Data Transmission by Trellis Coded Modulation using Convolution Codes

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Abstract: - The purpose of this paper is to design Trellis Coded Modulation (TCM) system using convolution codes and Phase-Shifted Key (PSK) modulation. Convolution codes are widely used in telecommunication applications to improve the data transmission reliability over noisy channels. The performance of the TCM system is evaluated by simulations in Matlab Simulink environment.

Key-Words: - BER, communication channel, convolution codes, MATLAB Simulink, PSK modulation, TCM

1 Introduction

Nowadays, one of the most important human demands is to obtain and share information. Information can be spread by various sources across the continents, but the question is, how would be this information is transmitted.

Closely associated with the transmission of information is the communication channel, which the information is disseminating. The quality of the transmission is subject to ever-increasing demands.

Development of communication technology has reached a point, where it is necessary to evaluate the current possibilities of transmitting. It is important to realize that for the current demands of transmission is also-needed to improve the utilization of communication system. Therefore, the need is to deal with methods that allow improve the transmission quality at the present set conditions.

This paper focuses on data transmission over a communication channel using Trellis coded modulation (TCM), which consists of convolution codes and PSK modulation. Encoding contributes more ensure communications and simultaneously constitutes an advantage of transmitting messages without magnification wide bandwidth of the modulated signal.

The aim of this paper is to describe the code modulation principles, evaluate the key parameters of TCM, evaluate a bandwidth of TCM and design the TCM system in MATLAB Simulink.

2 Communication system

Communication systems encroach to all branches such as industry, services or science. The communication system enables the successful transmission of idea or any other important information among the individuals. For further understanding of the communication system is required to recognize the individual elements of communication channel. These individuals subsequently determine the characteristics proprieties of transmitting.

3 Communication channel

The communication channel is the set of devices and systems that connects the transmitter to the receiver. The transmitter and receiver consist of an encoder and decoder, where the information is translated into a stream produced by the source into a signal suitable for channel transmission.

Four general rules of communication channel have to be followed in the design state:

- The modulation must not expand the required transmission bandwidth beyond the available bandwidth
- BEM based systems must be interoperable with other technologies
- The required optical signal to noise ratio must be met even under worth case conditions
- The hardware and software needed for BEM implementation must be simple and inexpensive

Figure 1 shows a block diagram of the transmission system due to the communication channel. As illustrated in the figure 1, this scheme is basically divided into Transmitter, Channel and Receiver.

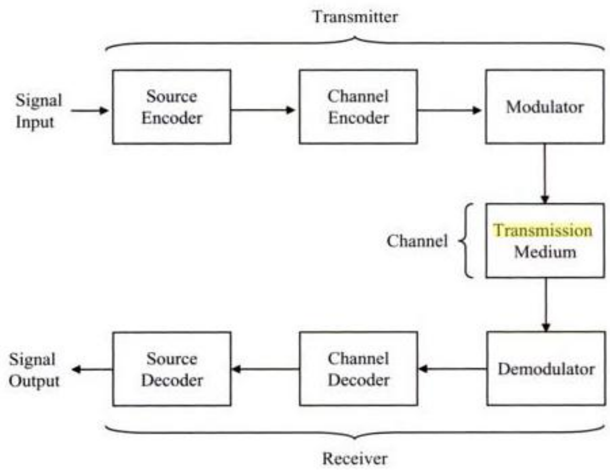

Fig. 1 Block diagram of Digital Transmission system

3.1 Channel capacity

The channel capacity theorem is concerned on the rate of information transmitted over a communication channel. The theorem describes the maximum possible efficiency of error-correcting methods against the levels of noise interference in the data corruption. The maximum rate of clean data *C* that can be sent through an analog communication channel subject to Gussian-distribution noise interference is given by formula (1):

$$C \le B \log_2 (1 + \frac{S}{N}) \tag{1}$$

Where C is the effective channel capacity [bit/s], bandwidth B is raw capacity in [Hz] and $\frac{S}{N}$ is signal-to-noise ratio of the signal and Gaussian noise.

3.2 Bit error rate

One of the most important ways how to determine the quality of digital transmission system is to measure the Bit Error Ratio (BER). The BER is calculated by comparing the sequence of transmitted bits and the bits received, where the number of errors is counted. The connection between received bits in error (N_{Err}) and the number of total received bits (N_{bits}) is called the bit error probability P_e, (2).

$$P_e = \frac{N_{Err}}{N_{bits}} \tag{2}$$

This measured ratio is affected by many factors including: signal to noise, distortion, and jitter.

