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RESEARCH ARTICLE

Studying the influence of correction codes on coherent reception of M-PSK signals in the presence of noise and harmonic interference

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Abstract

Objectives. Signals with multiple phase shift keying (M-PSK) exhibiting good spectral and energy characteristics are successfully used in many information transmission systems. These include satellite communication systems, GPS, GLONASS, DVB/DVB-S2, and a set of IEEE 802.11 wireless communication standards. In radio communication channels, the useful signal is affected by various interferences in addition to noise. One of these is harmonic interference. As a result, high intensity harmonic interference practically destroys the reception of M-PSK signals. One of the important requirements for the quality of data transmission is the system error tolerance. There are different ways of improving the quality of information transmission. One of these is the use of corrective encoding technology. The aim of the paper is to assess the noise immunity of a coherent demodulator of M-PSK signals using Hamming codes (7,4) and (15,11), and convolutional encoding with Viterbi decoding algorithm (7,5) when receiving M-PSK signals under noise and harmonic interference in the communication channel.

Methods. The methods of statistical radio engineering, optimal signal reception theory and computer simulation modeling were used.

Results. Experimental dependencies of the bit error rate on the signal-to-noise ratio and on the intensity of harmonic interference of coherent reception of M-PSK signals in a channel with noise and harmonic interference were obtained using computer simulation modeling. This was done without using correction codes and with Hamming code (7.4) and (15.11) and convolutional encoding with Viterbi decoding algorithm (7,5).

Conclusions. It is shown that the application of the correction codes effectively corrects errors in the presence of noise and harmonic interference with lower intensity. The correction is ineffective in the presence of high intensity interference. These results can provide important guidance in designing the reliable and energy efficient system.

Keywords: multiple phase shift keying, correction codes, Hamming code, convolutional encoding, Viterbi decoding algorithm, noise immunity, bit error rate, harmonic interference

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НАУЧНАЯ СТАТЬЯ

Исследование влияния корректирующих кодов на когерентный прием сигналов с многопозиционной фазовой манипуляцией при наличии шумовой и гармонической помех

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Резюме
Цели. Сигналы с многопозиционной фазовой манипуляцией (М-ФМ), обладающие хорошими спектральными и энергетическими характеристиками, успешно применяются во многих системах передачи информации, таких, как системы спутниковой связи, GPS, ГЛОНАСС, DVB/DVB-S2, в наборе стандартов беспроводной связи IEEE 802.11. В каналах радиосвязи на полезный сигнал действуют, кроме шумовой, разные помехи, одной из них является гармоническая, которая при большой интенсивности практически разрушает прием сигналов М-ФМ. Одним из важных требований, предъявляемых к качеству передачи данных, является устойчивость системы к ошибкам. Существуют разные способы повышения качества передачи информации, один из которых – применение технологии корректирующего кодирования. Цель статьи – оценка помехоустойчивости когерентного демодулятора сигналов М-ФМ с применением кодов Хэмминга (7,4) и (15,11) и сверточного кодирования с алгоритмом декодирования Витерби (7,5) при приеме сигналов М-ФМ в условиях воздействия в канале связи шумовой и гармонической помех.
Методы. Использованы методы статистической радиотехники, теории оптимального приема сигналов и компьютерного имитационного моделирования.
Результаты. С помощью компьютерного имитационного моделирования получены экспериментальные зависимости вероятности битовой ошибки от отношения сигнал/шум и от интенсивности гармонической помехи для когерентного приема сигналов М-ФМ в канале с шумовой и гармонической помехами без применения корректирующих кодов и с применением кодов Хэмминга (7,4) и (15,11), сверточного кодирования с алгоритмом декодирования Витерби (7,5).
Выводы. Показано, что применение корректирующих кодов позволяет эффективно исправлять ошибки при наличии шумовой и гармонической помех с малой интенсивностью. При большой интенсивности помехи коррекция неэффективна. Результаты могут служить важным руководством при проектировании надежных и энергоэффективных систем передачи информации.

Ключевые слова: многопозиционная фазовая манипуляция, корректирующие коды, код Хэмминга, сверточный код, алгоритм декодирования Витерби, помехоустойчивость, вероятность битовой ошибки, гармоническая помеха

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Автор заявляет об отсутствии конфликта интересов.

INTRODUCTION

Many studies have examined the impact of encoding on the noise immunity of multivariable signal reception when only white Gaussian noise operates in radio communication channels. In [1–13], the authors define the effectiveness of different correction codes used in encoding channels with different modulation techniques. Table 1 presents the energy gain from using such codes by the particular example of Hamming code and convolutional encoding with Viterbi decoding algorithm.

Figure 1 shows the theoretical dependencies of the bit error rate (BER) P_{eb} on the signal-to-noise ratio (SNR) E_b/N_0 (E_b is average bit energy, N_0 is noise power spectral density) for receiving signals with multiple phase shift keying (M-PSK) in the channel with additive white Gaussian noise. The solid lines correspond to BER without using correction codes. The dashed lines refer to BER using Hamming code (7,4), the dash-dotted lines stand for using Hamming code (15,11), and dotted lines correspond to BER using convolutional encoding with Viterbi decoding algorithm (7,5) [14].

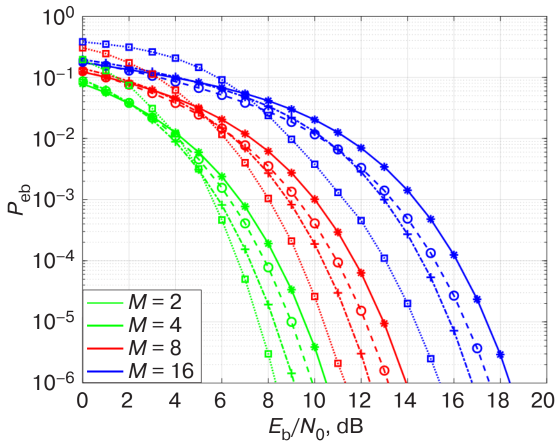


Fig. 1. Theoretical dependencies of the BER P_{eb} on SNR E_b/N_0 for receiving M-PSK signals in the channel with additive white Gaussian noise

In [15–18], the impact of harmonic interference in the reception of signals with multi-position shift keying is analyzed. Harmonic interference is shown to be the most dangerous in the event that its frequency coincides with the useful signal frequency. As a result of its impact, the noise immunity is greatly reduced.

