Design of Trellis Coding Algorithm for a Robust Data Transmission over AWGN Channel

Ramdan A. M. Khalifa [1], Khaled ELgantri [2] , Osama M .Abuzaid [3] , Adel Issa Ben Issa[4]

[1,2] High Institute of science and Technology-Suk Algumaa Tripoli, Libya

[3] Faculty of Technical Science, Bani Walid, Libya

[4] Higher institute of engineering technologies Tripoli, Tripoli, Libya

Ramadanamharree@gmail.com [1] , K..elgantri@gmail.com [2], Osamamasuod233@gmail.com[3], adelissa.1976@gmail.com [4]

Abstract

For a fixed link margin, a wireless communication system's performance can be considered as dissatisfactory when the received power is lower as compared to noise power, which is called as deep fade. To overcome this, multiple links are utilized for transmission, which is called as diversity. During the deep fades, Shannon’s capacity is achievable by adapting appropriate data rate as well as modulation scheme and power relative to the fade level, which can play an important role for successful data exchange between the receiver and the transmitter. The Trellis Coded Modulation (TCM) is considered as a bandwidth-efficient modulation. In the current paper, complete encoder and decoder design that transmits data with a code rate 3/2 (Trellis Code) is discussed. A trellis encoder performs as a Finite State Machine (FSM) that uses convolution coding and moreover, the decoder uses Maximum Likelihood (ML) detection with the help of state table and trellis diagram. Both the algorithms are simulated using MATLAB.

Keywords— Maximum Likelihood (ML), TCM, Encoder, Decoder, AWGN, Ray-light, FSM, State table (ST), Present state (PS), Next state (NS), Generator matrix (GM), Inter-sample interface (ISI).

I. INTRODUCTION

The term fading or small-scale fading implies quick fluctuations pertaining to amplitude, phase, or multi-path delay in a radio signal over a short distance or time period. It can be so serious that large-scale radio transmission loss impact can be ignored. The multipath effect of the transmitted information can be seen as quick signal strength changes through a limited time interval or distance. The random frequency modulation takes place because the Doppler shifts into multi-path signals. The multi-path communication delay causes echo/time dispersion, which is an issue of the fading channels. Fading is limited with some factors including the situation of the objects surrounding the communication pairs (transmitter and receiver), the speed of the receiver, and transmission band-width of the signal.Inter-symbol interference (ISI) is a signal distortion and it is experienced when a symbol intaercepts/disturbs other symbols.[1] This phenomenon distorts/disturbs the overall communication process because its effect is just like noise. The pulse takes more than its designated time, which makes it interfere with other pulses. ISI is experienced when either non-linear frequency response or multi-path propagation result in "blurring" successive symbols. Existence of ISI is a source of error-creation in the system specifically its receiver's end decision device. Many types of wireless communication channels were studied in order to analyze and review the performances of different fading channels. Different kinds of modulation techniques are applied on channels, which are influenced through noise and fading. For each modulation technique, its bit error rate (BER) was measured for every channel. Outcomes of the testing process indicate that the BER dramatically improves at low SNR as compared to higher SNR.Some [2] wireless antennas such as Multiple-Input Multiple-Output (MIMO) have been recognized as a futuristic wireless communication technology. In the present wireless devices, spatial diversity results in high data rates.Coded modulation has been recognized as a significant technology that makes the coherent optical communication systems/RF systems more efficient. The performance of coded modulation will be presented with different error rates with respect to Rayleigh and AWGN channels. Trellis coding has been proposed in the current research. We have divided the data bits into some parallel streams while each of them represents the code word which is coded through trellis algorithm. The system performance may be examined by permitting end-to-end data transmission through White Gaussian Noise (WGN) and fading channel..

II. COMMUNICATION SYSTEM

Communication is a significant factor in today's world. All the communication systems have three common and significant elements such as transmitter, receiver and medium. The block diagram (Figure 1) depicts a basic communication system.

