25.05.2022	Done
3.	Information transmission via low noise immunity channels of telecommunication systems	26.05.2022-29.05.2022	Done
4.	Error correcting codes in modern mobile systems	30.05.2022-01.06.2022	Done
5.	A Low-density parity check code in 4G telecommunication systems	02.06.2022-04.06.2022	Done
6.	Elimination of short comings	04.06.2022-09.06.2022	Done
7.	Preparing the electronic report and illustrations	09.06.2022-17.06.2022	Done

7. Date of issue of the assignment: “25” April 2022.

Supervisor ___________________ I. Terentieva
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Accepted task for execution ____________________ Lomachewska A. D.

ABSTRACT

Graduate work on the topic «Error correcting codes for present generations of mobile communication systems». It contains, 40 p., 15 figures, 2 tables, 11 sources.

ERROR, TELECOMMUNICATION SYSTEMS, ERROR CORRECTING CODES, LDPC.

The object of the study is.error correcting codes.

The purpose of the thesis is methods of detecting errors in telecommunication systems and correcting them with the help channel coding.

Research of methods why errors occur, as well as opportunities and ways to correct errors in telecommunications systems.

Materials of diploma work are recommended to be used in conducting scientific research, educational process and practical activity in the teaching of undergraduate disciplines.

CONTENTS

LIST OF ABBREVIATIONS

ECC – Error Correction Codes

DSL – Dictionary Specification Language

IMT – Advanced - International Mobile Telecommunications-Advanced

MIMO – Multiple Input Multiple Output

GSM – Global System for Mobile Communications

UMTS – Universal Mobile Telecommunications System

LDPC – Low-Density Parity Check Code

BER – Bit Error Rate

CRC – Cyclic Redundancy Check

FECC – Forward Error Control Coding

WLL – Wireless Local Loop

DVB – Digital Video Broadcasting

CDMA – Code Division Multiple Access

INTRODUCTION

Actuality of theme.

The rapid development of global telecommunications technologies in the field of mobile communications is due to the increasing every year the need of users for faster and more accessible Internet. Currently, the most popular mobile system is 4G. However, when transmitting channels with noise and a specified signal-to-noise ratio, problems such as noise and interference occur. Therefore, it is necessary to find a solution to these problems, the services were delivered continuously and uninterruptedly.

Connection of work with scientific programs, plans, themes. Scientific articles and research were used.

The purpose and objectives of the study.

The purpose of the thesis is methods of detecting errors in telecommunication systems and correcting them with the help channel coding.

To achieve this goal, the following scientific problems are solved.

1. find the causes of errors in telecommunications networks
2. find a solution on how to fix these errors
3. analyze which error correction codes are best to use
4. calculate the BER and show that using these codes has reduced the probability of bit / packet error.

The object of the study is.error correcting codes.

The subject of research is correcting errors in telecommunication systems.

Research of methods why errors occur, as well as opportunities and ways to correct errors in telecommunications systems.

Scientific novelty of the obtained results. Determined by both theoretical and practical results of scientific research.

CHAPTER 1

INFORMATION TRANSMISSION VIA LOW NOISE IMMUNITY CHANNELS OF TELECOMMUNICATION SYSTEMS

1.1. Noise and interference in mobile systems

A mobile communication system can be defined as a communication system that allows people to communicate without any physical connection, independent of location, time and distance. A modern communications system is needed to support increased data rates, seamless user access to the backbone network, and the integration of multiple services such as video and movie downloads, security tracking, video conferencing, telemedicine, and telerobotics over a wide geographical area.

Table 1.1

Evolution of mobile communication networks from 1G to 5G.

Generation	1G	2G	3G	4G	5G
Band Width	30 KHz	1.25 MHz	5 MHz	20 MHz	100 MHz
Freq. band	824-894 MHz	850-1900 MHz	1.5-2.8 GHz	2-8 GHz	3-300 GHz
Data Rate	Few Kbps	22.8 Kbps	Up to 2 MHz	Up to 20 MHz	1 Gbps/higher
Access	FDMA	CDMA TDMA	WCDMA	OFDM	OFDM MIMO

In practice, the effectiveness of information transmission is limited by the presence of noise in the channel, the physical embodiment of which is random interference in signal transmission. The influence of noise leads to the loss of a portion of the transmitted information. In practice, such losses are compensated, and this requires an additional consumption of sources, including the transmission time, and, consequently, a decrease in the channel capacity (bit/s).

Various failures and noise can occur in any communication system, including telecommunication. Noise is an unwanted signal, it interferes with the output signal, and violates the parameters of the message signal. In the process of communication, the message itself may change because of this.

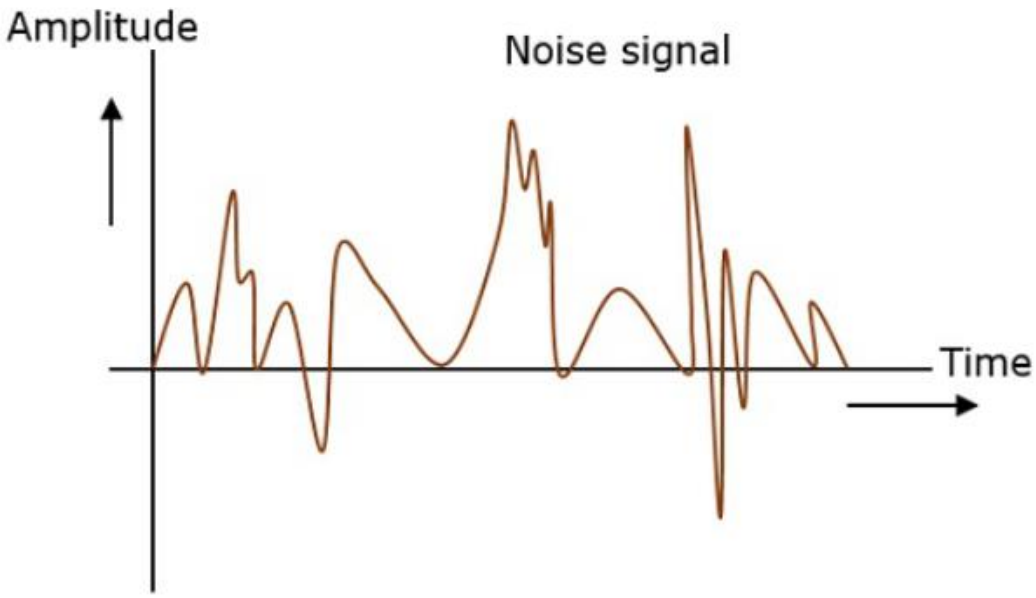


Fig. 1.1. The noise signal

In this picture we can consider the noise signal. This signal has no pattern and no constant frequency or amplitude.

Noise in a communications channel can cause errors in the transmission of binary digits. For some types of information, errors can be detected and corrected but not in others.

Transmit: 1 1 0 0 0 0 1 0 1 1 1 0 0 0 0 1 1 1 0 …

Receive: 1 1 0 0 1 0 1 0 0 0 1 0 0 0 0 1 1 1 0 …

Example:

Transmit: Call me please at 12:00 …

Receive: Call ma pleace at 14:00…

So, the problem is that there is noise which cause errors due to which we may receive incorrect information. To correct this situation, you need to reduce noise, minimize errors, as well as improve the performance of error correction codes the information will be more correct.

In the course of this work, we should investigate how noise and interference affect communication, which errors occur, how to avoid them, and how error detection and correction codes work in mobile communication systems.