The most important contribution to resolving this problem is made by the noise-resistant coding theory. The aim of the paper is to evaluate the noise immunity for the coherent demodulator of M-PSK signals using Hamming codes (7,4) and (15,11) as well as convolutional encoding with Viterbi decoding algorithm (7,5) when receiving M-PSK signals under the noise and harmonic interference in the communication channel.

1. MODEL OF THE DIGITAL INFORMATION TRANSMISSION SYSTEM

Figure 2 shows the structural diagram of the digital information transmission system. The encoding and decoding algorithm using Hamming code or Viterbi algorithm is implemented in units of channel encoder and channel decoder. The M-PSK signal shaping scheme is based on the universal quadrature modulator, while the receiving scheme is implemented on the basis of a multichannel coherent demodulator which is optimal according to the maximum likelihood criterion (Fig. 3) [19, 20].

2. MATHEMATICAL MODELS OF M-PSK SIGNALS, NOISE AND HARMONIC INTERFERENCE

Mathematical models of M-PSK signals, noise, and harmonic interference may be described as follows:

a) Mathematical model of M-PSK signals

The M-PSK signal at timing period T_s equal to the duration of the channel symbol carrying information about $k = \log_2 M$ information bits can take one of M possible values:

$$s_i(t) = A_0 \cos(\omega_0 t + \varphi_i + \varphi_s),$$
$$\varphi_i = \frac{i2\pi}{M}, t \in (0, T_s], i = \overline{0, M-1},$$

where $A_0 = \sqrt{2E_s / T_s}$ is signal amplitude; $E_s = kE_b$ is channel symbol energy; ω_0 is carrier frequency; φ_s is initial PSK of the signal constellation.

Table 1. Energy gain in SNR (dB) at $P_{eb} = 10^{-5}$

Modulation modes	Hamming code (7,4)	Hamming code (15,11)	Convolutional encoding with Viterbi decoding algorithm (7,5)
BPSK, QPSK	0.56	1.31	1.99
8-PSK	0.78	1.49	2.59
16-PSK	0.91	1.57	3.07

Note: BPSK—binary phase shift keying, QPSK—quadrature phase shift keying.

