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Error Correction Codes Performance using Binary Phase Shift Keying over Fading Channel

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Abstract

In a communication system, two main resources are used: transmission power and channel bandwidth. Transmission power is the average power of the transmitted signal, while channel bandwidth is defined as the frequency band allocated for the transmission of the message signal. A goal of general system design is to use these two resources as efficiently as possible. This scientific paper presents the experimental results of the Binary Phase Shift Keying (BSK) communication system on the additive white Gaussian noise (AWGN) channel and the fading channel. To improve system performance, error correction codes, including convolutional code and Hamming code, were used for information encoding.

Keywords: BPSK, Convolutional Codes, Fading Channel, Hamming code

I. Introduction

Today, communication enters our daily life in so many different ways that it is very easy to see the magnitude from the tap. Mobile phones, radios and televisions, and computer connections with access to the internet in our offices and homes, all provide instant communication from all over the world. Communications provide sensing for ships' navigation, aircraft maneuver, and rockets and satellites orbiting in space. Communication, via a mobile phone, keeps the car driver in touch with the office or a distant home. Communications keep a weather forecaster informed of conditions measured by multiple sensors. Indeed, the list of applications that involve the use of communication in one direction or another is almost endless [1].

In the most basic sense, communication involves the implicit transmission of information from one point to another through a sequence of processes. First, the generation of message signals is in the form of sound, music, images, or computer data. Second, the sending side forms the message signal with a certain precision using a set of symbols in the form of electricity, sound, or visuals. Third, the encoding of this symbol in a form suitable for transmission over the desired physical medium. Fourth, the sending side transmits the encoded symbol to the desired destination. Fifth, the receiving side performs decoding and reproduction of the initial symbol, and finally, the reformation of the original message signal with an acceptable loss of quality.

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Of course, many other forms of communication do not directly involve human intervention. For example, computer communication involves communication between two or more computers, human decisions may enter only in setting up programs or commands for computers, or in controlling the results.

II. LITERATURE REVIEW

This section discusses the latest scientific works on communication systems, channel models, and several types of error-correcting codes.

A. Basic Communication System

Regardless of the form of the communication process being discussed, there are three basic elements for any communication system: transmitter, channel, and receiver, as shown in Fig.1. The transmitter is located at one point in space, and the receiver is located at a point different from the sender, and the channel is the physical medium that connects the two. The purpose of the transmitter is to convert the message signal generated by the information source into a form suitable for transmission over the channel. However, as the transmitted signal propagates through the channel, it is distorted due to channel imperfections. Moreover, noise and interfering signals originating from other sources can be added to the channel output and hence the received signal becomes a corrupted version of the transmitted signal. The receiver, on the other hand, processes the received signal to reconstruct a recognizable form of the original message signal for a user.

Some of the latest scientific papers related to wireless communication systems recommend the use of deep learning [2] for an end-to-end communication system which includes the functions in Fig. 1. Authors in [3] suggested a deep learning approach based on the convolutional neural networks for intelligent communication systems. The design of the satellite communication system is narrated in [4], while radar-based communication systems are discussed in [5]. Scientific works that summarize the latest articles in the field of smart grid communication systems are discussed in this paper [6].

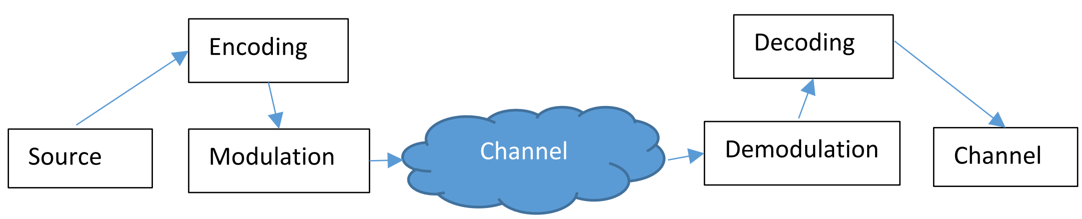

Fig. 1. Communication System Model

B. Channel Model

The channel is the primary medium through which information is sent to the recipient. The most commonly used channel for modeling communication systems is the additive white Gaussian noise (AWGN) channel [7]. In addition, there is a fading channel which is characterized by the reflection of signals from various objects on the communication line. The fading channel has a noise power distribution following the Rayleigh distribution [8] or Rician distribution [9]. The Weibull fading model is also commonly used for indoor and outdoor fading channels [10]. Another model of interest is Nakagami fading which uses the Gamma distribution [11].

