BIT-ERROR RATE COMPARISION BETWEEN M-QAM AND M-PSK IN CASE OF TURBO CODING

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One of the most important elements of a successful space missions is to establish a secure and reliable communication between spacecraft and ground station. Many difficult challenges should be deal with because of the long communication ranges. The messages which carried by electromagnetic (E/M) waves propagate not only in vacuum but also in atmosphere. In addition to free-space losses because of dispersion, E/M waves subject to absorption and contamination respectively by gas molecules and different type of noise sources. Noise contamination causes corruption of digital data. Some bits change their states because of noise in the communication channel. To reduce the bit-error-rate (BER), different methods are developed and used. Solutions include to increase the transmission power and/or use larger antennas for high gains. However, spacecrafts have limited electric power capacity in space. Additionally, launch vehicles are restricted for a limited payload volume and mass. Consequently, we investigate how to decrease BER using Turbo codes which is one of the most effective channel coding methods. Additionally, these codes are modulated by 16-PSK (phase shift keying) and 16-QAM (quadrature amplitude modulation). After modulation step, different amount of white Gaussian noise (WGN) is added to modulated messages which simulates communication channels. After demodulating and decoding signals, BER values are calculated and reported. Simulations are run on the MATLAB Satellite Communications Toolbox.

Key Words: Channel coding, modulation, turbo coding, bit-error-rate, Gaussian white noise

1. Introduction

The first radio communication between a satellite and Earth was accomplished when Sputnik was placed into orbit around Earth in 1957. This communication was one-way only, from Sputnik to Earth in the form of beep signals consists of two different frequencies. With a 65^0 orbit inclination angle and an elliptical LEO (low Earth orbit), Sputnik was capable to reach almost all the world's habitants. After the Sputnik, the capabilities of the satellites increased considerably. Spacecraft communication became a bidirectional process. Satellites not only transmit, but also receive data from the ground or other satellites.

If communication direction is from spacecraft to ground station, it is called downlink. Depends on the satellite mission, satellites transmit different type of data. Telemetry unit collects the health information from different units of the satellite and transmits these data to ground control station. Next, payload data is transmitted to related mission centers. Additionally, communication satellites relay signals sent from ground stations using their transponders. Finally, satellites transmit beacon signals for the identification and tracking purposes. Telecommand signals are sent to satellites for maintenance or orbit/attitude adjustment purposes. Uplink indicates a communication direction from ground to spacecraft.

One of the most important elements of a successful space mission is to establish a reliable communication link between spacecraft and ground station. With the advent of the digital technology, data is converted to digital signals first, and then modulated and transmitted in both downlink and uplink directions. Electromagnetic (E/M) signals are decayed and added noise when they travelled in propagation channels. As a result, erroneous bits are developed in the signal. One of the prominent methods to reduce the bit errors is called channel coding. However, the efficiency of channel coding methods also depends on the applied modulation technique. In this study we will investigate BER (bit error rate) performances of the white Gaussian noise (WGN) added Turbo codes. These codes are first modulated by 16-QAM (16-quadrature amplitude modulation) and then 16-PSK (16-phase shift keying) modulators. Simulations are run on the MATLAB Satellite Communications Toolbox.

2. Communication Quality

Communication quality is measured in terms of BER. BER is defined by the number of erroneous bits in unit time or ratio of erroneous bits to total transferred bits as in (1).

$$BER = \frac{number\ of\ erroneous\ bits}{total\ number\ of\ bits} \tag{1}$$

The quality of the communication is represented by a rectangle law **[1]** shown in Figure 1.

Fig. 1. Rectangle law **[1]**.

Firstly, for a higher communication bit rate (BR), bandwidth should be increased. Secondly, to decrease the BER, the transmission energy should be increased. It is a well-known fact that, power capacity and antenna dimensions of the spacecrafts are limited. To overcome to these limitations and decrease BER, different channel coding methods are proposed **[2].**

3. Channel Coding

The main purpose of the channel coding is to increase the information reliability between transmitter and receiver. This technique requires addition of extra control bits to original data. Consequently, receiver unit become capable of detect and correct errors. Penalty is sending more bits than required. The most prominent channel coding techniques are repetition codes, parity-check codes, Hamming codes, Reed-Solomon codes, Turbo codes, and Low-Density Parity-Check (LDPC) codes as in Figure 2.

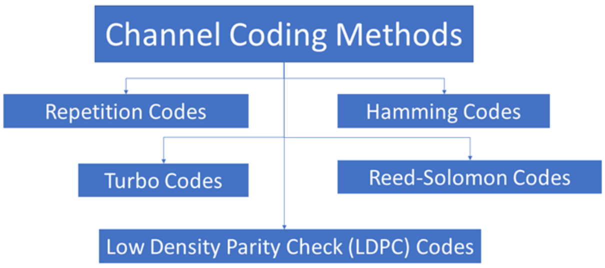

Fig. 2. Prominent channel coding methods

3.1. Repetition codes

In this method, a codeword is created repeating same information word many times [3]. Through the transmission channel some of the bits in the codeword can be corrupted. However, these corrupted bits can be detected and corrected using suitable techniques such as majority voting as shown in Table 1 below.