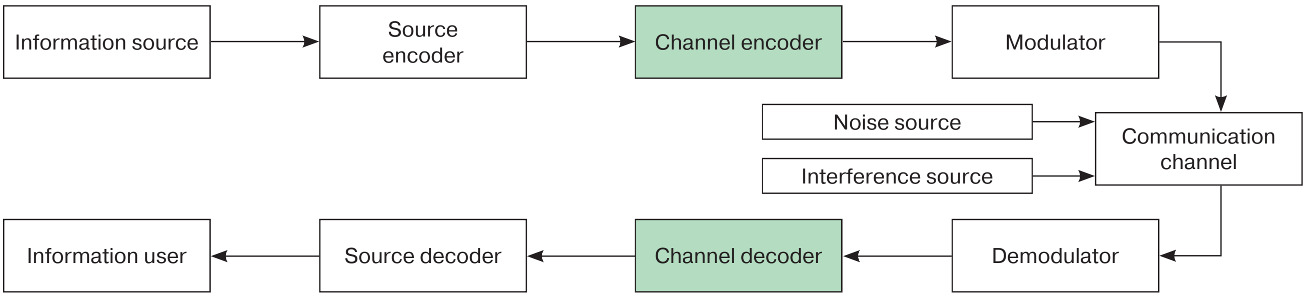


Fig. 2. Structural diagram of the digital information transmission system

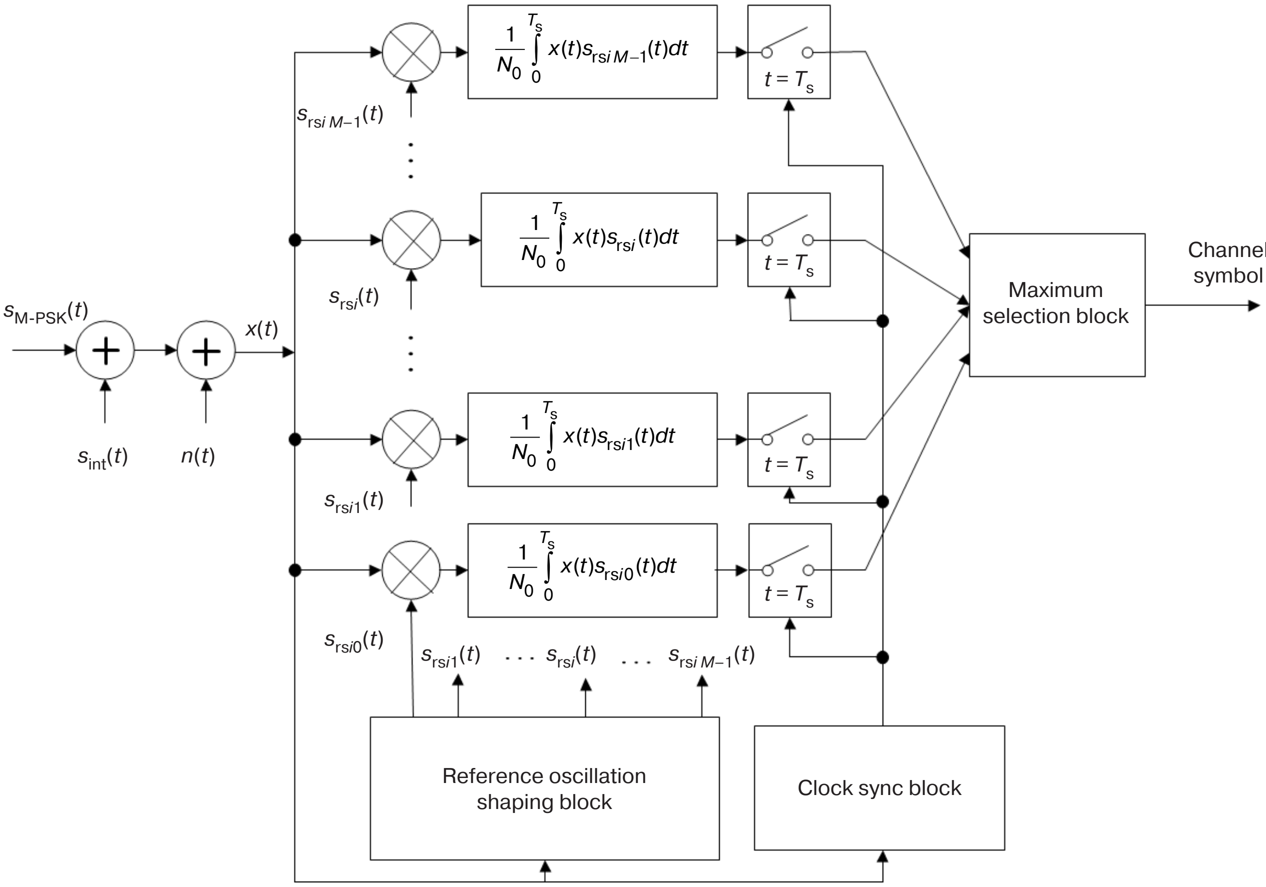


Fig. 3. Structural diagram of the M-PSK coherent demodulator: t is time; $x(t)$ is input process; $s_{rsi}(t)$ is reference signals

The M-PSK signal constellations using Gray encoding are shown in Fig. 4. Here the signal points corresponding to channel symbols are marked, and the decision boundaries are shown as dotted lines.

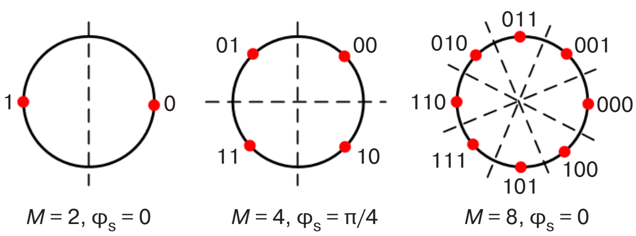


Fig. 4. M-PSK signal constellations

b) Noise interference model

A stationary random process $n(t)$ of the "white Gaussian noise" type with correlation delta function and zero mean is considered as a noise interference.

c) Harmonic interference model

$$s_{int}(t) = \mu A_0 \cos[(\omega_0 + \Delta\omega_{int})t + \varphi_{int}],$$

where μ is relative intensity; φ_{int} is random initial phase of interference uniformly distributed on the half-interval $(-\pi, +\pi]$; $\Delta\omega_{int}$ is interference detuning relative to the center frequency of the spectrum of the useful signal ω_0.

3. HAMMING CODES (7,4) AND (15,11)

The Venn diagrams for the relationship between parity check bits and data bits in Hamming codes are shown in Fig. 5.

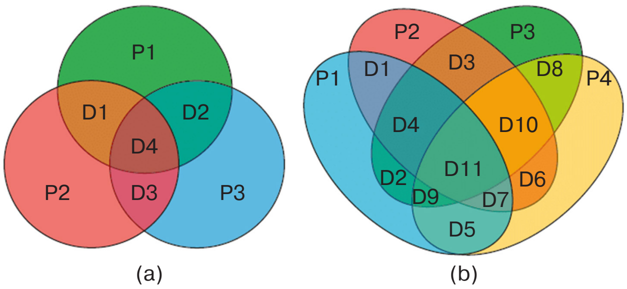


Fig. 5. Venn diagrams describing parity check bits and data bits: (a) Hamming code (7,4), (b) Hamming code (15,11) [21]

There is a certain set of Hamming code parameters:
- number of characters for checking m ($m \geq 3$),
- number of code message symbols $n = 2^m - 1$,
- number of informational symbols $k = 2^m - m - 1$,
- error correction capability $t = 1$ ($d_{\min} = 3$),
- code rate $R = k/n$.

The code parameters used in the paper are given in Table 2.

Table 2. Hamming code parameters

Parameters	Hamming code (7,4)	Hamming code (15,11)
m	3	4
n	7	15
k	4	11
R	4/7	11/15

4. CONVOLUTIONAL ENCODING WITH VITERBI DECODING ALGORITHM (7,5)

Figure 6 shows the convolutional encoder scheme with rate 1/2, $K = 3$, generator polynomial is [7,5], octal.

There is a certain set of convolution code parameters:
- number of information symbols k,
- number of symbols transmitted into the communication channel for one clock cycle of information symbol n arriving at the encoder,
- relative code rate $R = k/n$,
- constraint length K,
- number of convolution code states $2^K - 1$.

The convolution code parameters used in the paper are given in Table 3.

Table 3. Convolution code parameters

Parameters	Value
n	1
k	2
K	3
R	1/2

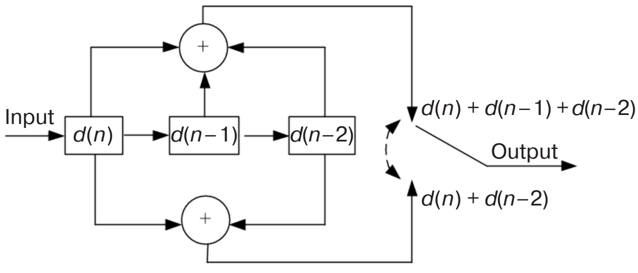


Fig. 6. Convolutional encoder scheme

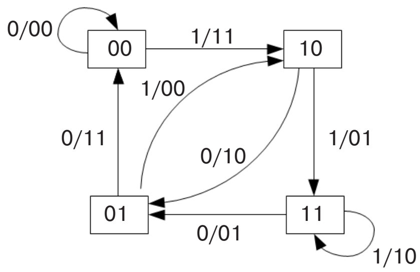


Fig. 7. Convolutional encoding state diagram

5. MODELING AND RESULTS

5.1. Modeling

The information transmission channel is modeled with the parameters presented in Table 4.