Interference or interference is a phenomenon that prevents the GSM signal from spreading. Radio interference is a phenomenon that mutually increases or decreases as a result of summation that propagates in space, the amplitudes of waves, and is accompanied by alternating highs and lows of intensity. The result of interference or interference depends on the phase difference of the intersecting waves. Signaling or interference occurs when transmitting simultaneously in the same band (for example: if two subscribers try to talk on the same mobile phone). The frequency range is divided into bands (bands) to prevent interference. The cellular communication uses the bands 900 MHz, 800 MHz, 1800 MHz, 2100 MHz, 1900 MHz and others depending on the standards and the country.

A situation where two receivers are in close proximity and talking on the same frequency cannot be tolerated, because in this case interference cannot be avoided. In cellular communication systems, it is impossible to allow interference; sectors at the same base station must broadcast at different frequencies. Also, close and neighboring base stations are also not required to operate at identical frequencies. The most primitive solution is to use in every cell (cell) its own frequency throughout the network [4].

1.2. Error detection and correction in mobile telecommunication system

Bits transmitted over a computer network can be damaged due to network problems and interference. Corrupted bits lead to erroneous data by the recipient and are **called errors** [2].

Types of Errors

Errors can be of three types, namely single bit errors, multiple bit errors, and burst errors [2].

- Single bit error

Only one bit is damaged in the received frame, ie changed from 0 to 1 or from 1 to 0.

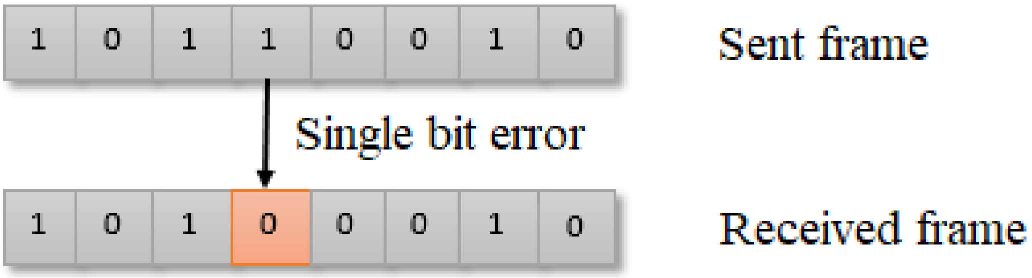


Fig.1.2. The single bit error

- Multiple bits error

In the received frame, more than one bits are corrupted.

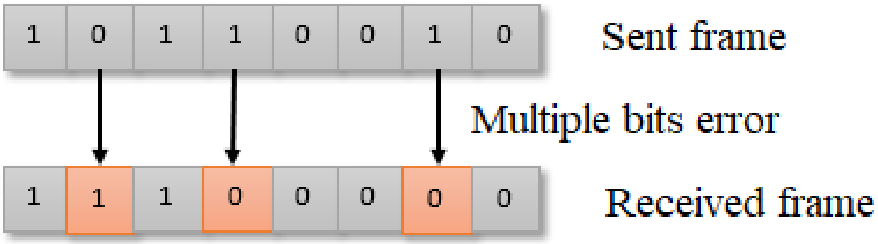


Fig.1.3. The multiple bits error

- Burst error

In the received frame, more than one consecutive bits are corrupted.

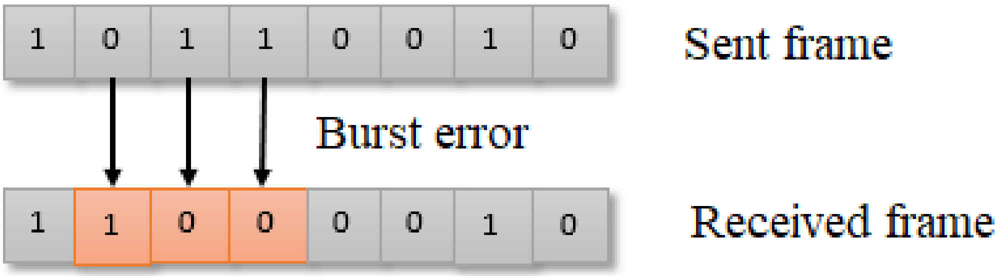


Fig.1.4. The burst error

Network errors

Digital communication networks contain errors. They are caused by transients caused by metal wires (or devices), changes in temperature, changes in the atmospheric conditions of microwave channels, equipment failure (a faulty device can send a distorted bitstream), and so on.

Errors result from:

1. Failures in time and sampling
2. Pulse noise (transients) One bit (1 is converted to 0 or vice vice versa)
3. Error bursts (bit error groups)

4. Excessive attenuation due to lack of repeaters over long distances Loss-of-signal or distorted waveforms

5. Equipment failures Interruptions, garbled data, distorted waveforms

6. Temperature variations (wander)

7. GEO satellite clock (wander)

Communications Error Definitions

The telecommunications industry typically measures performance against a performance standard. Two such standards are described in detail below. Because no network would expect to operate at a constant bit rate, and this would not be desirable, network performance is measured in seconds with errors, seconds with serious errors, and, for the G.821, minutes of deterioration. They are defined as follows:

1. Errored Second

The second when any bit error is detected. This may be a single bit error giving a BER as low as 10^{-6}

2. Severely Errored Second

Any second when more than 320 blocks out of 333 detected errors. This may be a BER at a low level as 2×10^{-6} (320 bits out of 15444000) or as high as 9.6×10^{-1} (320x193x24 bits out of 15444000). The BER worse than 5×10^{-1} are of no consequence as random data is 5×10^{-1}

3. Degraded Minutes

The network should work for 98.5% of 1-minute periods with BER> 10^{-6} [1].

Error tolerance of the information transmission system is the ability to withstand interference created in the external environment, as well as on internal elements of equipment and conductors.

Factors leading to errors:

- Instability of power supplies of devices;
- Influence of external factors (operation of electrical installations, atmospheric phenomena)
- Characteristics of the physical environment
- Sync errors;

- Offset of operating points and internal noise of electronic elements of the SPI equipment;
- Inconsistency of the parameters of the communication channel with the transmitted signals in terms of transmission speed, bandwidth and electrical parameters;

Noise immunity of SPI is characterized by the number of errors at a given signal-to-noise ratio.

Interference immunity of SPI is estimated by indicators:

- BR (Bit Rate) - the probability of a bit error;
- BER (Bit Error Rate) - the intensity of bit errors

BER is defined as the ratio of the number of erroneously received bits to the total number of sent:

$$BER = {}^{N_E}/_{N} \tag{1.1}$$

The reliability of data transmission characterizes the probability of distortion of each transmitted bit of data. Sometimes the same indicator is called **the intensity of bit errors** (Bit Error Rate). The BER value for communication lines without additional error protection (for example, self-correcting codes or protocols with retransmission of distorted frames) is usually 10^{-4} -10^{-6}, in fiber optic communication lines - 10^{-9}. The data transmission reliability value, for example, 10^{-4}, indicates that, on average, out of 10,000 bits, the value of one bit is distorted.

To ensure noise immunity of SPI, the following methods are used:

- ☐ Noise-tolerant coding.
- ☐ Increasing the signal power to reduce the number of errors by increasing the signal-to-noise ratio;

Errors inevitably occur in the process of storing data and transmitting information over communication networks. Data integrity control and error correction are important tasks at many levels of information handling, including the channel, physical, and transport levels of the OSI network model. In communication systems, several strategies for dealing with errors are possible:

- detection of errors in data blocks, as well as automatic request for retransmission of damaged blocks. This approach is mainly used at the canal and transport levels;
- detection of errors in data blocks and rejection of damaged blocks. This approach is sometimes used in streaming media systems, where there is no time for retransmission and important transmission delay;
- forward error correction is applied at the physical level.

1.3. Error Control

Error control can be done in two ways: error detection and error correction.

Error detection - error detection involves checking whether an error has occurred or not. The type of error and the number of error bits do not matter.

Error Correction - error correction involves setting the exact number of damaged bits and the location of the damaged bits.