C. Error Correction Codes

In the encoding stage, digital signals that have been damaged by channel conditions will be corrected by an Error Correction Code (ECC). There are several ECC mechanisms reported in the literature including the Hamming code [12], Linear block code [13], Reed Solomon code [14], Hadamard code [15], and Convolutional code (ConvCode) [16]. Linear block code [13] is widely used in communication systems due to its simplicity in detecting and correcting errors. In this paper, apart from Hamming code, Convolutional code (ConvCode) is also used to handle multipath models.

III. RESEARCH METHOD

This section discusses digital modulation techniques, Binary Phase Shift Keying (BPSK), and communication channel models.

A. Binary Phase Shift Keying

BPSK is a digital modulation with the modulated signals for binary signal “0” and binary signal "1". $s_0(t)$ and $s_1(t)$ are given by (1) and (2), respectively.

$$s_0(t) = -\sqrt{\frac{2E_b}{T_b}}\cos(2\pi f t)\ , \tag{1}$$

Where E_b and T_b are the bit amplitude and interval, respectively.

$$s_1(t) = \sqrt{\frac{2E_b}{T_b}}\cos(2\pi f t), \tag{2}$$

Where f is the baseband frequency.

B. Communication Channel Model

The AWGN channel model has a normal distribution with a mean of 0 and variance or noise power of σ^2. For a random variable Z, then $Z \sim \mathcal{N}(0, \sigma^2)$.

The Rayleigh fading channel model has the following probability density function, $p(Z = z)$, given by:

$$p(Z = z) = \frac{2z}{\sigma} e^{-\frac{z^2}{\sigma}} \tag{3}$$

C. Performance measure

This system uses the Bit Error Rate (BER) to measure system performance, the BER is calculated using the following equation

$$BER = \frac{Number\ of\ Bit\ Error}{Number\ of\ all\ Bits} \tag{4}$$

which will be displayed as a function of the signal-to-noise ratio (SNR).

IV. RESULTS AND DISCUSSION

This section contains experimental results considering Hamming code on the AWGN channel with BPSK modulation, ConvCode on AWGN, and a comparison of performance on various channels.

A. Hamming coded BPSK over AWGN Channel

In this section, the experiment was carried out by transmitting binary data using BPSK either by encoding with Hamming code or without using any encoding technique. Experiments were carried out at SNR from 0dB to 12 dB.