The block diagram of the modeling algorithm is shown in Fig. 8.

The relationship between SNRs with and without encoding is taken into account in modeling.

$$\frac{E_{\text{cb}}}{N_0} = \frac{E_{\text{b}}}{N_0} + 10\lg\left(\frac{k}{n}\right) \text{(dB)}.$$

5.2. Simulation modeling results

Figure 9 shows the experimental dependencies of BER P_{eb} on SNR E_{b}/N_0 and on the relative intensity of harmonic interference μ at coherent reception of M-PSK signals using Hamming codes for different code rates. The solid lines correspond to BER without using Hamming code, while the dashed lines refer to BER using Hamming code (7,4), and dash-dotted lines stand for the use of Hamming code (15,11).

Figure 10 shows the experimental dependencies of BER P_{eb} on SNR E_{b}/N_0 and on the relative intensity of harmonic interference μ at coherent reception of M-PSK signals using convolutional encoding with Viterbi decoding algorithm. The solid lines correspond to BER without encoding, while the dashed lines stand for BER using convolutional encoding with Viterbi decoding algorithm (7,5).

Table 4. Modeling parameters

Parameters	Value
SNR	$E_b/N_0 = 0$–25 dB
Communication channel	Additive Gaussian white noise, Harmonic interference
Relative interference intensity	$\mu = 0$–1
Interference initial phase	$\varphi = 0$–2π
Ratio of sampling frequency to carrier frequency	$f_s/f_0 = 20$, $f_0 = \omega_0/2\pi$
Number of information bits	$N = 1080000$
Modulation modes	BPSK, QPSK, 8-PSK, 16-PSK
Code types	Hamming code (7,4), Hamming code (15,11), convolutional encoding with Viterbi decoding algorithm (7,5)