For both error correction and error detection, the sender must send several additional bits along with data bits. The receiver performs the necessary checks based on additional redundant bits. If it detects that the data does not contain errors, it removes the extra bits before sending the message to the top level.

❑ Error Detection Techniques

There are three main techniques for detecting errors in frames: Parity Check, Cyclic Redundancy Check (CRC) and Checksum [2].

❑ Error Correction Techniques

Error correction techniques determine the exact number of bits that have been damaged, as well as their location. There are two main ways: backward error correction (retransmission) and forward error correction.

1. Backward error correction (Retransmission)

If the recipient finds an error in the input frame, he asks to retransmit the sender's frame. It's like a simple technique. But it can be used effectively only where retransmission is not expensive, such as fiber-optic, and the time for retransmission compared to the requirements of the program is short.

2. Forward error correction

If the recipient detects an error in the input frame, it executes an error correction code that generates the actual frame. This saves the bandwidth required for retransmission. This is inevitable in real-time systems. However, if there are too many errors, the frames need to be retransmitted [2].

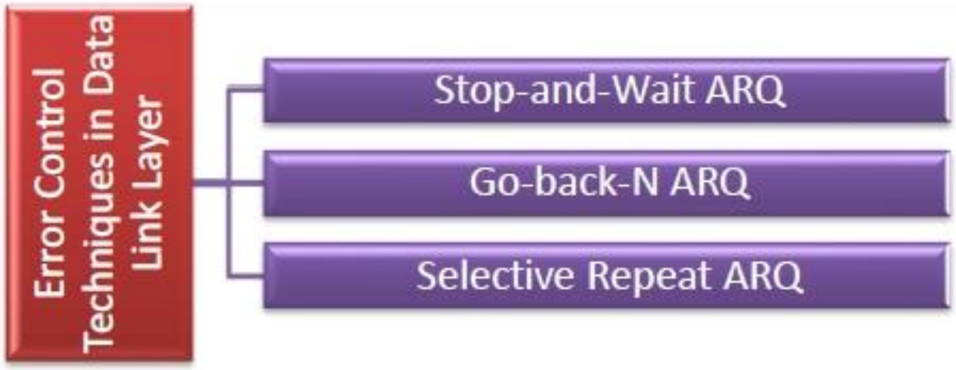


Fig.1.5. Three main techniques for error control [3]

The four main error correction codes are:

1. **Hamming codes**

Hamming codes are block codes that can detect up to two simultaneous bit errors and correct single-bit errors.

This is a code for error correction with detection and correction. The Hamming code can detect two bit errors at the same time and correct errors of one bit. In the Hamming code, it sends the message code, adding additional bits to it.

2. **Binary convolutional code**

Binary convolutional code - here the encoder processes the input sequence of bits of arbitrary length and generates a sequence of output bits.

The binary convolution code is a code that corrects errors, it produces the original bits by performing the desired logical operation on the current bitstream, taking into account some bits of the previous stream. This coding technique, not the bit block dependence, shows the bit stream dependence.

3. Reed – Solomon code

Reed - Solomon code - are block codes that are able to correct batch errors in the resulting data block.

This is a linear block code that inserts or adds extra bits before the message is sent and receives the data block.

4. Low-density parity check code

A low density parity check code is a block code defined by a parity check matrix containing a low density of 1c. They are suitable for large block sizes in very noisy channels.

This is a linear block code that allows you to correct errors in large blocks. With the help of a sparse graph of Tanner, he built. The code defined by the parity check matrix is called the parity check code.

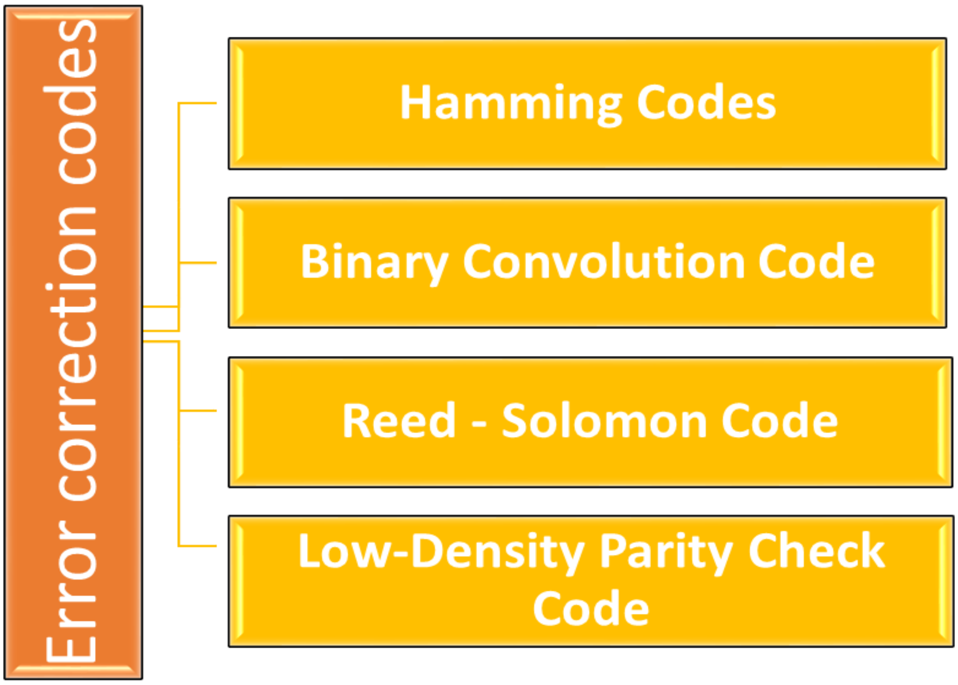


Fig.1.6. Common Error Correcting Codes

Therefore, to explore error correcting codes for present generations of mobile communication systems is the aim of this diploma work.

CONCLUSIONS TO CHAPTER 1

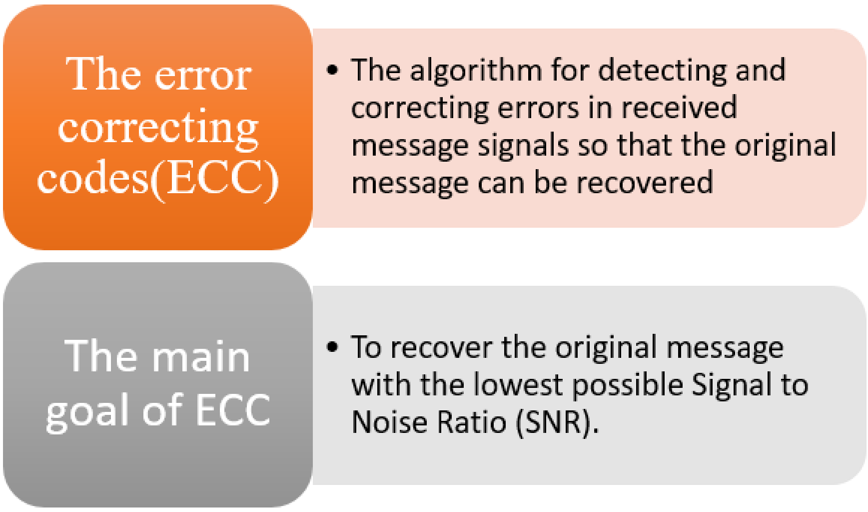
So, in this chapter it was looked at what noise and interference are, and also looked at emerging errors and how to protect against them. The probability of channel errors and the technique of systems response to error detection were considered. Also was analyzed what is error control and how can be corrected theirs in two ways: error detection and error correction. In the chapter was shown the four main error correction codes are: Hamming codes, Binary convolutional codes, Reed - Solomon codes, Low-density parity check codes.