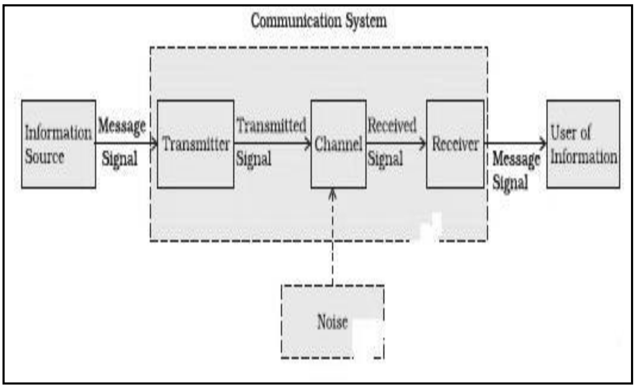


Fig.1. Fundamental Structure of a Communication System

On one end of a communication system, there is a transmitter while the receiver on the other end (can be farther or closer), and there is a medium of transmission between the two, which is a physical medium that connects them.

A. Channel Characteristics

A channel is a highly important factor for any kind of communication system. Several channels/medium types have been introduced so far including Additive White Gaussian, Rician Fading, and Rayleigh Fading channels. Rayleigh fading implies that the transmitted signal s(t) goes through multiplicative distortion h(t), which can be mathematically represented as follows:

$$y(t) = h(t) \bullet s(t) + n(t) \qquad (1)$$

Here, y(t) is the received waveform while n(t) represents noise. Since wireless communication is generally unstable, fading takes place because of multi-path propagation.

B. MIMO and SISO channels

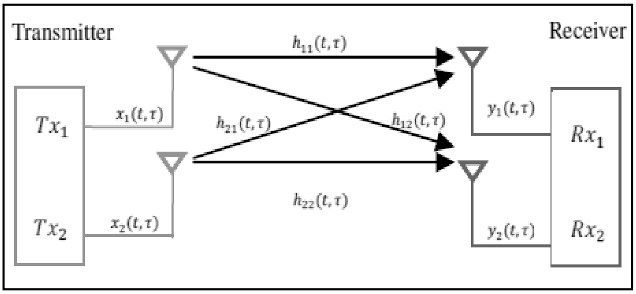
In the wireless communications, greater data transmission rate is possibly assured by using the MIMO systems. The MIMO uses several antennas both on transmitter as well as receiver ends. Their performances are improved using diversity in comparison with traditional single antenna systems. Some future trends of wireless communication demand for the development of MIMO. They are mentioned below:

1. Need for “high data rate” and “high link quality”
2. Limited RF spectrum

3. Requirement for increasing the capacity of the transmission system because of limited transmission power
4. Frequency and time limits.

.2. MIMO (MxN) System

The MxN MIMO has been illustrated in Fig 2.



In this paper; many antenna configurations have been discussed for MIMO systems in the context of AWGN, which are believed to improve the SISO system performance.

C.Modulation

During transmission of the signal, modulation is used for information delivery. Modulation is possible either through digital or analog domains. Modulation takes place through a carrier wave, which is usually a high-frequency wave that conveys the information with much lower frequency input signal. The main digital modulation types include frequency shift keying (FSK), binary phase shift keying (BPSK), and quadrature phase shift keying (QAM). The modulation and de-modulation are represented through complex notations including quadrature and in-phase components, which may be imaginary or real. The complex notations are convenient to represent since quadrature and in-phase components of any signal behave similarly towards the real and the imaginary complex numbers. S(t) represents a transmitted signal, which can be expressed as below:

$$S(t)=Si(t)+j.Sq(t) \quad (2)$$

S(t) represents transmitted signal, which is obtained by just taking real part of the complex carrier part (ωct) as mentioned below:

$$M(t)=Real[S(t).e(-JWct)] \quad (3)$$

$$M(t)=Si(t).cos(wct)+Sq(t).sin(wct) \quad (4)$$

The figure 3 represents the generation and detection of the QPSK modulation, and these signals are converted to discrete signal level, and they are mapped to quadrature and in-phase elements by assigning them to the particular points. They are shown through a constellation diagram or constellation patterns. The formula given below shows the interval of each point:

$$s_t(t) = \sqrt{2E/_T}\,COS\left(2\pi f_c + \frac{2\pi}{M}(i-1)\right) \quad (5)$$

Where E is the energy per symbol and fc is the carrier frequency.