Table 1. Repetition codes

Information word	Codeword	Propagation Channel	Codeword in Receiver	Codeword Corrected	Information word in receiver
0	00000	→	00101	00000	0
1	11111	→	10111	11111	1
1	11111	→	10001	00000	0
0	00000	→	00010	00000	0

In case one of the bits is different from the rest in the codeword, an error is detected. A request can be made for retransmission. Alternative is to use majority voting to correct the codeword. However, correct information word cannot be recovered if the number of corrupted bits higher than the correct bits. This case is shown with red color in Table 1. Because of repetition bits, useful data transmit rate is decreased.

3.2. Parity-check codes

This method is both simple and very effective method to detect errors. An extra parity bit is added at the end of string of data bits as shown in Table 2. Even or odd parity condition is checked at the receiver unit. In case of even parity checking mode, number of bits equal to 1 in the word are counted. If this value is equal to an even number, a zero-parity bit is added. In case of odd parity checking mode, a one-parity bit is added. In the receiver unit, a decision is made whether an error does exist or not based on parity check **[4].**

Table 2. Parity-check codes

5 bits information	6 bits information with even parity	Propagation channel	6 bits information with even parity	Even parity error check
00110	001100	→	101100	Error
00010	000101	→	000101	Correct
10010	100100	→	100100	Correct
10110	101101	→	101101	Correct

Although transmission rate is higher than repetition codes, erroneous data cannot be detected in case of even number of errors.

3.3. Hamming codes

Hamming codes developed to overcome the error detection limitations of the parity-check codes **[5]**. In Hamming (7,4) codes, three control bits are added to four data bits. These three control bits are a function of the data bits and calculated using Hamming algorithm as shown in Figure 3. Hamming (7,4) codes can detect 2 errors and correct 1 error.

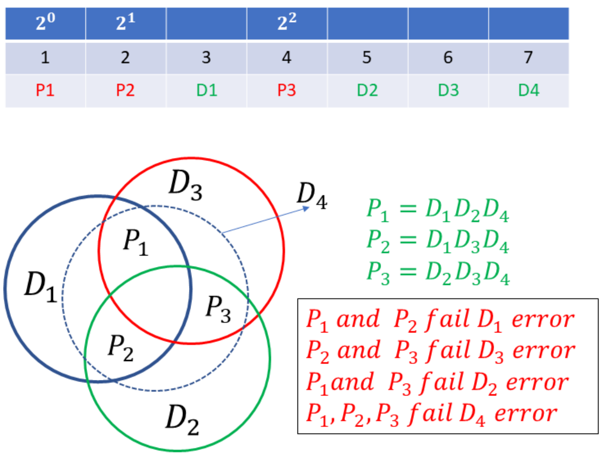

Fig. 3. Hamming (7,4) codes.

3.4. Reed-Solomon (RS) codes

Reed–Solomon codes are a group of error-correcting codes which used in satellite communication **[6]**. RS (n, k) encoder takes k bytes data and add $t = n - k$ parity check bytes as shown in Figure 4. In the decoder side, this method can detect t errors and correct $t/2$ errors. Special polynomials are used to generate Reed-Solomon codewords.

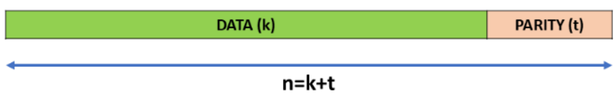

Fig. 4. Reed-Solomon (n, k) codes.

3.5. LDPC codes

A low-density parity-check (LDPC) code is a linear error correcting code which work close to Shannon channel capacity **[7]**. LDPC codes make it possible to transmit data over a noisy transmission channel. This method is quite effective in terms of correcting transmission errors. To increase the error correction efficiency, an iterative decoding technique is put into force as shown in Figure 4. Here LDPC codes constructed using six data bits $d = (d_1\ d_2\ d_3\ d_4\ d_5\ d_6)$ and 5 parity bits $p = (p_1\ p_2\ p_3\ p_4\ p_5)$ as in Figure 5.

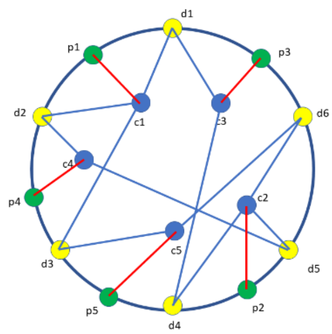

Fig. 5. LDPC parity check matrix.