CHAPTER 2

ERROR CORRECTING CODES IN MODERN MOBILE SYSTEMS

2.1. Types of error correcting codes

The analysis performed in Chapter 1 showed problems such as noise and interference in the transmission of channels with noise and with a given signal-to-noise ratio. One of the effective solutions to these problems is channel coding. Channel coding, also known as forward error control coding (FECC), is a process of correcting and detecting bit errors in digital communication systems. Error correcting codes are used only for discrete or digital signals and are binary and non-binary.



- The algorithm for detecting and correcting errors in received message signals so that the original message can be recovered

- To recover the original message with the lowest possible Signal to Noise Ratio (SNR).

Fig.2.1 The definition of ECC

2.1.1. Block and convolutional codes

Codes that are used to correct or detect errors that occur during the transmission of information under the influence of interference and during its storage are called error correction codes (ECC).

To realize this, when writing to useful data add redundant information in a special way, and when reading it is used to correct and detect errors. the number of errors that can be corrected depends on the concrete code used and these are limited.

There are also error detection codes, unlike corrective codes, they can only find the error in the transmitted data, but not fix it.

Error correction codes and error detection codes belong to the same classes of codes. That is, any error-correcting code can also be used to detect errors.

Error correction code is correlated to data storage along the following steps:

1.When a data byte or word is put away into RAM otherwise peripheral storage space, a code-specifying bit sequence is evaluated and put away. Every one fixed quantity of bits for each word has an added fixed number of bits to save this code.

2.When the byte or word is called for comprehension, a code for the retrieved word is calculated agreeing to the fundamental algorithm and after that compared to the stored byte’s additional settled bits.

3.If the codes bout, the data is mistake free and is sent for processing.

4. If the codes do not bout, the changed bits are caught throughout a arithmetic algorithm and the bits are directly corrected.

Data is not checked during the storage period, but is checked for mistakes when asked. If required, the error correction phase takes after detection. Frequent repeating errors at the same storage address designate a permanent hardware error. In this case, the system sends the client a message, which is logged to make a note the error locations [6].

Error correcting codes can be divided into two types, block codes and convolution codes.

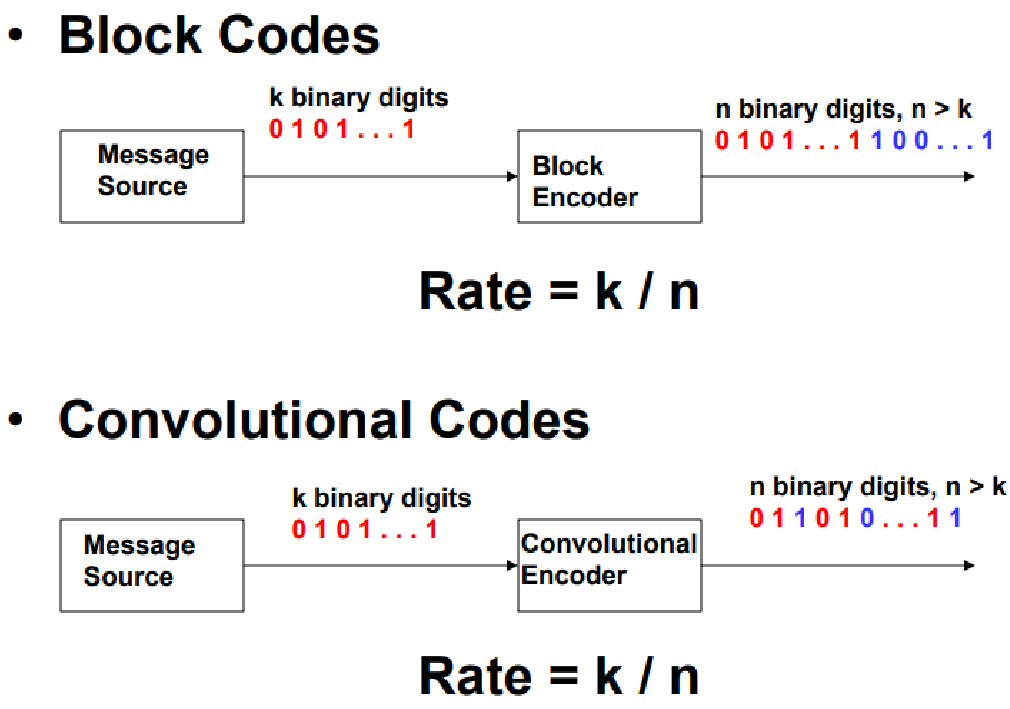


Fig.2.2. Schemes of block and convolutional codes [1]

- **Block codes**

Block codes messages are divided into blocks of bits of a fixed size, to which extra bits are added to correct and detect errors.

A type of code for correcting or detecting errors in which a fixed number (usually k) of digits is simultaneously entered into the encoder and then output as a codeword consisting of a larger number (usually n) digits. It is often referred to as code (n, k) with block length k and codeword length n. The corresponding decoder takes n digits and outputs k digits at a time. Because codewords are longer than input words, there are no more accepted words. Code words are just a choice of all possible words of their length: the method of choice gives any code its special properties [8].

Example:

- (7,4) Hamming Codes
- Binary Group Codes
- Low Density Parity Check (LDPC) Codes
- Reed Solomon (RS) Codes

- **Convolutional codes**

The message comprises of data streams of arbitrary length and parity symbols are generated by the sliding application of a Boolean function to the data stream.

Convolutional codes have been commonly used in applications such as cellular mobile, digital video broadcasting, satellite and space communications, etc. Its popularity is due from availability of easily implement able maximum likelihood soft decision decoding methods and simple structure .

Example:

- Rate ½ 4 State Code
- General Description of Convolutional Codes
- Punctured Codes
- Decoding and the Viterbi Algorithm
- Turbo codes [8]

2.1.2. Hamming codes

Hamming codes are block codes that can detect up to two simultaneous bit errors and correct single-bit errors [7].

This is a code for error correction with detection and correction. The Hamming code can detect two bit errors at the same time and correct errors of one bit. In the Hamming code, it sends the message code, adding additional bits to it. Excess bits are additional bits that are located at specific locations in the data bits to detect errors. At the receiver end of the code are decoded to detect errors and receive the original message.

- **Hamming code message**

The sender uses three standard steps to encode the message:

1. Calculate the total number of redundant bits. To calculate, assume that there are the number of data bits (n) and the number of redundant bits to be added (p). Here (n + p) represents the location of the error in each of the (n + p) bit positions, and one additional state indicates the absence of error. Since bits p can indicate states 2^p, 2^p must be at least equal to (n + p + 1). That is, it is possible to mathematically assign the above lines in the equation as:

$$2^p >= (n + p + 1) \tag{2.1}$$

2. Placement of redundant bits. All extra bits that need to be added must be placed in positions that have a degree 2.

3. Calculate the value of excess bits. Excess bits make the number 1 even or odd in the message. This property is known as parity, which can be even or odd. Odd means that the message has an odd number of 1, and even parity - the message has an even number of 1. As parity, the excess bits are calculated. It must cover all bit positions whose binary representation must include 1 in the 1st position, except for the p1 position (in the first position) [8].

- **Decryption of the message in the Hamming code**

Recalculations must be performed to detect and correct existing errors when the recipient receives the message. There are 3 standard steps to perform to detect and correct errors:

1. Count the number of redundant bits. As in the coded message above, the concept is the same. We simply use the above process to find the number of extra bits. That is, this formula is used, where n is the number of bits of data, p is the number of redundant bits:

$$2^p >= (n + p + 1) \tag{2.2}$$

2. Proper placement of redundant bits. As in the above process, we will place the extra bits in positions that have a degree 2, for example 1,2,4,16 ...

3. Parity check. The same as above, here we also perform the same method of oddness and parity. In the review, we see that the steps for encoding and decrypting a message are the same. Having seen how it works, we will see some applications, advantages and disadvantages of the Hamming code [8].