In a noisy channel, the BER is often expressed as a function of normalized carrier-to-noise ratio measure denoted E_b/N_0 - energy per bit to noise power spectral density ratio, or E_s/N_0 - energy per modulation symbol to noise spectral density, which is given by formula (3):

$$BER = \frac{1}{2} erfc(\sqrt{E_b / N_0}) \tag{3}$$

The most common method of measuring BER is to brute force send bits through the system and calculates the P_e. Since this is a statistical process, the measured BER only approaches the actual P_e as the number of bits tested approaches infinity. Fortunately, in most cases it is required only to examine that the BER is under predefined threshold level. The number of bits required to accomplish this state will only depend on the essential confidence level and BER threshold. The confidence level is the percentage of tests that the system's true BER is less than the specified BER. Since an infinite number of bits cannot be measured and it is impossible to predict when errors will occur with certainty, the confidence level will never reach 100%.

3.3 Power and efficiency of modulations

Power efficiency η_e is defined as the ratio of the power of noise spectral density N_0 and median of signal energy E_b, transducing 1 bit of information at a certain bit error rate $BER = P_e$ (4),(5):

$$\eta_e = \frac{N_0}{E_b}, \qquad \eta_{edB} = 10 \log \frac{N_0}{E_b} \;\; [dB] \tag{4),(5}$$

3.4 Spectral efficiency of modulations

Spectral efficiency is defined as the ratio of the bit rate f_b and bandwidth of the transmitted signal B_{RF}. The pattern is clear by following definition (6):

$$\eta_s = \frac{f_b}{B_{RF}} \;\; [bit / s / Hz] \tag{6}$$

3.5 Error-control coding

The probability of error for a particular signaling scheme is a function of signal-to-noise ratio at the receiver input and the information rate. The only practical alternative for reducing the error probability is the use of error-control coding. Basically, there are two error correction methods:

- ARQ (Automatic Repeat Query)
- FER (Forward Error Correction)

ARQ is an error-control protocol that automatically initiates a call to retransmit any data packet or frame after receiving flawed or incorrect data. When the transmitting device fails to receive an acknowledgement signal to confirm the data has been received, it usually retransmits the data after a predefined timeout and repeats the process a predetermined number of times until the transmitting device receives the acknowledgement.

In FEC method, an automatic mechanism of error correction in the form of error-correction code is employed and further data retransmission is not necessary. The channel encoder systematically adds digits to the transmitted message. The limitation factors for closely spaced levels in multilevel coding can be overcome with FEC coding to enable a 70% increase in the number of channels of a 60% increase in the transmission distance. [3] Additionally, FEC allows an improvement in QoS by guaranteeing a received BER better than 10^{-15}.
Error-control codes are divided into two categories:

- Block codes
- Convolution codes

4 Code Modulation

Code modulation has brought power-bandwidth thinking to coded communication and focuses attention on bandwidth efficiency.

Inter-symbol interference (ISI) is another key issue when dealing with modulation. Generally, a wireless channel has multipath fading, which causes ISI - the data symbol duration is the same magnitude or smaller than the delay spread of the channel. When the data rate increases, the amount of symbols affected by ISI increases at the same time. This effect generally expands the complexity of the receiver. One method to avoid this effect is to transmit information on many different carrier frequencies simultaneously. That makes the symbol duration on each carrier longer, by factor equal to the number of carriers, and thus decreases the amount of ISI. However, multicarrier modulation techniques have a particularly high fluctuation of the signal envelope and to avoid generating of unwanted signals.

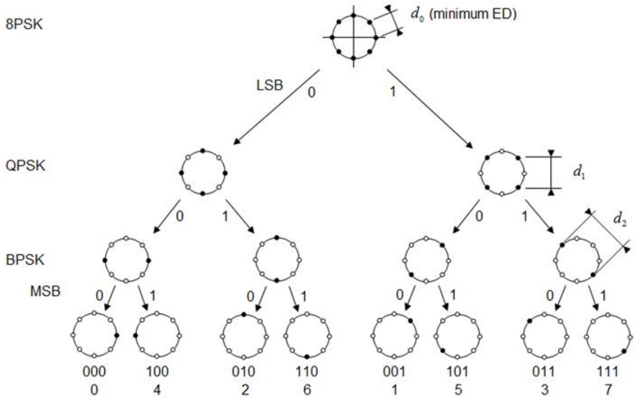

Fig. 2 Euclidean distance of modulations BPSK, QPSK, 8PKS

The main advantage of the code modulation is that it does not require the use of protective channel coding recognizable increase bandwidth communication channel. In some applications it is advantageous to associate the process of channel coding and modulation as well as associate and process channel decoding and demodulation. This consolidation creates code modulation, which is becoming more and more useful in a modern digital communications.