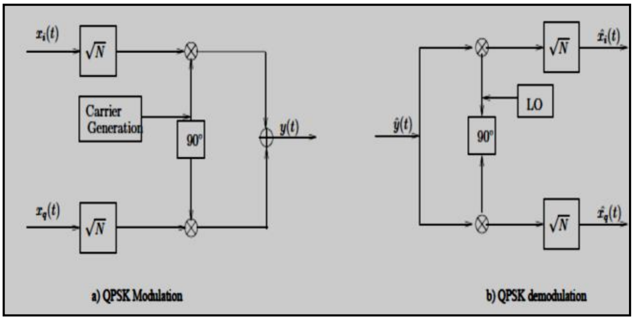


Fig.3 De-modulation and Modulation of QPSK.

D.Convolutional encoding

In general, a convolution encoder (k/n) has M-element shift register, k per input bit and n output coded bits, which are given by the linear combination of the input information bits and the register.

Generally, convolution encoder (rate 1/n) is used, which is a binary convolutional code. The n generator polynomial is described by the specific connections to the register stage. When clocked, shift register output moves to the next state and the process continues.

The generator polynomials form through a binary pattern, which indicates that either a specific link is present or absent in a shift register stage. If we look at Figure 4, generator polynomial is constituted by:

$$g1=[1\ 0\ 1] \quad , \quad g2=[1\ 1\ 1] \qquad (6)$$

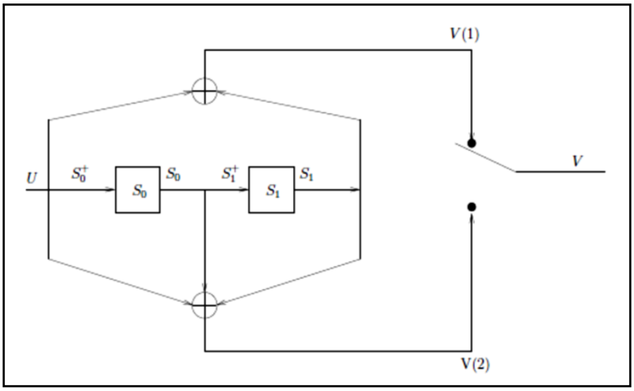


Fig.4 Convolutional Encoder

E. Viterbi decoding

The hard-decision Viterbi decoding is based on the received and coded symbol location, and a coded bit is possible to estimate only if the received symbol is more than 0.When a received symbol is either 0 or less, the received coded bit must be 1. In case of soft-decision decoding, the coded bit is not estimated. In that case, hamming distance is calculated, and this represents the distance between the transmitted symbol and the received symbol. It happens on confidence level 8, and in this context, +4 shows biggest confidence level concurred to the demodulator's choice of binary 1 and -4 for the lowest possible confidence. In fact, if the demodulator output is -4, the low confidence implies a high probability of a binary zero. Bearing this 8-level confidence scale in mind, the received bits can be decoded.

III. Simulation and results

For investigating the communication system performance over Additive White Gaussian Noise (AWGN) and ray-light fading channel, the above-mentioned method is applied using Matlab software simulation. in a simulation by Matlab software. Firstly, random bits were generated, and these bits were transmitted through fading channels and AWGN, so that the equivalent characteristics of this noise parameters are combined with the transmission signal while this hierarchy acts as a transmission channel.

The receiver is designed to filter the received signal, which recalls the original signal properties as soon as and as much as it can. During this stage of simulation, the system is tested under AWGN fading channel without involving any coding scheme in the channel, and it is only limited to modulation-demodulation processes on receiver and transmitter. On a later stage of simulation, a coding scheme is designed to perform channel coding on a signal. The after-decoding results are shown with many properties.

A. Transmitter formation

A signal is formed with magnanimous numbers of bits. First, 10e5 bits are generated randomly (here random stands for bit-wise amplitude). The generated signals are later processed by PBSK modulator to perform the mapping of those signals (bits) to (-1 and

+1) as shown in Figure 5. The following diagram is showing the performed process in the initial stage of simulation as Figure 6 shows.