Applications:

1. Modems
2. Open connectors
3. Satellites

4. Computer memory

5. Embedded processor

6. PlasmaCAM

Advantages: Typically, Hamming codes are useful for networks that have single-bit errors because they can only correct single-bit errors. The Hamming code provides bit error detection and helps you indent the error so that it can be corrected. Looking at the different applications of the code, we can say that the Hamming code is very useful for correcting errors [8].

Disadvantages: The main problem with hamming code is that this code can correct only a few errors, so for example, if a few bits are placed incorrectly, the hamming code will not be able to correct several errors [8].

2.1.3. Binary convolutional code

Binary convolutional code - here the encoder processes the input sequence of bits of arbitrary length and generates a sequence of output bits [7].

The binary convolution code is a code that corrects errors, it produces the original bits by performing the desired logical operation on the current bitstream, taking into account some bits of the previous stream. This coding technique, not the bit block dependence, shows the bit stream dependence. It is also a linear code, it consists of a shift register used for temporary storage of bits, bit shift operations together with X-OR logic circuits to generate source code. One of the most commonly used methods for correcting digital wireless errors is convolutional encoding [8].

Basic approach

In the technique of convolutional coding, the main elements include a shift register, it acts as a temporary storage and stored bits of which are shifted by a window, a logic circuit that performs modulo-2 addition, including XOR function. There are two important parameters that determine convolutional coding: constraint length and code rate [8].

1. Constraint length.

The length of the convolutional encoder, which is the total size of the window in the bit shift register, corresponds to the length of the constraint. It is sometimes denoted as **L**, and most is denoted as **K**. There is also the parameter **m**, which corresponds to the number of input bits that are stored in the shift register after it is entered into the encoder.

2. Code rate.

This is the ratio of the number of bits shifted simultaneously in the shift register (K) to the total number of bits in the encoded message (n). Mathematically, this is intended as:

$$r = {}^{K}\!/_{n} \tag{2.3}$$

2.1.4. Reed – Solomon code

Reed - Solomon code - are block codes that are able to correct batch errors in the resulting data block.

This is a linear block code that inserts or adds extra bits before the message is sent and receives the data block. The receiver decrypts the message and corrects errors. Reed Solomon's code has parameters that play an important role in this: n, k, q. n is the length of the block symbol, k is the length of the message symbol, q is the size of each character. Each code symbol and each message in the block corresponds to an element of the Galois field. A Galois field is a set of numbers with arithmetic operations of subtraction, addition, division, and multiplication that are commutative, closed, and associative.

Applications:

- Digital communication protocols such as DSL
- Data storage media such as DVDs and CDs
- Barcode formats such as QR codes [8]

2.1.5. Low-density parity check code

A low density parity check code is a block code defined by a parity check matrix containing a low density of 1c. They are suitable for large block sizes in very noisy channels [7].

This is a linear block code that allows you to correct errors in large blocks. With the help of a sparse graph of Tanner, he built. The code defined by the parity check matrix is called the parity check code.

As we have seen above it is specified by a parity check matrix, which contains a major amount of 0's and very less amount of 1's. The parity check matrix has rows and columns which represent equations and bits in code symbols respectively. In this there are basically two parameters as n,i,j where n is block size, i is fixed number of 1's in each column and j is fixed number of 1's in each row.[8]

2.2. Error correcting codes in cellular networks

Modern error correction codes are applied in 4G and proposed for future wireless cellular networks to achieve improved channel error debugging capability. In such systems, turbo codes and their improved variants with better error correction prospects are used, and LDPC codes are also close to Shannon boundary channel codes.

Turbo codes:

Turbocode consists of convolution codes as component codes with interleaving. Convolutional codes do not break the code word into small blocks of fixed size, unlike block codes. Additional parity bits are instead constantly added to the bitstream message. Turbo codes provide a gain in coding that far exceeds classic block codes, such as Hamming codes and Goley codes. Turbo codes are widely used in digital audio and video broadcasting (DVB) and wireless local loop (WLL) for high-speed wireless data transmission. Turbo codes are also included in the specifications for Universal Mobile Telecommunication (UMTS) and CDMA-2000, which are wireless standards. third generation (3G) [5].

LDPC (Lower Density Parity Check) codes :

These codes are a kind of linear block error correction codes. They are also known as Gallagher codes because they were invented by Gallagher in 1962. McKay and Neil reinvented the LDPC codes in 1996, and their performance is close to the Shannon limit. Compared to Turbo code, they have better performance when the block length is too long and less computational complexity to decode. And the possibility of paralysis facilitates the hardware implementation of LDPC codes [5].

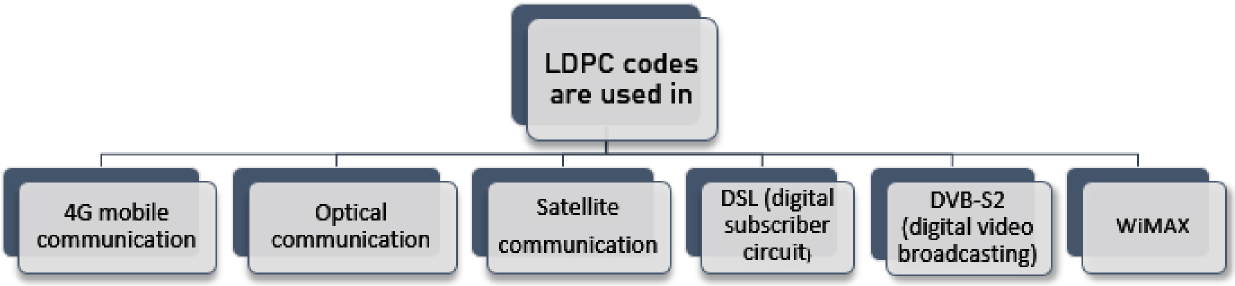


Fig.2.3. The applications where used LDPC

The key to the success of next-generation mobile networks is the choice of appropriate error correction codes. There is no one-size-fits-all coding technique. The best choice depends on the encoding speed, BER, code gain, maximum block length and decoding complexity. For low coding speed (≤12), the turbocode works better than convolutional block codes and convolutional codes. But LDPC codes with a large length of information work better than Turbo codes at high encoding speeds.

Table 2.1

The various error correcting codes for next generation mobile networks

	Parameters	**2G**	**3G**	**4G and beyond**
1.	**Error Correcting Codes**	**RS, BCH codes**	**Turbo Codes**	**LDPC codes**
2.	BER	Poor 10^{-3}	Better 10^{-6}	Best 10^{-8}

3.	Code Rate	Low $\frac{1}{6},\frac{1}{4}$	Moderate $\frac{1}{3},\frac{1}{2}$	High $\frac{2}{3},\frac{3}{4}$
4.	Decoding complexity	Moderate	Higher	Lower

The data transfer rate has increased exponentially from a few kbit / s to Gbit / s, as special technology has advanced from the first generation (1G) to the fifth generation (5G). The bit error rate of BER increases with increasing data rate, because for the provided transmission power, the energy per bit of EB/No decreases with increasing data rate. Error control codes are used to improve the early formation of the BER system over time with changing channels. Ideally, the application of the code should reach a data rate that is close to Shannon's theoretical limit. But this requires a very complex decoder, which will lead to long delays and very long code length. In other words, one of the fundamental challenges in the field of next-generation mobile communication systems is the development of channel code with low decoding complexity and higher error performance. As the Turbo and LDPC codes approach these capacities, they and their improved version are favorable candidates for use in next-generation mobile communication systems [5].

