

Low SNR GMSK Synchronization Scheme for GSM Communication System

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Abstract

The high pace rise in the number of customers for communication systems and associated service provisioning has alarmed the requirement for certain optimal communication technique for optimal service of provisioning. The global system for mobile communication (GSM) has emerged as one of the most potential candidate to for communication systems. There is an inevitable need to enhance the key components of GSM systems such as, modulators and signal decoders. The assurance of these factors can lead low SNR communication in major application scenarios. Furthermore, ensuring efficient synchronization can be of great significance for GSM systems. In this paper, a highly robust and efficient system for low SNR, GMSK synchronization scheme has been developed for GSM system. The proposed joint synchronization scheme encompasses, symbol timing offset estimation, carrier frequency offset and carrier phase offset estimation scheme.

Index terms— GSM synchronization, GMSK modulation, symbol by symbol decoder, low signal to noise ratio.

1 Introduction

In the last few decades, the high pace increase in communication system and the well known success of the Global System for Mobile Communication (GSM) has expanded its fin across globe to serve approximate 4 billion users globally (2010) [1]. GSM has emerged as a potential communication technology across industrialized as well as non-industrialized countries and it has established itself as a reliable solution for sophisticated 3rd generation and 4th generation communication systems. Interestingly, in numerous countries GSM is the only cellular network accessible till. The recently introduced enhanced GPRS (EGRPS) system, GSM can facilitate data rates of up to 1.2 Mb/s by means of enhanced modulation approached like 16 QAM and 32 QAM, and effective synchronization schemes etc. in general, the data retrieval of higher order modulation EGPRS signals at certain adequate SNR levels needs higher end radio frequency (RF) transceivers having very low noise figure [2] with effective channel equalization and respective demodulation mechanism at receivers [3]. To facilitate the low cost characteristic of 2G devices, the Author : e-mails: smke.sam@gmail.com, mail2pshari@yahoo.com sophisticated and low complexity solutions are needed that might ensure efficient communication even at low SNR-levels and this is a key issue in the digital baseband of GSM based receivers. The efficiency of Gaussian Mean Shift keying (GMSK) based modulation technique has enhanced the GSM performance dramatically that enables it to deliver reliable solution even at lower SNR conditions with the input signal power level of -110 dBm that represents an SNR of approximate 7 dB. This is the fact that in communication system, numerous modulation approaches depicts varied functional tradeoffs between the noise tolerances and cost in addition to other interferences as well as spectral efficiency etc. GMSK is one of the most employed modulation technique which is a type of the MSK modulation approach. In GMSK modulation technique, the phase of the carrier signal is varied constantly using a Gaussian filter shaped antipodal signal. Being a member of MSK modulation technique family, GMSK possesses the modulation index of 0.5. The implementation of the Gaussian filter emphasizes the energy, thus permitting

lower band power output. The unvarying envelope permits GMSK modulation technique to be comparatively less vulnerable to the fading channel and hence an ideal mechanism for GSM communication.

The symbol-by-symbol (SBS) demodulator [4] is considered to be a robust candidate for GMSK because of its robustness towards efficient decoding and less complex architecture as compared to Viterbi Algorithm (VA). To design an efficient demodulator, there is an inevitable need for perfect synchronization [4]. This paper intends to explore an efficient synchronization approach for GMSK modulation in GSM system.

Synchronization states a multi-parameter estimation issue that comprises the synchronization of key parameters such as symbol timing offset, carrier frequency offset and carrier phase offset. A number of researches have been done so far to enhance synchronization. In general, the approaches like maximum-likelihood or maximum-a-posteriori based joint estimation are of theoretical significance but are typically intricate in implementation [5]. Taking into consideration of the operational complexity and robust environment requirement in GSM communication system, fast synchronization algorithms permit low complexity. In this paper, we have emphasized on feed forward synchronization paradigm to alleviate the issues of hang-up problem that is common in major feedback based approaches [6]. An effort was made to implement complete feed forward scheme for joint carrier offset estimation and symbol timing offset estimation for MSK signals [6]. Unfortunately, it can't implement narrow-band GMSK signals due to poor performance [7]. An approach for joint frequency and timing recovery was suggested in [5] using MSK modulation technique that incorporated an estimation approach by combining multiple correlation functions having varied time lags. Unfortunately, this approach turns out to be much complicated for GSM implementation. One more effort was made in [8] where a combined time and phase synchronization approach was proposed, which was employed with MSK signals.

Then while, the influence of the carrier frequency offset could not be examined. A well calibrated synchronization scheme for GMSK can facilitate optimal performance and can be a flexible alternative for digital implementation [9]. The existing systems for synchronization in GSM mobile communication are not sufficient while considering noise, power and mobility constraints. In this paper, a low SNR GMSK synchronization scheme has been proposed for GSM communication system. A brief of the implemented GSM system is given in the following section.