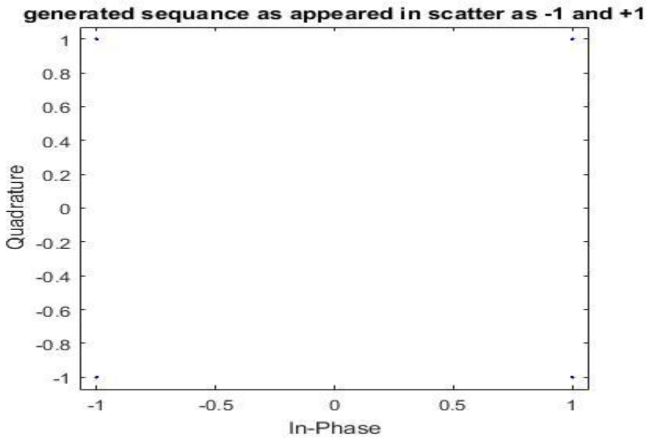


Fig.5 PBSK signal at the modulator output.

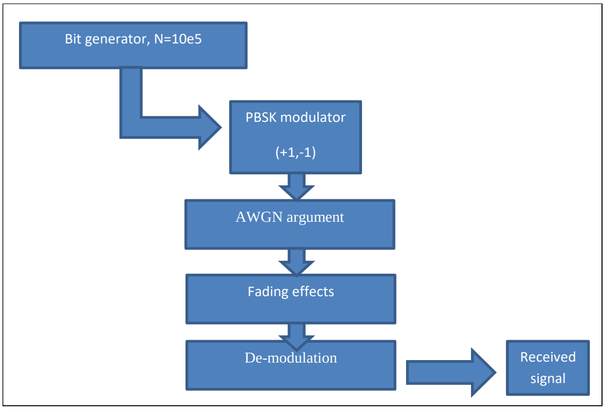


Fig.6 Structure of simulated system

As the generated bits were modulated with PBSK modulator, the resulting signal is supposed to be transmitted by the fading channel and AWGN, so the noise component will be added into the signal and the resulting output will look as Figure 7 depicts.

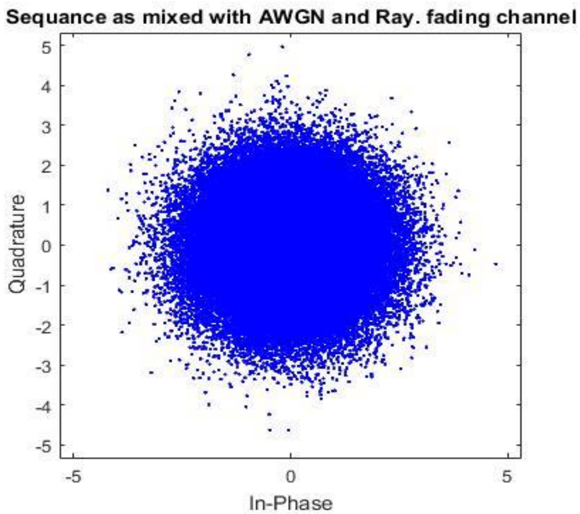


Fig.7 Received signal with noise effects

For recovering original bits, firstly bit-to-noise ratio is taken as variable having range from 1 to 20, so that we will be having twenty different transmitted signals for testing. In other words, the signal is transmitted under different bits of energy, we had tried twenty possibilities of bit energy to examine signal performance over this noisy channel. Later, the receiver received the signal and demodulator recovered the originally transmitted bits. For each EtN value, a different output was calculated as shown in Figure 8.

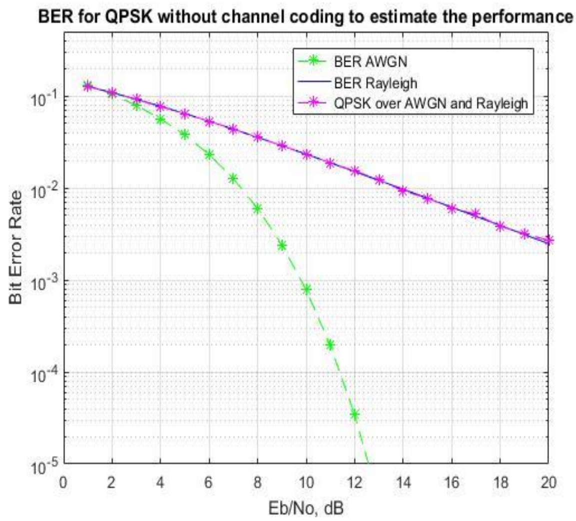


Fig.8 QPSK received signal after noise elimination with 0-20 EtN.