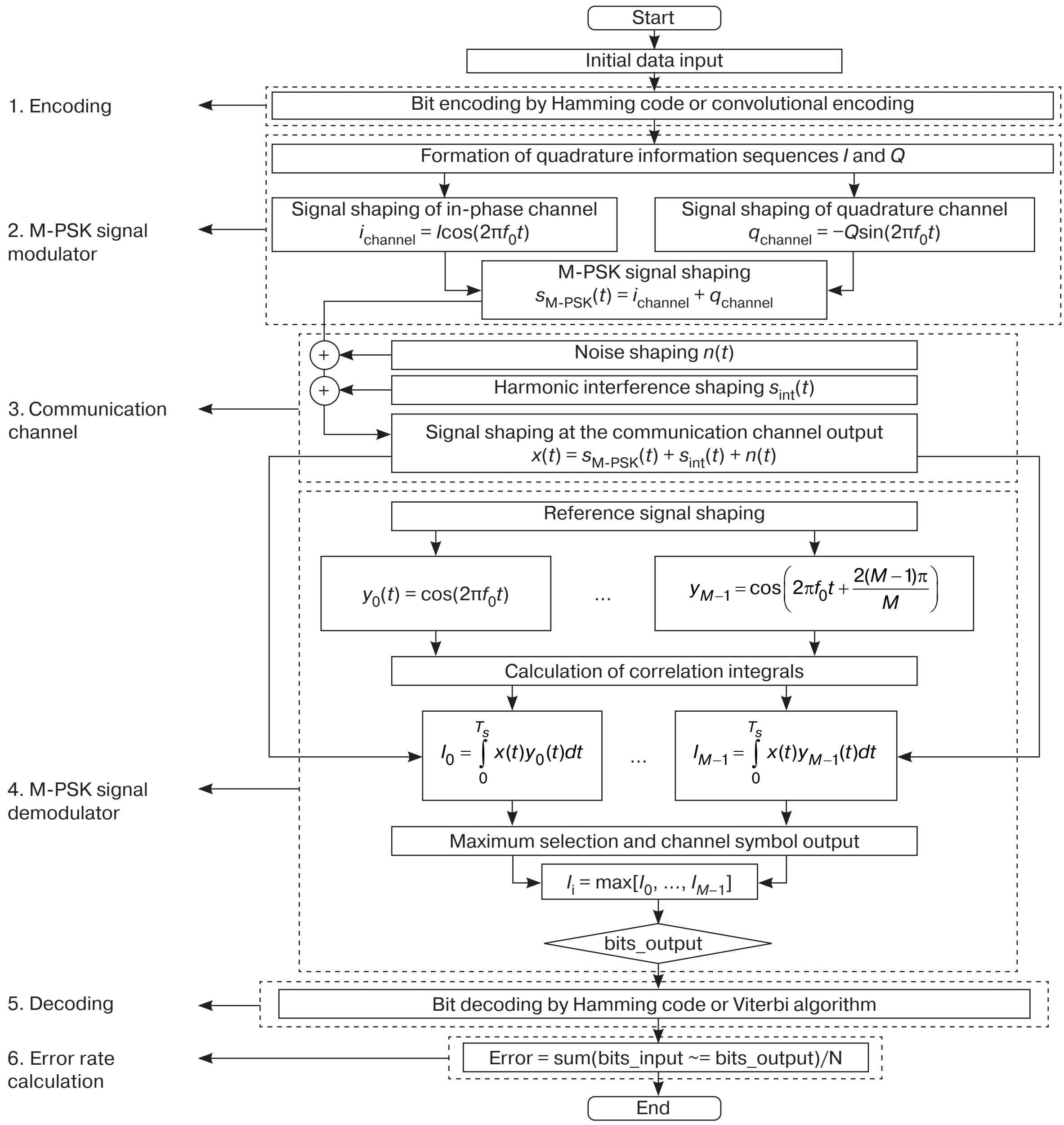
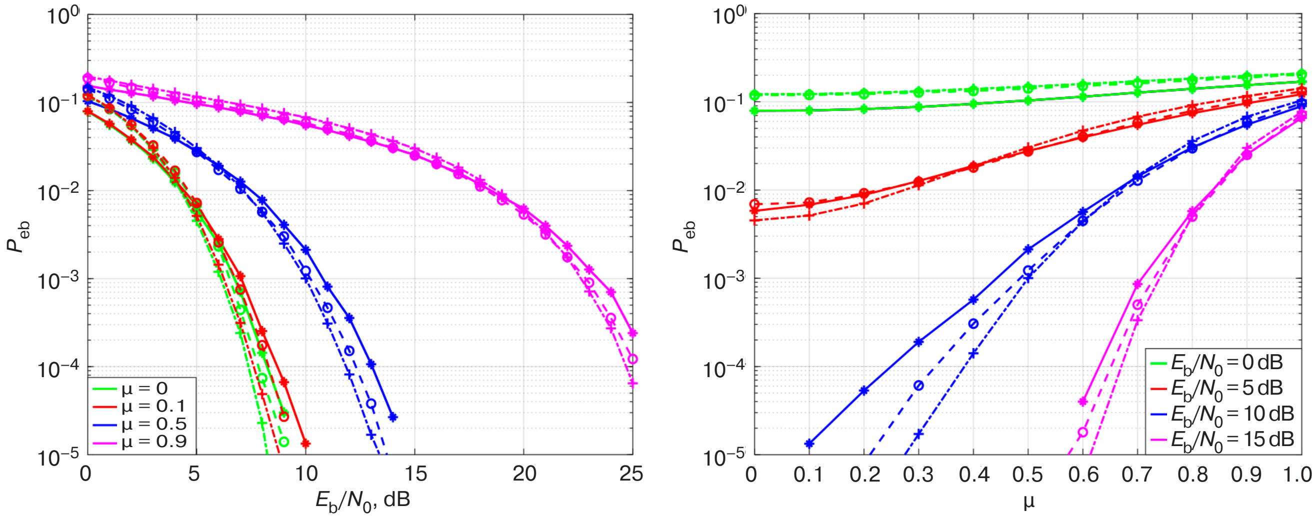
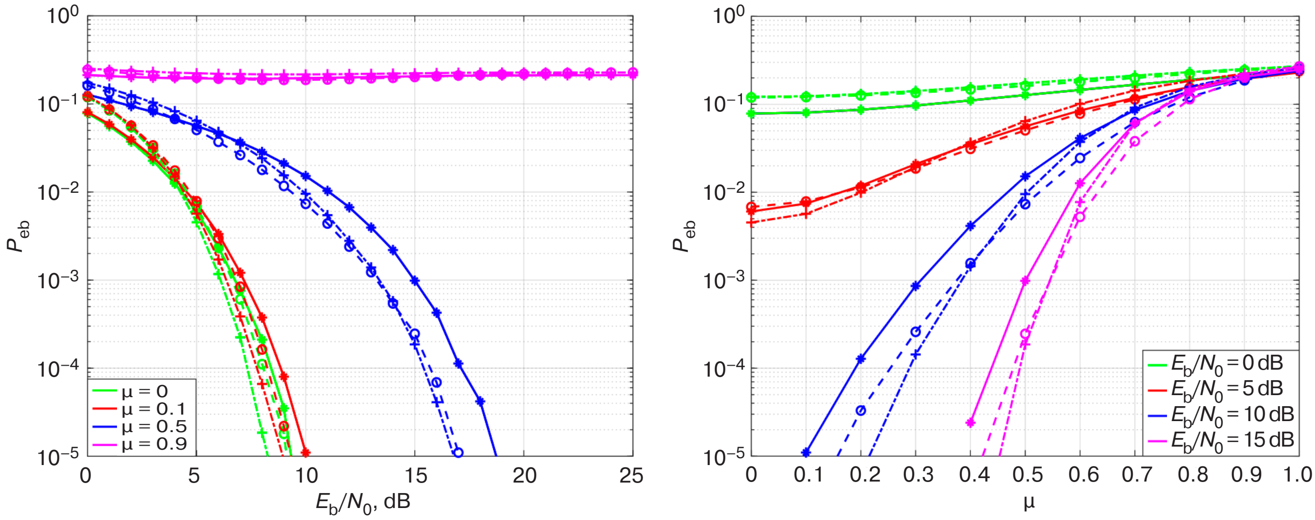


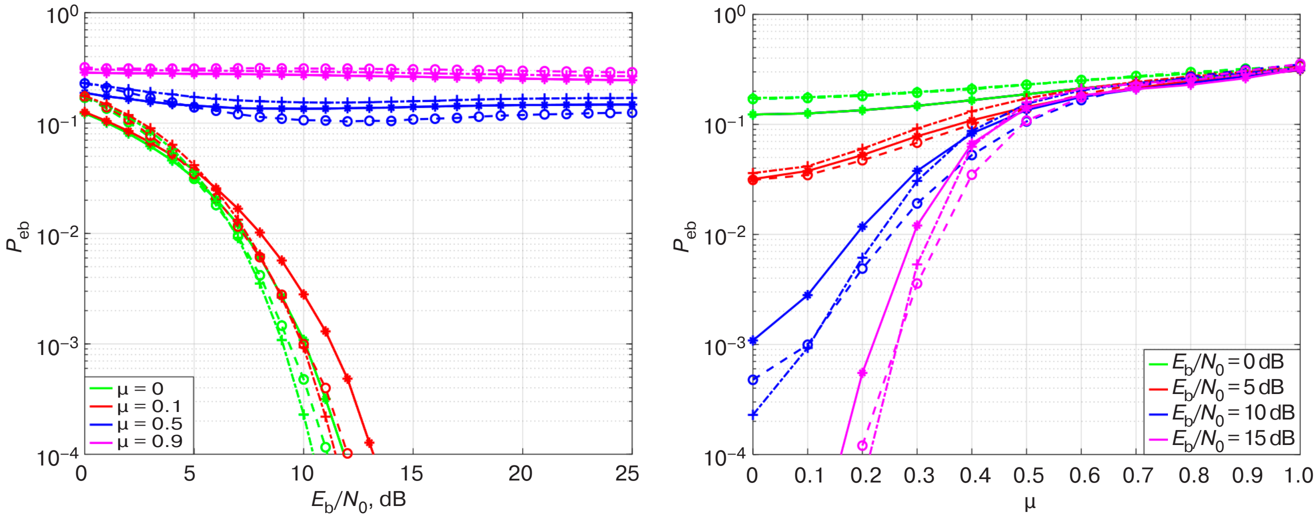
Fig. 8. Block diagram of the modeling algorithm