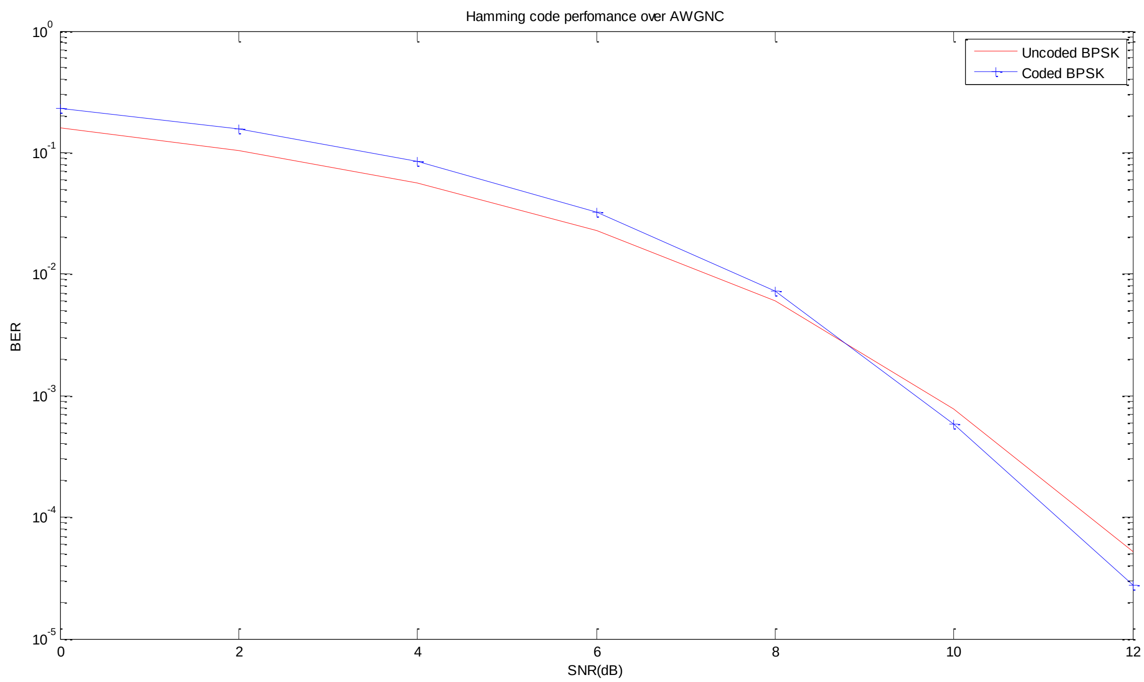

Fig. 2. Hamming code and uncoded over AWGN

Fig. 2 shows that at SNR less than 9dB, BPSK without encoding has a lower BER than BPSK with Hamming code. However, for SNR higher than 9dB, BPSK with Hamming code produces lower BER. This indicates that at high SNR or low noise levels, BPSK with Hamming code produces better performance.

TABLE I
BER OF CODED AND UNCODED BPSK OVER AWGN CHANNEL

SNR (dB)	0	2	4	6	8	10	12
BER uncoded	0.1587825	0.1039775	0.05661	0.0233425	0.0058325	0.0007625	3.5e-05
BER coded	0.2297275	0.1563175	0.084585	0.0317425	0.0067250	0.0006375	5.0e-06

Table I summarizes the BER of coded and uncoded BPSK over the AWGN channel. Both cases reach BER around $> 10^{-4}$ at SNR=10dB but exceed less than 10^{-4} at SNR=12dB, hence $\gamma_{max} = 12dB$. Using simulation (increment 0.1dB) Coded BPSK BER achieves exactly 10^{-3} at SNR=9.6dB and for uncoded BPSK BER exactly at 10^{-3} at SNR=9.75dB. It can be noticed that coding gain at $BER = 10^{-3}$ is $G = 9.75dB - 9.6dB = 0.15dB$.

B. Convolutional and Hamming Comparison over AWGN Channel

In this section, ConvCode, Hamming code, and uncoded BPSK are compared to the AWGN channel. BER is measured in each encoding scheme at SNR from 0dB to 12dB as depicted in Fig. 3.