LDPC codes were opted for different space missions by the NASA such as travel to Mars and Moon.

3.6. Turbo codes

Like LDPC, iterative Turbo codes can also approach the Shannon channel capacity. Turbo codes provide high performance with a moderate complexity **[8].** These codes are preferred in deep space communications, because of their resistance to latency and different type of noises. Turbo codes use two encoders at one end and two decoders at the other as shown in Figure 6.

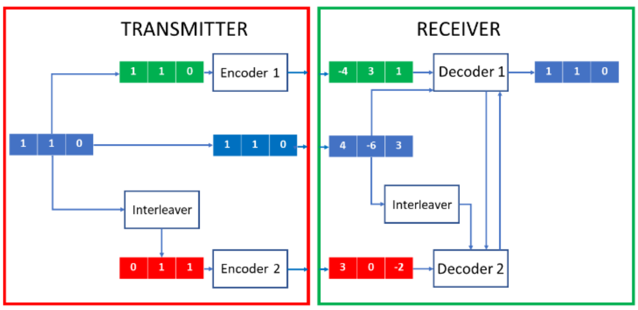

Fig. 6. Turbo codes flowchart.

In Turbo codes, codeword is generated using three different data. First part is original data. Second part comprise of parity bits calculated by the first encoder. Finally, third part is formed by both an interleaver and second encoder. Task of the interleaver is to scramble the original data. The structure of the transmitted data is shown in Figure 7.

Fig. 7. Transmitted data structure.

In the receiver unit, incoming data are processed by 2 different decoder and an interleaver. Additionally, two decoders communicate iteratively to exchange reliability information. Consequently, error-free original data is extracted from corrupted data.

4. Modulation Methods

Different communication channels are used to transmit data such as electrical cables, optical fibers, wave guides, and free space. Data transfers between satellites and ground stations require to use of free space. Digital data consist of 0s and 1s. The range of frequency of these data which depends on BR and pulse shape is low. Antennas are used to transmit data in free space. The dimensions of the antennas are related with the signal wavelength as given in (2).

$$\lambda = c/f \tag{2}$$

In this equation λ, c, f are wavelength, speed of light ($\cong 3 \times 10^8$ m/s), and frequency respectively. This equation dictates that lower the frequency bigger the antenna dimensions. We need 300 m diameter antenna to transmit a 1 MHz digital baseband signal. The solution is to use a high frequency carrier signal to transmit the digital data through communication channel. This technique is called modulation. Modulated and modulating signals are represented by carrier wave and data respectively as shown in Figure 8.

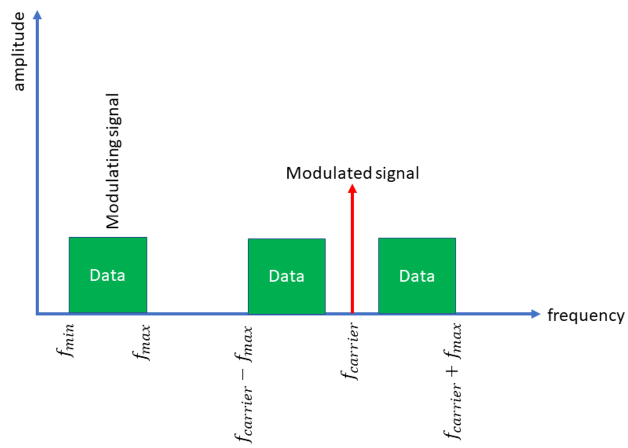

Fig. 8. Signal modulation.

In general, we can modify either amplitude, frequency, or the phase of the carrier signal using modulator units.

4.1. M-QAM

In this digital modulation method, digital data bits are grouped into M-bits and modulated signals are formed using different amplitude and phase values **[9].** M value is a power of 2. The most common values of M are 2, 4, 8, 16, 32, 64, 128 and 256. M-QAM technique is used to decrease the bandwidth for a given BR. For example, 8-QAM uses four carrier phases plus two amplitude levels to transmit 3 bits per symbol as shown in Figure 9.

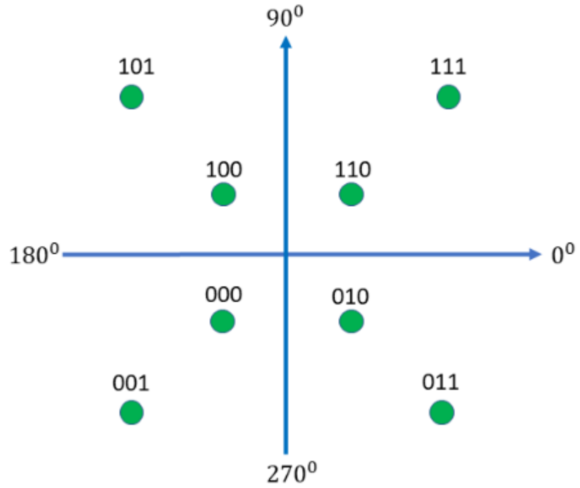

Fig.9. 8-QAM digital modulation.