(a)

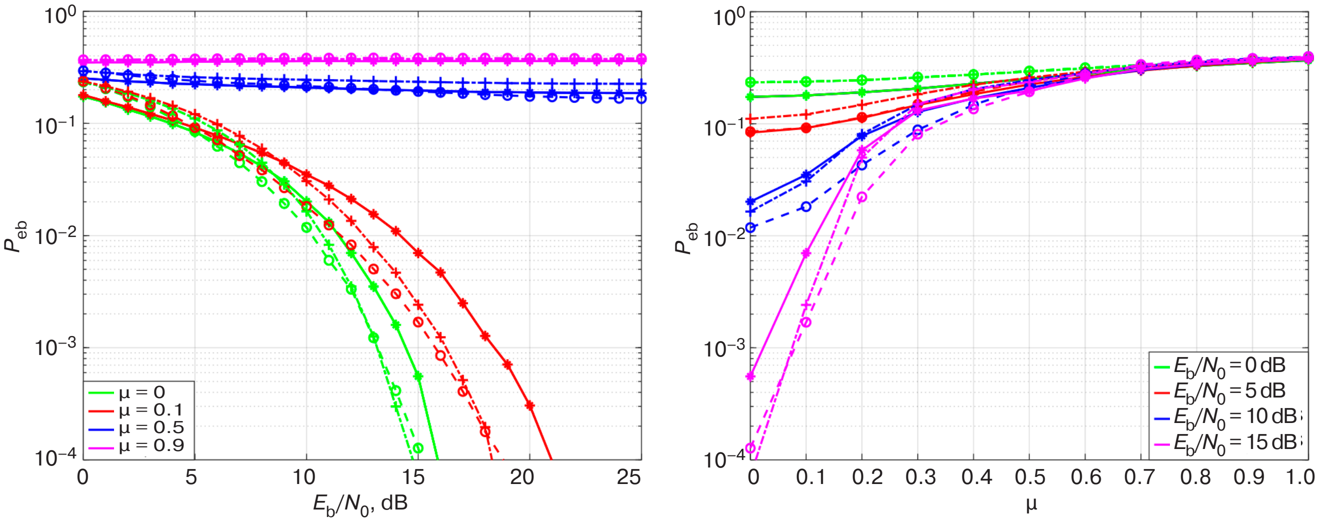


(b)



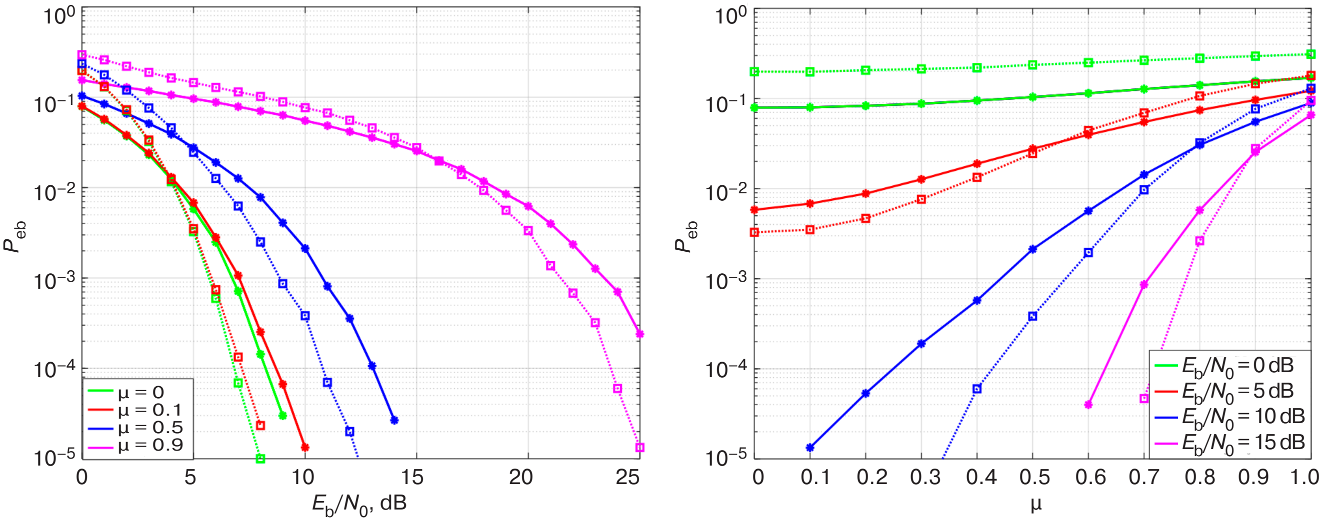
(c)

Fig. 9 (*start*). Experimental dependencies of BER P_{eb} on SNR E_b/N_0 (left) and on the relative intensity of harmonic interference μ (right) during coherent reception of M-PSK signals using Hamming codes: (a) BPSK; (b) QPSK; (c) 8-PSK;