4.1 Code rate

Another important parameter for code modulation is the code rate r_c, which is given by formula (7):

$$r_c = \frac{k}{n} \tag{7}$$

The code rate is in the range $0 \leq r_c \leq 1$, where for r_c equal to the value 1, it is a state with no channel encoder. Conversely, in the most sophisticated protective channel coding would be the encoding speed $r_c = 0$ and thus ensures that the spectral efficiency transmission is reduced. Higher bit rate f_{bc} requires an enlarged ratio of bandwidth $1 / r_c$.

4.2 Bandwidth efficiency

Bandwidth efficiency modulations open new regions in the frequency domain that were occupied by redundant information. In order to maintain quality signaling in any assigned channel, the reserved channels are no longer required to be sitting idle waiting for traffic from other channels to be switched into them.

The high-frequency bandwidth B_{RF} is an important parameter for specifying band-modulated signals. In practice, using several different definitions of variables, which provide for a specific modulated signal different values, and therefore required is to be exactly specified. Different definitions of bandwidth are mostly based on the concept of power spectral density bandwidth signals *S(f)*.

In examining some noise transmitted bandpass filter is an important concept noise bandwidth B_n, also known as power bandwidth. Power bandwidth is usually determined by amplitude characteristic $|H(f)|$ of the filter with respect to formula (8):

$$B_n = \frac{1}{H_{\max}} \int_0^{\infty} |H(f)|^2 \, df \quad (8)$$

Absolute bandwidth B_a is defined as the range of frequencies where the signal has non-zero spectral density. This is not always appropriate example, because the amount of modulation signal has unlimited frequency range, resulting in an unlimited range of modulated signals. Thus frequently used bandwidth one-one B_{00}, which is the bandwidth of the main lobe of the power spectrum. This definition, however, is effective only if it has a unique range of zero points, limiting the main lobe.

5 Trellis Coded Modulation

Trellis Coded Modulation (TCM) has evolved over the past decade as a combination of coding and modulation technique for digital transmission over band-limited channels. The most interesting fact is that allows the achievement of significant coding gains over conventional encoded multilevel modulation without compromising bandwidth efficiency.

5.1 TCM Convolution encoder

The base of TCM convolution encoder is a shift register with a constraint length *K*. Convolution encoder has a memory as the current output block on bits depends not only on the input bits of the data block, but in addition, in the *(n - 1)* samples from previous input blocks. The total number of inputs *n* affecting a single output block are called restraining constraint length *K*, the expression *n - 1* is the order of the memory code. Convolution encoder transmits the output blocks with a certain delay.

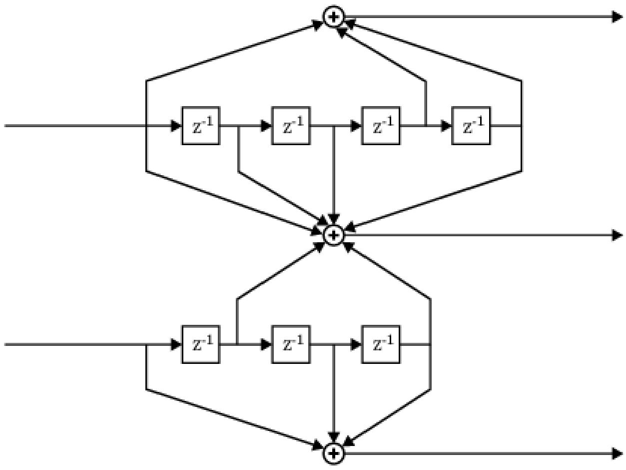

Fig.3 Convolution encoder for TCM system

Convolution encoder poly2trellis function *([5 4], [23 35 0, 13 0 5])*, used in the TCM system is illustrated in Figure 3. Selection of this encoder was conditioned by the ability of protection against the bit error rate for this system. Convolution encoder uses the encoding speed $r_c = 2/3$ and its restrictive constraint length is $K = 2$, resulting from the two inputs of the system. The elements of this vector indicate the number of bits stored in each of the two shift registers. Numbers *[5 4]* in poly2trellis function determine the constraint length *K - 1* for both of shift registers. Generational polynomials for described shift registers are (9):