4.2. M-PSK

Like M-QAM, in M-PSK modulation method, digital data bits are grouped into M-bits. However, modulated signals are formed using only different phase values **[10].** M value is again a power of 2. For example, 8-PSK uses eight different carrier phases to transmit 3 bits per symbol as shown in as shown in Figure 10.

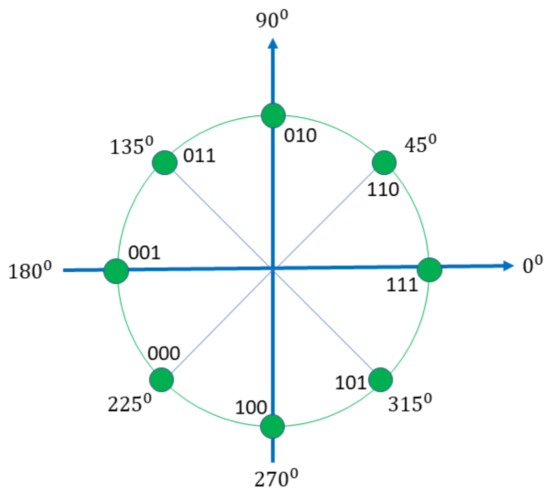

Fig. 10. 8-PSK digital modulation.

5. BER Tests

In this part of the study, Turbo code is applied to a message which contains 1197 bits. Together with parity bits, total length of the codeword after turbo encoder unit becomes 2048 bits. This message is first modulated with 16-PSK as shown in Figure 11.

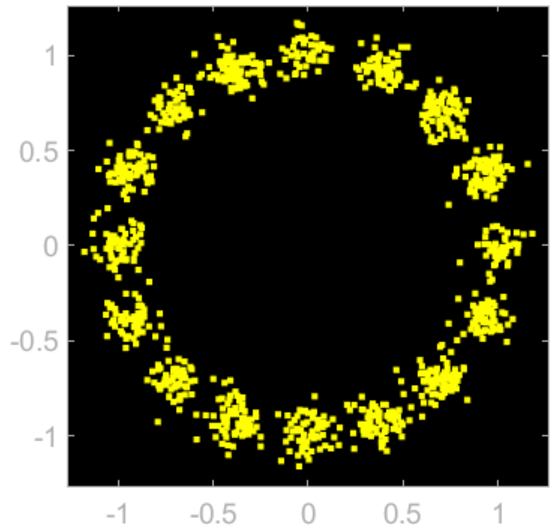

Fig. 11. 16-PSK scatter plot.

Following, the same codeword created by Turbo coding encoder is modulated by 16-QAM modulator as shown in Figure 12.

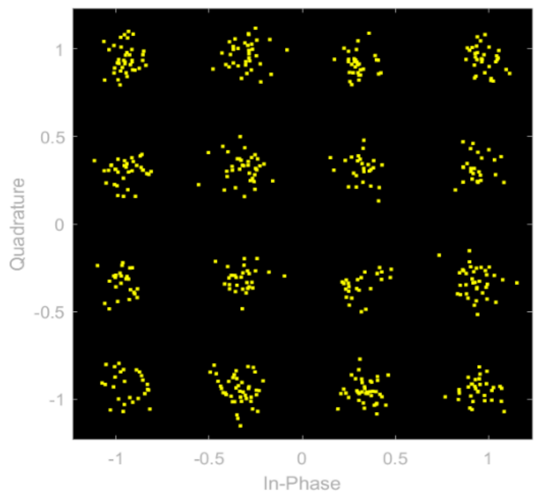

Fig. 12. 16-QAM scatter plot.

After modulations, white Gaussian noise is added to the messages to simulate noisy communication channel by changing signal-to-noise ratio. Next, both messages are demodulated by 16-PSK and 16-QAM demodulators. Then these signals are decoded using Turbo code decoders. For different signal-to-noise ratio (SNR) values, different BER results are recorded as shown in Table 3.

Table 3. BER values for different SNR values.

	16-PSK BER	16-QAM BER
SNR=20	0	0
SNR=10	0	0.2916
SNR=5	0.189	0.356
SNR=2	0.242	0.385

5. Conclusions

Data transfer reliability and security between satellites and ground stations are important for successful space missions. In this study we analyze BER performances of the 16-QAM and 16-PSK modulation methods feed with messages encoded using Turbo codes. Simulations are realized in MATLAB environment using Satellite Communications Toolbox. Results showed that, 16-QAM modulation technique is less vulnerable to white Gaussian noise compared to 16-PSK modulation. In future studies we will also study other modulation techniques using higher M-values.

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