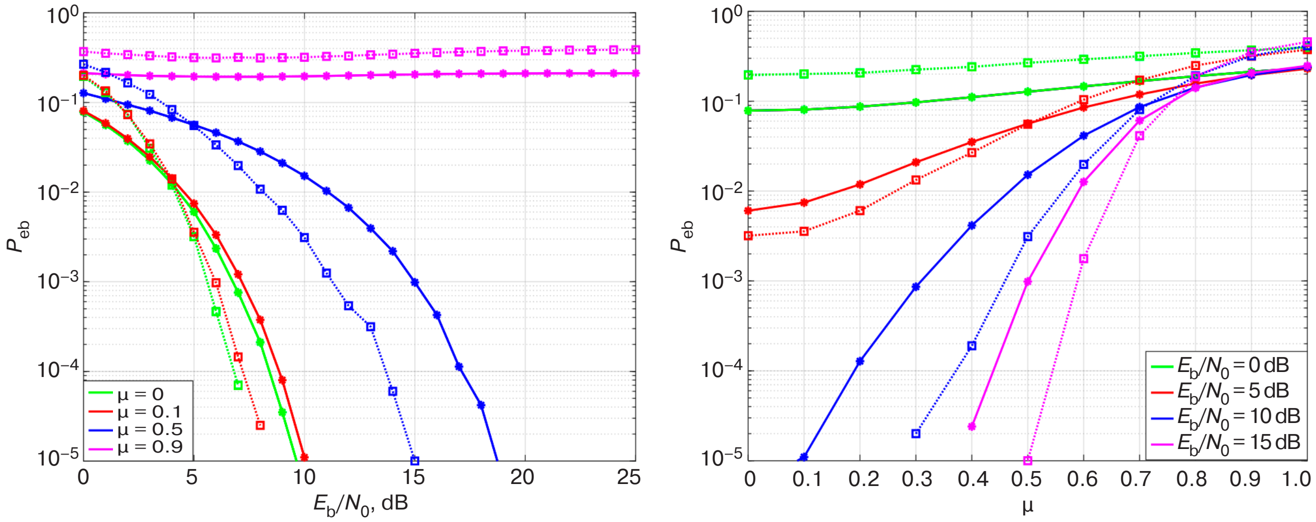


(d)

Fig. 9 (*end*). Experimental dependencies of BER P_{eb} on SNR E_b/N_0 (left) and on the relative intensity of harmonic interference μ (right) during coherent reception of M-PSK signals using Hamming codes: (d) 16-PSK

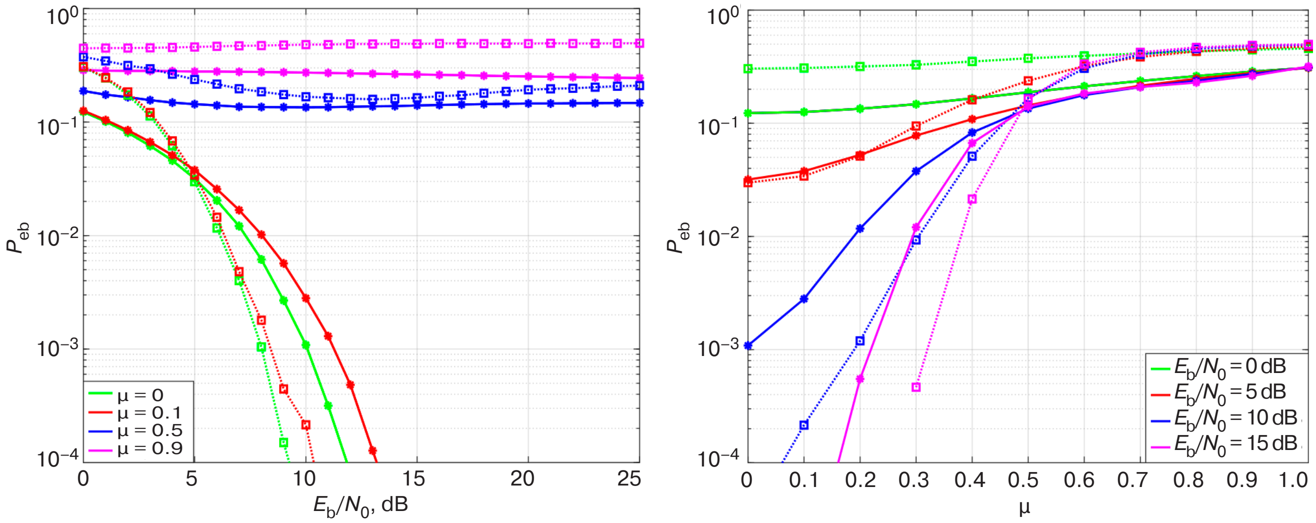


(a)

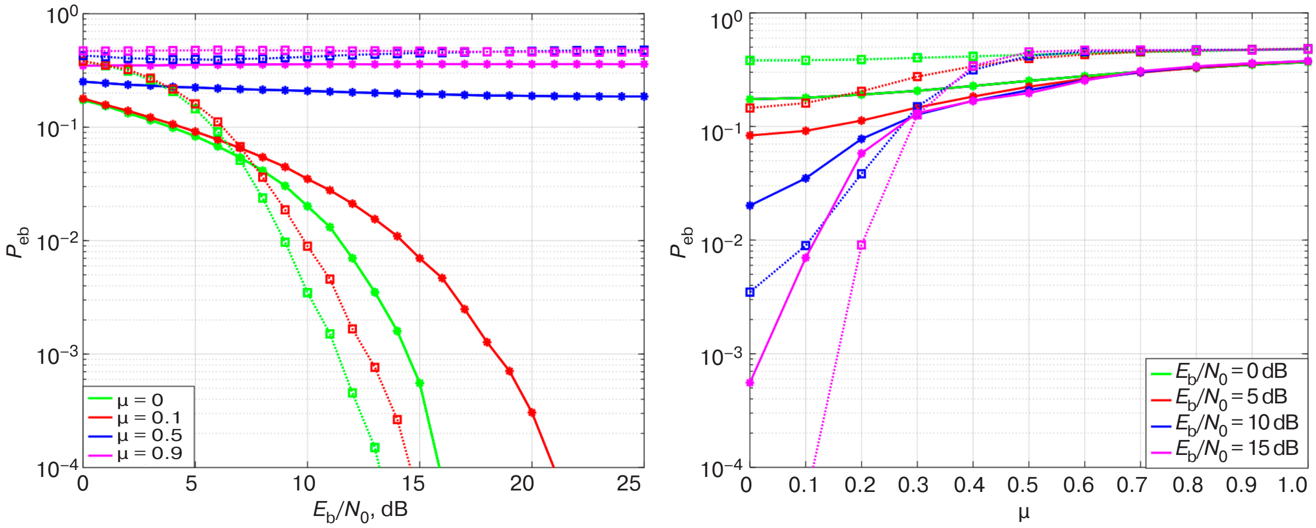


(b)