CONCLUSIONS TO CHAPTER 2

In this chapter it was considered types of error correcting codes and which types use in 4G. Also was shown various types of error correcting codes and methods in telecommunications system which help in correcting the errors. In this chapter was shown that Hamming code, binary convolution code, Reed - Solomon code, Low-density parity check can corecct the errors. Also was analyzed that Turbo codes and LDPC codes best to use in cellular networks, because one of the fundamental challenges in the field of next-generation mobile communication systems is the development of channel code with low decoding complexity and higher error performance since Turbo and LDPC codes approach these capacities, they and their improved version are favorable candidates for use in next-generation mobile communication systems

CHAPTER 3

A LOW-DENSITY PARITY CHECK CODE IN 4G TELECOMMUNICATION SYSTEMS

The previous chapters discussed what an error is, their types, why they occur, the codes that fix them, and the types of these codes. In this section, we will look at which error-correcting codes will be most effective for today's generations of mobile systems.

Currently, the most common modern mobile communication system is 4G. 3G has been replaced by the 4G cellular network, which is the 4th generation of broadband cellular technology. It provides the capabilities defined by the ITU in IMT Advanced. The maximum speed of the 3G network is 14 Mbit/s, and in the 4G network up to 100 Mbit/s.

4G system uses the Turbo and LDPC codes but in this mobile systems the Low parity check codes works better at high code rates then the Turbo codes.

As compared with Turbo code they have lower computational complexity for decoding and better performance when the block length is too large. In addition hardware implementation of LDPC codes parallization capability facilitates.

This parity check sets can be represented in two ways it shows in Figure 3.1.

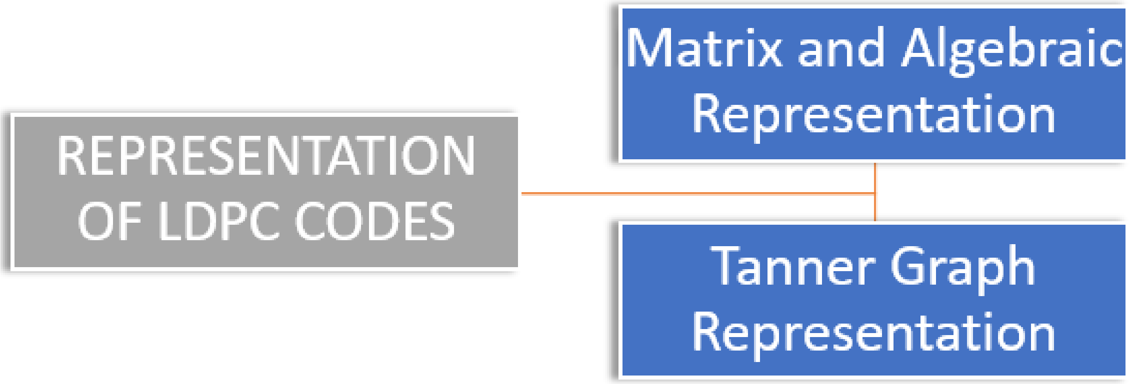
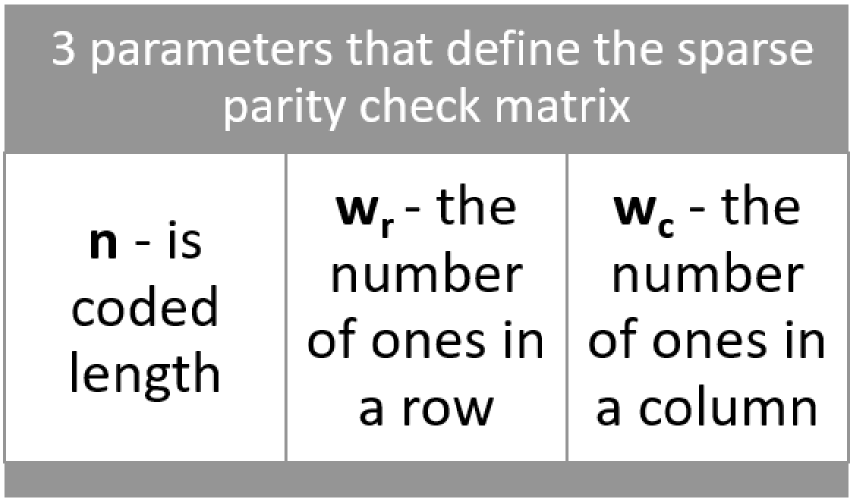


Fig. 3.1. Representation of LDPC codes

3.1. Matrix and Algebraic Representation

The parity sets in the LDPC code are expressed in terms of a sparse parity matrix. The word "sparse" means that the number "0" is much greater than the number of times "1". The sparse parity check matrix has the size (n-k) × n. For a large bitstream, the LDPC parity check matrix is typically 1000 × 2000. Therefore, of the n × (n-k) records, the number has zeros greater than ones.



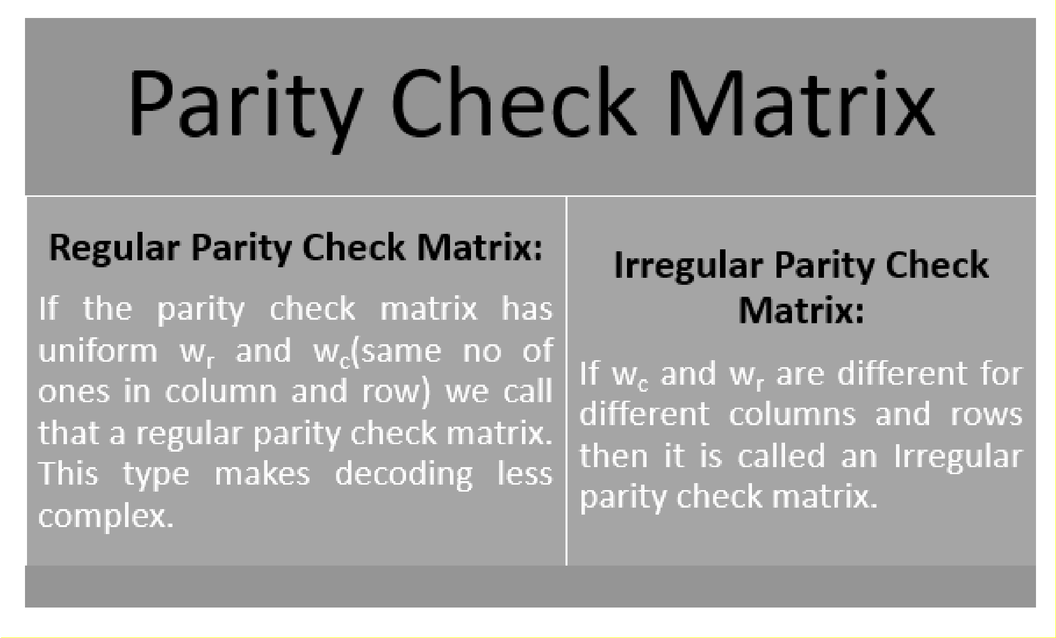
3 parameters that define the sparse parity check matrix		
n - is coded length	**w_r** - the number of ones in a row	**w_c** - the number of ones in a column

Fig. 3.2. The parameters of parity check matrix

The condition is that in order for the matrix to be called sparse or low density, the parity check matrix must be very large.

$$H = \begin{bmatrix} 1 & 0 & 0 & 1 & 1 & 0 & 1 & 0 \\ 0 & 0 & 1 & 0 & 0 & 1 & 1 & 1 \\ 1 & 1 & 1 & 0 & 0 & 1 & 0 & 0 \\ 0 & 1 & 0 & 1 & 1 & 0 & 0 & 1 \end{bmatrix} \tag{3.1}$$

Formula (3.1) shows a disparate parity check matrix 4 × 8 (8,4,2). Columns of the matrix H represent variable universities, and rows - control nodes. Variable nodes indicate of the code word the elements and check nodes - the set of parity check conditions [4].