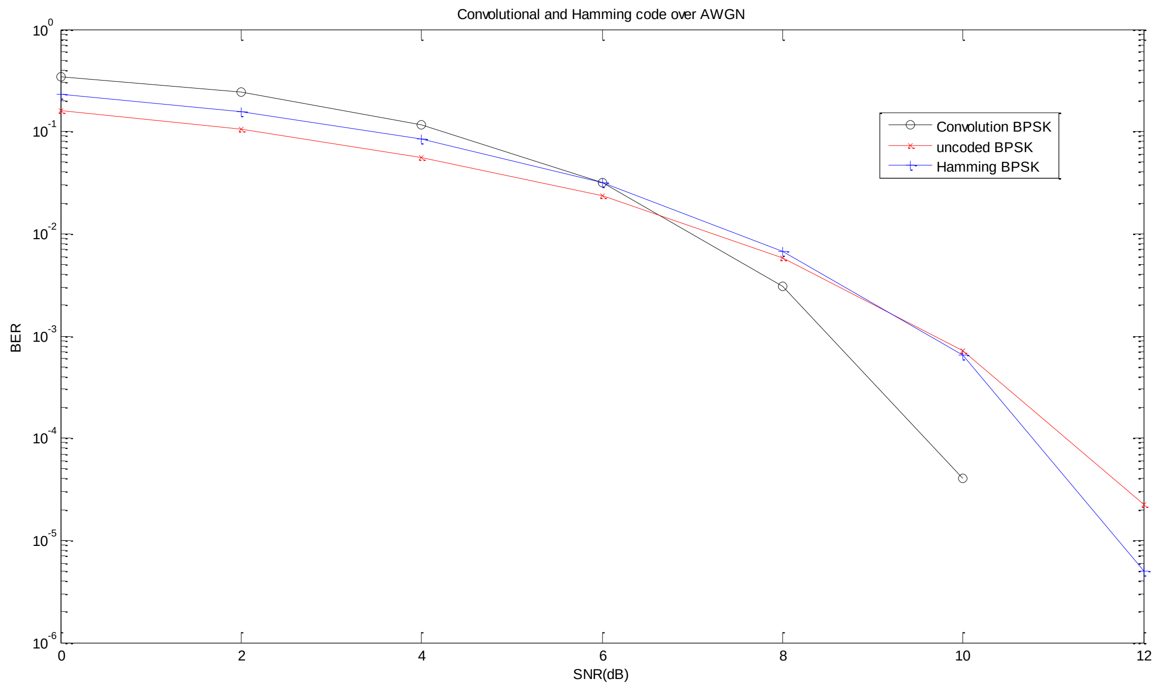

Fig. 3. Convolutional, Hamming code, and uncoded over AWGN

Fig. 3 shows that at SNR less than 6dB, BPSK without encoding has the lowest BER followed by Hamming Code and ConvCode has the highest BER. At SNR>6, ConcCode has the lowest BER. It can be seen that ConvCode performs well at higher SNRs.

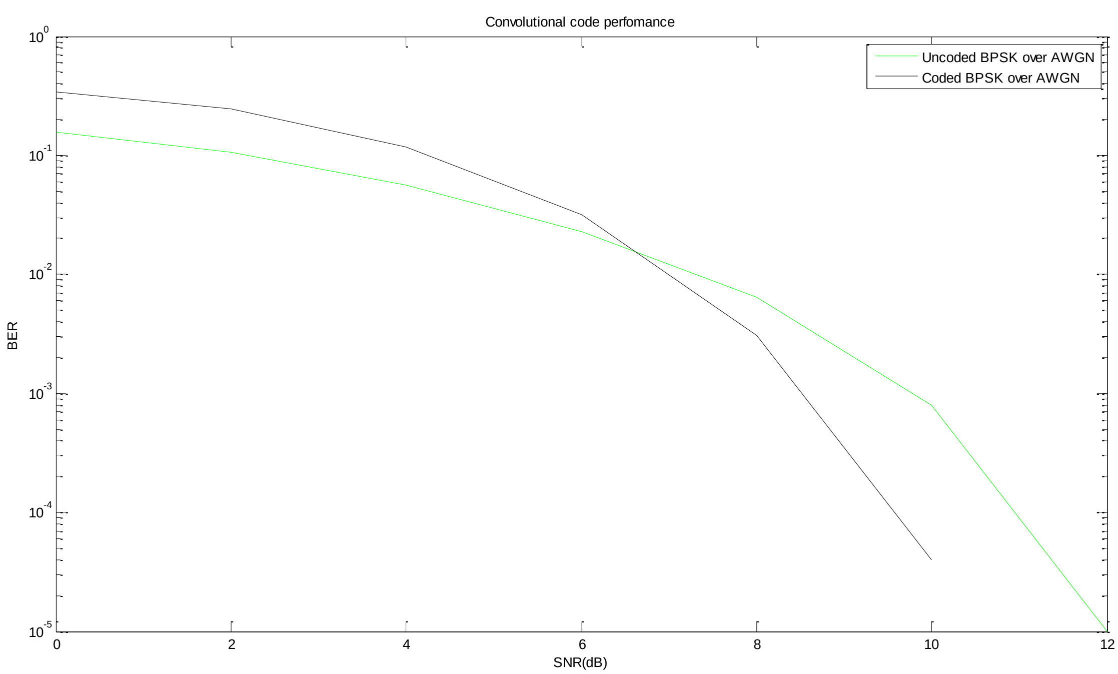

Fig. 4. Convolutional code and uncoded over AWGN

As shown in Fig. 4 and Table II, it can be noticed that Convolution code performance surpasses Hamming code at 6dB and uncoded AWGN at 8dB. To reach $BER = 10^{-4}$, uncoded BPSK under the AWGN channel requires $SNR \approx 11.5\ dB$ to reach $BER = 10^{-4}$. Meanwhile, Hamming code BPSK under the AWGN channel requires $SNR \approx 11.025\ dB$. Therefore, the coding gain of the ConvCode over Hamming code is $G = 11.5\ dB - 11.025dB = 0.475dB$. The ConvCode with BPSK under the AWGN channel with $SNR \approx 9.825\ dB$ achieves $BER = 10^{-4}$. Therefore, the coding gain of the ConvCode is $G = 11.5\ dB - 9.825dB = 1.675d$.