Fig. 10 (*start*). Experimental dependencies of BER P_{eb} on SNR E_b/N_0 (left) and on the relative intensity of harmonic interference μ (right) at coherent reception of M-PSK signals using convolutional encoding with Viterbi decoding algorithm: (a) BPSK; (b) QPSK;



(c)



(d)

Fig. 10 (*end*). Experimental dependencies of BER P_{eb} on SNR E_b/N_0 (left) and on the relative intensity of harmonic interference μ (right) at coherent reception of M-PSK signals using convolutional encoding with Viterbi decoding algorithm: (c) 8-PSK; (d) 16-PSK

Figure 11 shows the comparative experimental dependencies of BER P_{eb} on SNR E_b/N_0 ($\mu = 0.3$) and on the harmonic interference intensity ($E_b/N_0 = 10$ dB) at coherent reception of M-PSK signals using Hamming code and convolutional encoding with Viterbi decoding algorithm. The solid lines correspond to BER without using codes, while the dashed lines refer to using Hamming code (7,4), dash-dotted lines stand for using Hamming code (15,11), and the dotted lines correspond to using convolutional encoding with Viterbi decoding algorithm (7,5).

CONCLUSIONS

In this paper, simulation modeling is carried out to evaluate the efficiency of encoding by Hamming code and convolutional encoding with Viterbi decoding algorithm at coherent reception of M-PSK signals against noise and harmonic interference. The results allow the following conclusions to be made:

1. There is a significant gain from using correction codes in M-PSK signal demodulators in the presence of noise and harmonic interference with low intensity. For example, at $\mu = 0.3$ and $P_{eb} = 10^{-4}$ for QPSK, the energy gain is 1.24 dB with Hamming code (7,4), 1.6 dB with Hamming code (15,11), and 2.69 dB with convolutional encoding and Viterbi decoding algorithm (7,5). At $\mu = 0.3$ and $P_{eb} = 10^{-3}$ for 8-PSK, the energy gain is 2.89 dB with Hamming code (7,4), 2.54 dB with Hamming code (15,11), and 5.4 dB with convolutional encoding and Viterbi decoding algorithm (7,5).

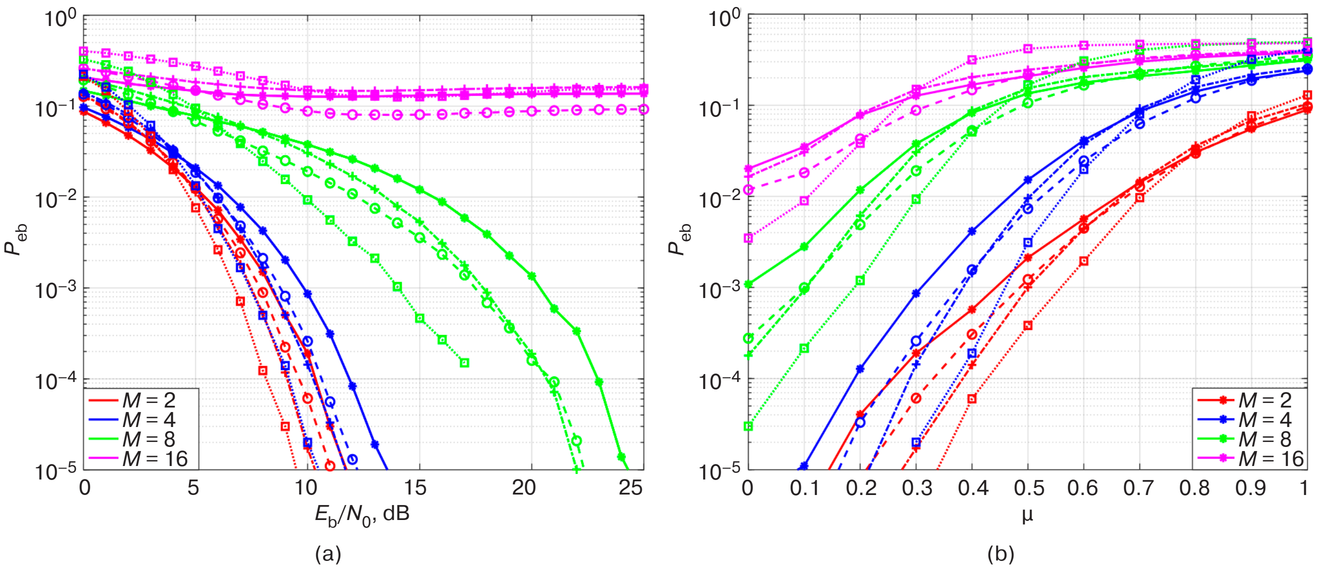


Fig. 11. Comparative dependencies of BER P_{eb} on SNR E_b/N_0 (a) and on the relative intensity of harmonic interference μ (b) at coherent reception of M-PSK signals for different encoding procedures

2. With increased positionality of M-PSK signals and a high intensity of harmonic interference, the use of convolutional encoding and Viterbi decoding algorithm decreases the BER of M-PSK signal reception error more than Hamming codes.
3. Hamming codes with higher code rates outperform codes with lower code rates at high SNR. For example, at $E_b/N_0 \geq 14$ dB, $\mu = 0.5$, and $P_{eb} = 10^{-4}$ for QPSK, the energy gain is 1.4 dB with Hamming code (7,4) and 1.7 dB with Hamming code (15,11) At $E_b/N_0 \geq 20.5$ dB, $\mu = 0.3$, and $P_{eb} = 10^{-4}$ for QPSK, the energy gain is 2 dB with Hamming code (7,4) and 2.3 dB with Hamming code (15,11).

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