$$g_0 = 1 + x^3 + x^4,$$
$$g_1 = 1 + x + x^2 + x^4 \quad (9)$$

5.2. TCM Convolution decoder

Convolution codes may theoretically have infinitely long sequence of output characteristics. Therefore, it may be difficult to decode them.

The convolution decoder determines the most likely coded signal sequence directly from the unquantized channel outputs. For decoding of convolution codes are mostly used trellis diagrams, thus the maximum certainty algorithm, called Viterbi algorithm. Viterbi algorithm is based on the assumption that the codewords have the same probability of being deployed. The number of possible paths in the trellis diagram for *k-bit* information sequence is 2^k.

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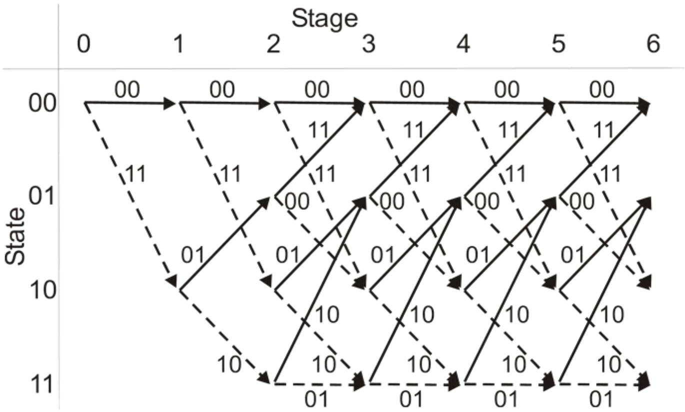

Fig. 4 Trellis diagram of convolution decoder

Figure 4 shows all possible states of Trellis diagram for a temporary coder in the range $1 \le i \le k$, where k is the number of information bits. Trellis diagram is searching for the codeword with the smallest Hamming distance from the received sequence, which tends to significant computational complexity reduction. The required number of operations for *k-bit* sequence is determined by $n2^{k(K-1)}$, which means that the number of operations increases linearly with value of k. However, the decoder memory requirements are increasing exponentially with the constraint length K, which in practice does not exceed the value of $K = 10$. Viterbi decoders are mostly implemented in the AWGN channels with one of PSK modulation.

6 Simulation Results

In this part, the simulation results obtained by Matlab Simulink have been described. For each of selected modulation (BPSK, QPSK, 8PSK) were proposed scheme of TCM system, which were based on blocks from the Communication System Toolbox.

Figure 5 shows the proposed scheme of TCM system using convolution coding and BPSK modulation.

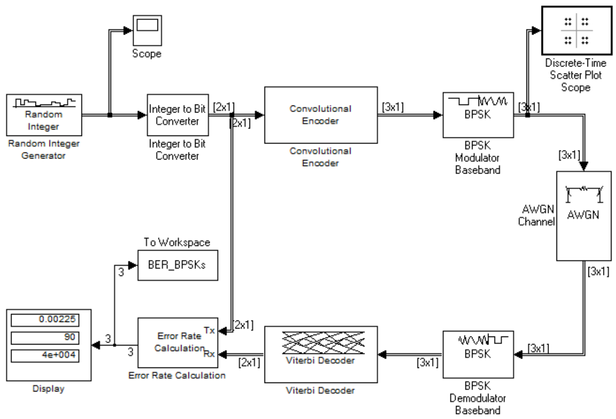

Fig. 5 Simulink model for TCM using BPSK modulation

The following Table 1 shows the simulation results for the selected PSK modulations depending on the signal-to-noise ratio E_b / N_0. Simulations results were conducted for the TCM system using convolution encoder and were compared with TCM system without convolution encoder, Figure 6.