Figure shows how BER is improving by increasing the energy of transmitted bits over noise energy

B. Channel coding

In this part of the process, the signal undergoes complete coding techniques as it was transmitted from the modulator towards the channel. The procedure of transmission has taken place as follows:

1. **MIMO:**

The bits, which are generated from the modulator, take the form of 0s and 1s because the coding scheme of this project must be in a binary shift keying format such as 0s and 1s. The signal is generated to be serially transmitted over the channel so, for enhancing the transmission signal performance; it can be broken into groups arranged in parallel, as shown in figure below.

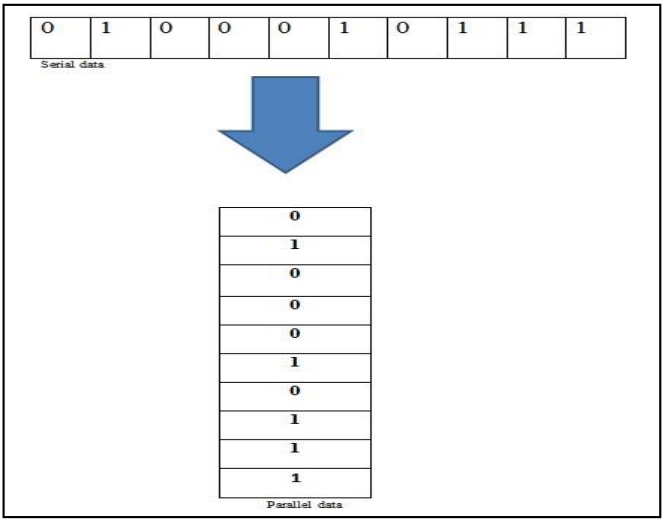


Fig.9 Data bits are converted from serial to parallel form before transmission.

As signal converts into parallel form, the encoder must be ready to intake the same and generate the code words to start with the signal transmission. In this project, trellis coding has been used to perform the channel coding prior to transmission. Encoder involves a generator matrix to generate a code word.

2. Encoder design

This stage is about designing encoder that is capable of generating a code word for each input set; however, the code will be the encoder output. For this project, encoding has been performed, which is illustrated in Figure 10.

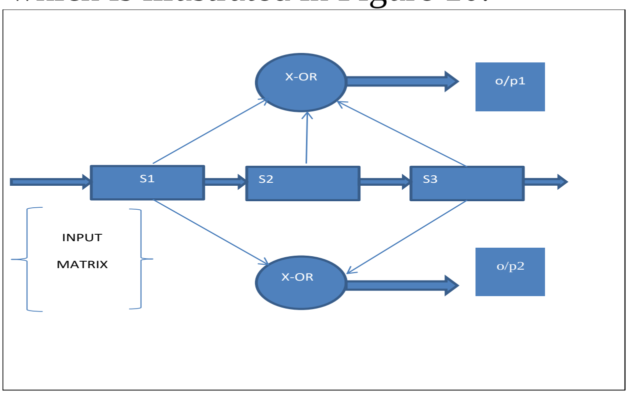


Fig10 Convolutional encoder

This encoder is designed by interfacing X_OR gate and the shift register for calculating the output. Two different outputs can be gained at code rate 3/2 as given below:

O/P1= S1 X_OR S2 X_OR S3

O/P2= S1 X_OR S3

3. Decoder design

Viterbi decoders make use of Viterbi algorithm to decode bit-streams, which are encoded with the help of convolutional or trellis codes. Many other forms of algorithms help decoding convolutional encoding. Viterbi algorithms use resources; however, it performs better decoding. Often it is used to decode convolutional codes having constraint length k<=10 but practically, k values are taken up to k=15.