Parity Check Matrix

Regular Parity Check Matrix:

If the parity check matrix has uniform w_r and w_c(same no of ones in column and row) we call that a regular parity check matrix. This type makes decoding less complex.

Irregular Parity Check Matrix:

If w_c and w_r are different for different columns and rows then it is called an Irregular parity check matrix.

Fig. 3.3. Classification of Parity Check Matrix

3.2. Tanner Graph Representation

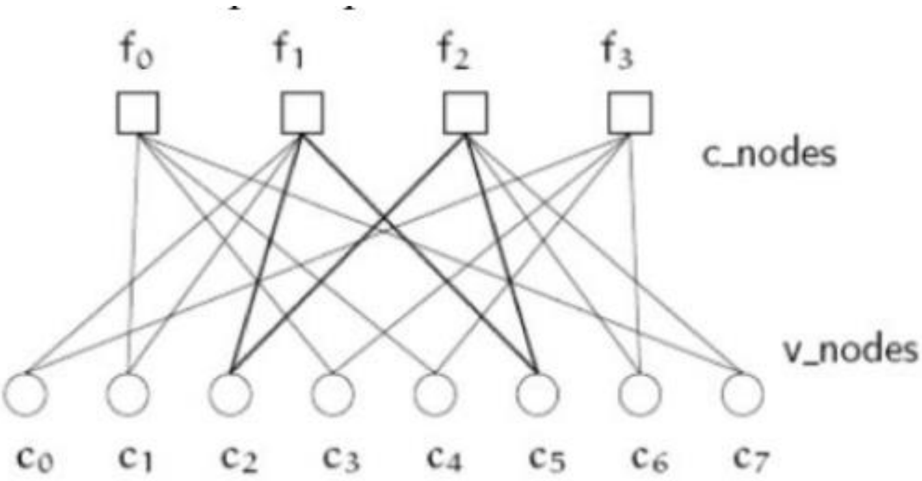


Fig. 3.4. The example for such tanner graph [4]

This figure 3.4. [4] shows the same code as the matrix from Figure 3.3. So, there will be (n-k) check nodes and n variable nodes. The connection is made between the variable node Vj if the element hij of matrix H is a 1 and the check node Ci.

Variable node Vj is connected to Check node Ci if the element hij of matrix H is a 1. We can see that there are 4 check nodes because columns of matrix H refers to the variable nodes and the rows in H matrix refers to the check nodes.

3.3. LDPC encoding

There are many decoding and encoding schemes for LDPC codes. We will now look at the most common ways the Linear Block Code is described below for the encoding process.

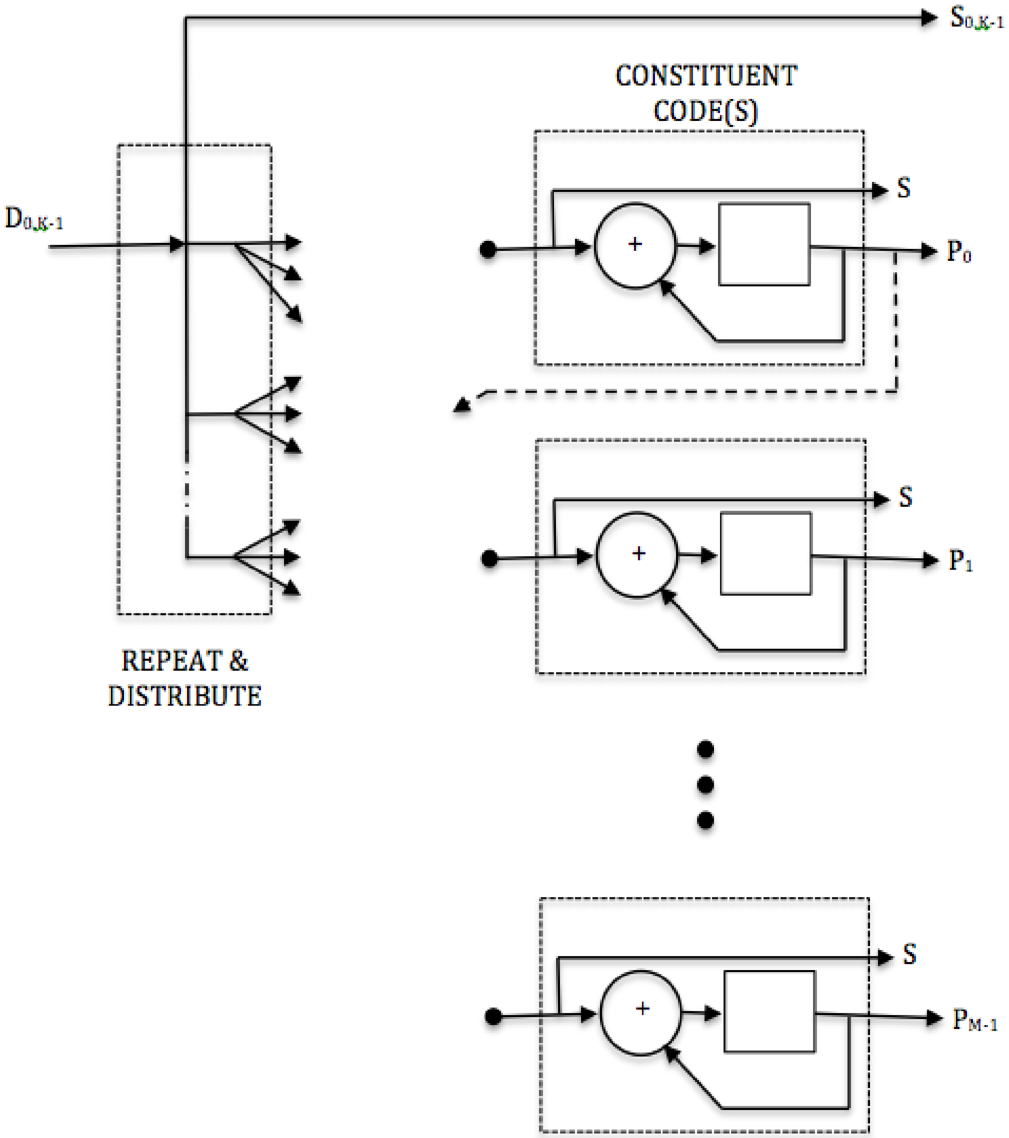


Fig. 3.4. The functional components of most LDPC encoders [2]

Linear Block Code Encoding

The codeword of Linear Block Code (n, k) is made up of the parity bits which we can describe as below and message bits.

$$C = |m_{1\times k} \div P_{1\times n-k}| \tag{3.2}$$

Where p – parity vector, m – message vector. As per the property of Linear Block Code:

$$C \times H^T = 0 \tag{3.3}$$

After matrix multiplication we get the equations for $P_{n-k\times 1}$ in terms of message bits to satisfy this condition. So, we can get the codeword of n bits after getting the values of $P_{n-k\times 1}$ [4].

Generator Matrix Formation based Encoding

H Generator matrix can be found with help of parity-check matrix for this we must performed Gauss-Jordan elimination on H to obtain

$$H = [AI_{n-k}] \tag{3.4}$$

Where A is a (n-k) × k binary matrix and Ink is the size of the (n-k) identity matrix. The generator matrix is then

$$G = I_K A^T \tag{3.5}$$

And then will get us a codeword of n bits by multiplying with the generator matrix the message bit stream

$$C = mG \tag{3.6}$$

However, most likely unlike the H matrix, the matrix G will not be sparse in this approach. So the encoder becomes complexsince the matrix multiplication is quite big as there are thousands of bits, that will be a drawback of this method. To significantly lower the implementation complexityfor that a structured parity-check matrix formation has to be used, but that does not go with the random selection of the parity check set.