TABLE II
BER OF CODED AND UNCODED BPSK OVER AWGN CHANNEL

SNR	0	2	4	6	8	10	12
BER Uncoded	0.158783	0.103978	0.056610	0.023343	0.005833	0.000763	0.000035
BER Hamming Coded	0.229728	0.156318	0.084585	0.031743	0.006725	0.000638	0.000050
BER ConvCode	0.350980	0.245120	0.122900	0.030910	0.002950	0.000050	0.000000

C. Comparison over Different Wireless Channels

In this section, the unencoded, Hamming, and ConvCode encoded BPSK communication systems are compared with various channel models, such as AWGN and Fading. The performance of the system is measured from BER on SNR Starting from 0dB to 12dB.

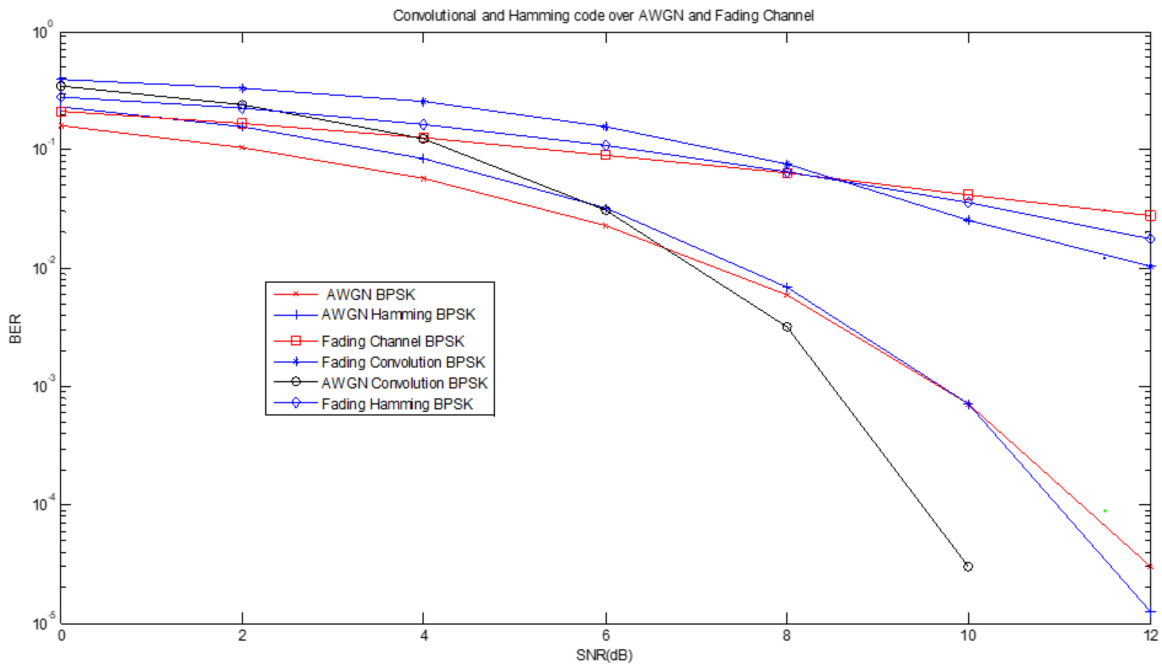

Fig. 5. Convolutional and Hamming code and uncoded over AWGN and Fading Channel

At SNR of 0dB to 6dB, BPSK unencoded in AWGN has the lowest BER while BPSK with ConvCode on the fading channel has the highest BER at SNR 0dB to 8 dB. At SNR between 8dB and 10dB, BPSK with ConvCode on the AWGN channel has the best performance. While at SNR between 10dB and 12 dB, unencoded BPSK demonstrates the worst performance as it registers the highest BER.