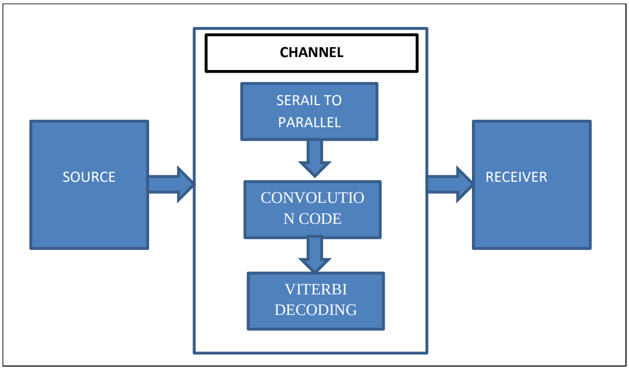


Fig.11 TCM system

IV. CONCLUSIONS

The current project deals with QBPSK modulation of data bits in large numbers, and the transmission of the resulting +1 and -1 formats using AWGN channel when the ray-light fading effects are coming into the image. The system starts receiving the distorted version of transmitted signals, which were distorted because of noisy channels when bit-to-noise (BtN) ratio changes. The experiments (simulation) shows that the energy in transmitted bits will increase the bit noise immunity and eliminate the noise effects on transmission. We assumed that BtN falls between 1-20 decibels, and we observed that twenty decibels yielded the optimum performance. Moreover, coding modulation is performed when convolutional encoder design generates a convolutional code for each input code word; the signal bit-streams are divided orthogonally for enhancing the signal performance in such a way that if some segment of a signal gets distorted because of noise, the other information of that signal will remain safe. The same is implemented by performing serial to parallel transmission. After doing so, every code word is sent to the convolutional encoder where the trellis code is generated for each code word. When the signal blocks reach the receiver, the Viterbi decoder is applied for recovering the genuine signal, and performing the decoding based on maximum likelihood approach.

REFERENCES

[1] ETSI TS 102 361-1 (V1.4.1): "Electromagnetic compatibility and Radio spectrum Matters (ERM); Digital Mobile Radio (DMR) Systems; Part 1: DMR Air Interface (AI) protocol".

[2] J. L. Masey, "Coding and modulation in digital communications" , Proc. 2020 Int. Seminar on Digital Comm., pp. E2(l)-(5), 2020 -Mar.

[3] Biglieri, E., D. Divsalar, P.J. McLane, and M.K. Simon, Introduction to Trellis-Coded Modulation with Applications, New York, Macmillan, 1991.

[4] [2] Pakis, John G. Digital Communications. 5th . New York: McGraw Hill, 2021.

[5] [4] A. Lapoth, “ the role of mismatch in rate distortion theory,” IEEE Trans. on Information Theory, vol. 43, no. 1, pp. 38–47, Jan.2021.

[6] Channel coding with multilevel/phase signals," IEEE Trans. Inf. Theory, vol. IT-28, pp. 55–67, 2020

[7] D. Divsalar and M. K. Simon "The design of trellis coded MPSK for fading channels: Performance criteria", IEEE Trans. Commun., vol. 36, 1988.

[8] P. Razghi and W. Yu, “Bilayer low-density parity-check codes for decode-and-forward in relay channels,” IEEE Trans. Inform. Theory, vol. 3, no. 10, pp. 3723–39. 2021.

[9] G. Hellstern, "Coded modulation with feedback decoding trellis codes", Proc. IEEE Int. Conf. on Communications, pp.1071 -1075 1993

[10] A. Aksu and M. Salehi “Multistage trellis coded quantization (mstcq) design and performance", IEE Proceeding of Communications, vol. 144, no. 2, pp.61 -64 1997.

[11] R. Mesleh, M. D. Renzo, H. Haas and P. M. Grant "Trellis coded spatial modulation", IEEE Trans. Wireless Commun., vol. 9, no. 7, pp.2349 -2361 2010.

[12] A. Stefanov and T. M. Duman, “Performance bounds for space-time trellis codes,” in Proc. ISIT’2001, p. 82, 2021.

[13] JS. Lin and D. Costello Error Control Coding Fundamentals and Applications, 2004: Prentice-Hall Inc.