Table 1. Simulation results of TCM system using PKS modulation

SNR	BPSK		QPSK		8PKS	
	with	without	with	without	with	without
E_b / N_0	BER	BER	BER	BER	BER	BER
4	0,09720	0,02608	0,21450	0,03935	0,29790	0,11470
4,5	0,05190	0,01980	0,14670	0,03040	0,25690	0,10040
5	0,02450	0,01490	0,08740	0,02105	0,20490	0,08936
5,5	0,00680	0,01065	0,04740	0,01473	0,15920	0,07752
6	0,00225	0,00760	0,02245	0,01025	0,11390	0,06551
6,5	0,00023	0,00478	0,00720	0,00775	0,07848	0,05483
7	0,00005	0,00333	0,00355	0,00500	0,04568	0,04500
7,5	0,00003	0,00143	0,00135	0,00308	0,02495	0,03398
8	0,00001	0,00085	0,00010	0,00195	0,01365	0,02715

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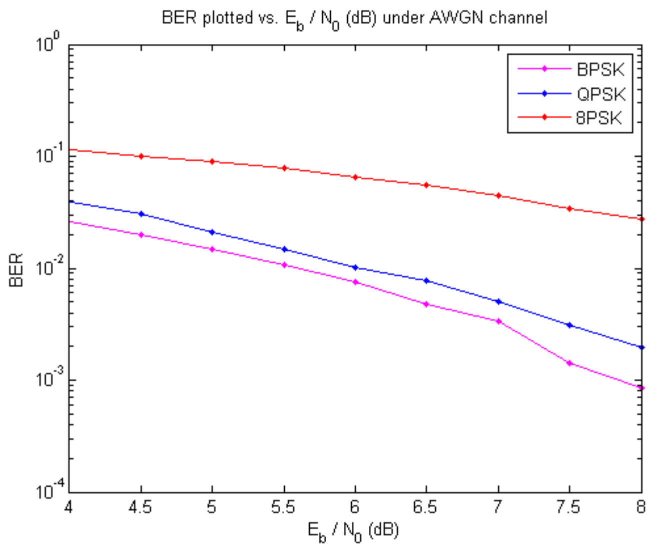

Fig. 6 Comparison of TCM systems without convolution coder

As the simulation results demonstrate, smallest BER achieves BPSK modulation, but that the 8PSK modulation is able to transfer larger amounts of data at the same frequency bandwidth. When comparing the modulation BPSK and QPSK then occur only slightly higher error rate, which is based on the difference of Euclidean distances between single-carrier frequencies.

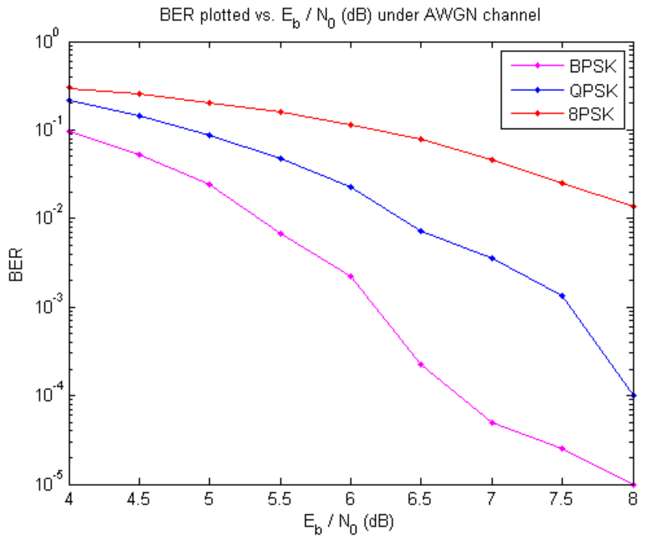

Fig. 7 Comparison of TCM systems with convolution coder

As can be seen from Figure 7, convolution coding, when used, leads to significant reduction of TCM system errors. From the simulation it is marked that the usage of convolution codes is suitable for transmission in a noisy environment.

7 Conclusion

Trellis coded modulation is a method which improves the noise immunity of digital transmission systems without expansion of bandwidth or reduction of data rate.

In this paper models of the communication channel are presented, using a combination of convolution coding and one of the selected PKS modulations. These simulation models have been transferred for BER measurement based on signal-to-noise ratio E_b/N_0. Simulated results were evaluated and discussed in details, when it is more efficient to use modulation-encoded or without coding.

The simulation results show that at higher values of E_b/N_0 is advantageous to use TCM system with convolution encoder, because it achieves lower BER. It was also verified that the TCM systems are able to work in distracting environments with minimal BER.

8 Acknowledgment

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