So, avoid constructing a G matrix at all is a good approach and to encode instead using encoding other schemes [4].

3.4. LDPC decoding

For LDPC codes decoding algorithms comes under different names because have been formed several times independently and discovered and hence. The sum-product algorithm and the bit flipping algorithm are the most common ones. Decoding is divided into two types: decision soft decoding and decision hard decoding. Message-passing algorithms termed the class of decoding algorithms are collectively because their operations can be explained by the passing between variable and check nodes or we can say passing of messages along the edges of a Tanner graph. They are passed into this algorithm as the encoded codewords are received then in which they forward between the variable and pass backand check nodes iteratively until a non-erasable result is obtained. Thus, they are also known as decoding algorithms iterative.

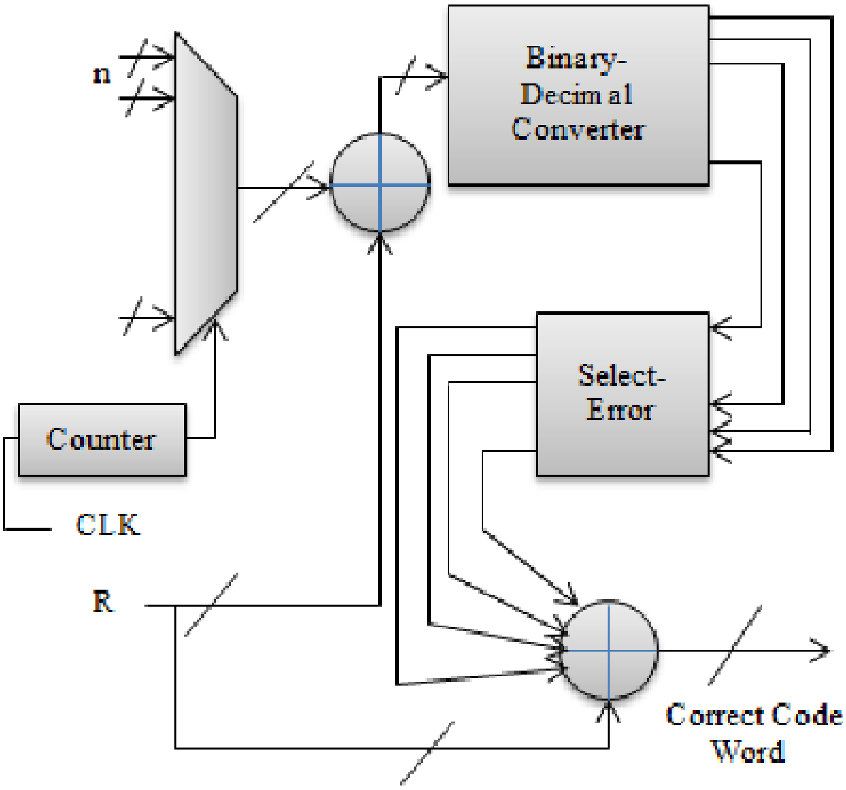


Fig. 3.6. Scheme of LDPC decoder [3]

Bit-flipping decoding

This is a tough solution for LDPC messaging algorithms. This algorithm is based on the principle that a bit of a codeword that participates in a large number of incorrect control equations will be incorrect in itself. The binary hard decision is passed to the decoderand is made by the detector for every received bit.

Also binary are the messages transmitted along the Tanner graph edges are also binary are the messages transmitted along the edges of the Tanner graph: the bit node sends a message, thereby declaring whether it is zero or one, and each connected bit node sends a message to each test node, then declares which bit value is based on available information for the control node. Whether the parity-check equation is not satisfied or yes determines the check node. The condition then is satisfied if the incoming bit values the modulo-2 sum of is zero. The bit node flips (1 to 0 or vice versa) its current value if the majority of the messages received by a bit node are different from its received value. This process is repeate until all equations of the parity-check are satisfied. Whenever a valid codeword has been found the bit-flipping decoder can be immediately stopped by checking if all equations of the parity-check are satisfied.

For all message-passing decoding of LDPC codes this is have two important benefits:

1. Additional iterations are avoided once a solution has been found
2. Always detecte a failure to converge to a codeword.

Sum-Product Decoding

The soft decision type messagepassing algorithm is a sum-product algorithm. Algorithm is quite similar to the bit-flipping algorithm but instead messages that represent in the bit-flipping algorithm each decision, now represent probabilities.

Bitflipping decoding accepts an hard initial decision on the bits which receive as input whereas the sum-product algorithm is a soft decision algorithm which the probability of each received bit accepts as input [4].

So, in conclusion can say that using LDPC codes lead to lower Bit Error Rate (BER) values and it is an iterative decoding process instead of Trellis based. The decoding complexity decreases with the length of the blocks ia an another advantage of LDPC codes. From the BER vs SNR graph (Fig.3.7.), it is observed that we can achieve compared to other coding schemes very low BER at low SNR. The transmission through the channel occur multiple erasures and we can correct these.

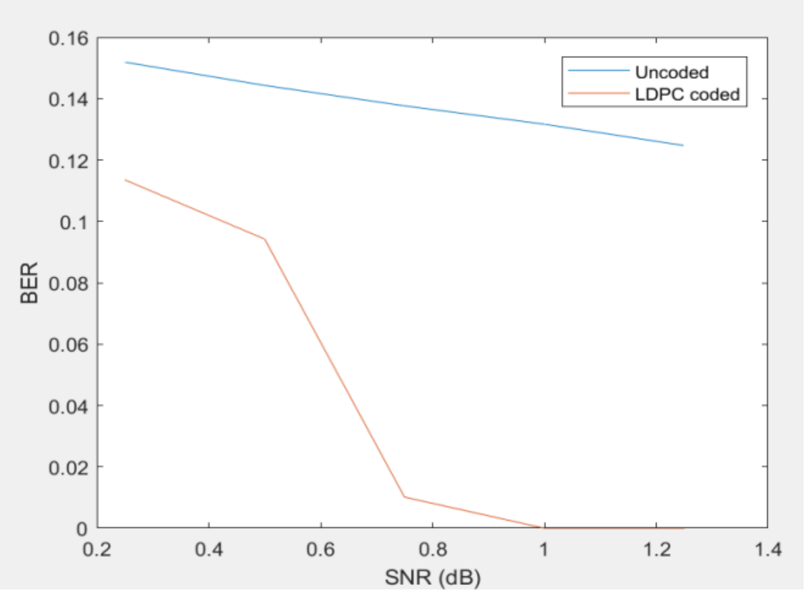


Fig.3.7. BER vs SNR curve for LDPC coded and uncoded signal [4]

CONCLUSIONS TO CHAPTER 3

In this chapter was considered 4G telecommunication system and LDPC codes for it. Also was gave an example to encoding and decoding of LDPC codes for this systems. It was analyzed that as compared with Turbo code LDPC codes have lower computational complexity for decoding and better performance when the block length is too large. In addition hardware implementation of LDPC codes parallization capability facilitates

Also was shown that using LDPC codes lead to lower Bit Error Rate (BER) values and it is an iterative decoding process instead of Trellis based. From the BER vs SNR graph, it was shown that can achieve compared to other coding schemes very low BER at low SNR. It was analyzed that hat using LDPC codes lead to lower Bit Error Rate (BER) values.

CONCLUSIONS

In this diploma project telecommunication systems were considered and why errors occur in them. It has been shown that when transmitting channels with noise and a given signal-to-noise ratio, problems such as noise and interference occur. Therefore, it was necessary to find solutions to these problems so that services were provided continuously and uninterruptedly. The 4G telecommunications network was taken as an example.

A general description of error correction methods is provided, namely Channel coding. All types of error correction codes such as Hamming codes, Binary convolutional codes, Reed - Solomon codes, Low-density parity check codes and their detailed description are presented.

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