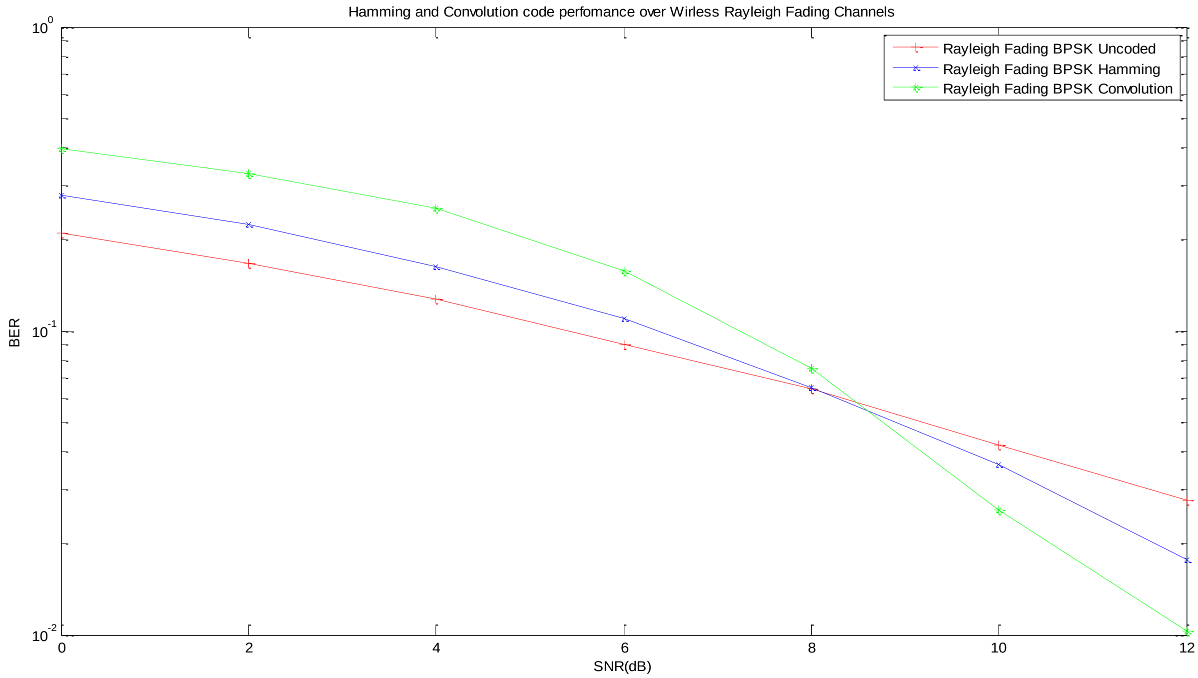

Fig. 6. Hamming and Convolutional code performance over Wireless Rayleigh Fading Channels

As shown in Fig. 6 and Table III, one can notice that ConvCode BER surpasses Hamming code between intervals 8dB and 10dB and uncoded Fading also between 8dB and 10dB. To reach $BER = 10^{-4}$, an uncoded BPSK under Fading Rayleigh requires $SNR \approx 38\,dB$. For the same BER, Hamming encoded BPSK under Fading Rayleigh requires $SNR \approx 24.715\,dB$. Therefore, the coding gain of the Hamming code over unencoded BPSK is $G = 38\,dB - 24.715dB = 13.285dB$. While to achieve $BER = 10^{-4}$, BPSK with ConvCode under Fading Rayleigh requires $SNR \approx 18.4dB$. Therefore, the coding gain of the ConvCode is $G = 38\,dB - 18.4dB = 19.6dB$.

TABLE III
HAMMING AND CONVOLUTION CODE AND UNCODED OVER FADING

SNR	0	2	4	6	8	10	12
BER Uncoded	0.210320	0.166300	0.126940	0.089960	0.064520	0.042070	0.027720
BER Hamming Coded	0.279098	0.223720	0.163390	0.110250	0.064873	0.036223	0.017665
BER ConvCode	0.396730	0.329390	0.254360	0.157130	0.075150	0.025710	0.010280

V. CONCLUSION

This paper presents the experimental results of the Binary Phase Shift Keying (BSK) communication system on the additive white gaussian noise (AWGN) channel and the Fading channel. To improve system performance, an error correction code (ECC) is used for encoding. The used ECC are convolutional code (ConvCode) and Hamming code. For $BER = 10^{-4}$, experimental results show that the coding gain of the ConvCode outperforms Hamming code under AWGN with the coding gain, $G = 0.475dB$. For the same BER, the coding gain of the ConvCode over unencoded BPSK is $G = 1.675dB$. Under fading channel, the coding gain of the Hamming code over unencoded BPSK is $G = 13.285dB$. Whereas the coding gain of the ConvCode over unencoded BPSK is $G = 19.6dB$. This indicates that the ConvCode preserves 19.6dB of SNR for BER=10^{-4}.

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