2 II.

3 GSM Transceiver: a Glance of System Model

This section discusses the implementation of GSM system and its synchronization. An overview of the proposed GSM model is presented in Figure 1. In this paper, we have used burst mode transmission for GSM simulation and a single GSM data block with 260 random bits has been generated. The generated random data bits have been feed as input data stream to the channel encoder and then interleaver. The interleaved data are then processed by a multiplexer (MUX) that splits the incoming sequence to form a GSM normal burst. Since, the burst type of input data requires certain training data sequence. In this model a 26 bit training signal has been introduced. Generating the GSM burst data the multiplexer returns it to the GMSK modulator that performs a differential encoding of the incoming burst to form a Non Return to Zero (NRZ) sequence, which is then subjected for GMSK modulation. The resulting signal is presented in terms of a complex baseband signal comprising real and imaginary signals, $x(t)$ and $y(t)$ respectively. In our simulation model, the number of samples per data bit has been defined in terms of the oversampling rate (OSR). In our developed model OSR of value four (OSR=4) has been used. Considering realistic simulation environment, in our simulation Gaussian and Raleigh multipath fading channel has been used for simulation.

4 Random Bit-Generator

Channel

On the receiver side of the developed GSM model, three operational blocks have been developed. These are demodulator, demultiplexers, and channel decoder. As illustrated in Figure 1, the GMSK demodulator receives a GSM received burst by means of a complex baseband representation. On the basis of this data sequence, OSR, training sequence, and the desired length of the receiving filter, the GMSK demodulator estimates the most probable bit sequence. Thus, the demodulated sequence is then employed as input to the demultiplexer where the bits are split in order to retrieve the actual data bits from the sequence. At this stage the other signal bits such as the control bits and the training sequence are released. Performing demultiplexing, the channel decoder has been done. In this paper the signal by signal (SBS) decoder has been implemented on the reconstructed sequence delivered by the channel decoder. This paper focuses on a joint synchronization paradigm for GSM system and has implemented SBS MAP decoder for data retrieval. The following sections focus on the implemented modulation, synchronization and decoding technique. The overall BER analysis has exhibited that the proposed joint synchronization approach enhances the performance of GSM system.

5 III. GMSK modulator

Gaussian Minimum Shift Keying (GMSK) algorithm has been the most suitable approach of the continuous phase modulation (CPM) mechanism. The higher bandwidth efficiency and constant envelope modulation feature

strengthens GMSK modulation for GSM systems ($B=0.3$) in mobile communication systems. Since last few decades CPM scheme has been explored to enable higher communication efficiency, better spectrum utilization and power efficiency. Primarily, CPM schemes are categorized into two broad types, called full response and partial response on the basis of the fact whether the modulation frequency pulse is of single symbol duration or longer. MSK is one of the popular types of a full response spectrally efficient modulation scheme. On the other hand, GMSK scheme is the most generic type of modulation scheme due to higher spectral efficiency and constant envelope modulation characteristics. GMSK modulation scheme has $h=0.5$ partial response CPM scheme originated from MSK with the addition of baseband Gaussian filtering implemented to the identically and distinctly distributed random rectangular pulse shaped input signal earlier to the frequency modulation of the carrier signal. The following section discusses the GSM receiver architecture and the proposed synchronization scheme at the GSM receiver.

IV.

6 GSM Receiver Signal Model

In our implemented GSM model, the complex envelope of the received baseband GMSK signal is obtained as:

where ω_c represents the carrier frequency offset, ϕ_c represents the carrier phase offset and t_0 states for symbol time offset. The noise component $n(t)$ states the complex valued Gaussian and Rayleigh fading channel noise with real and imaginary signal components, individually possessing two-sided power spectral density given by $S_n(f) = \frac{N_0}{2}$ where N_0 represents the received signal energy per symbol. The transmitted signal $s(t)$ is given by $s(t) = \sum_{k=-\infty}^{\infty} a_k e^{j\phi_k} \delta(t - kT)$ (2)

Where ϕ_k represents the information bearing phase. Here, $a_k = \pm 1$ refer the data symbols having the values of ± 1 with equal likelihood. The variable T represents the symbol period while $\delta(t)$ states the phase pulse of the modulator. It is in fact, the integration of the frequency pulse $\delta(f)$ (3). In order to facilitate the estimation of symbol time offset, carrier frequency offset and carrier phase offset, $s(t)$ in the n th duration $(t - nT)$ can be represented as follows [10]: $s(t) = \sum_{k=-\infty}^{\infty} a_k e^{j\phi_k} \delta(t - kT)$ (3)

and $\delta(t) = \frac{1}{T} \text{rect}\left(\frac{t}{T}\right)$.

(4)

Considering (2), it can be found that the baseband signal $s(t)$ can be represented in a linear form [10] as depicted below: $s(t) = \sum_{k=-\infty}^{\infty} a_k e^{j\phi_k} \delta(t - kT)$ (5)

The probable values of the parameter a_k can be ± 1 . In our developed model, we have initialized $a_0 = 1$, without any loss of generality by considering that there is no data transmission to time $t = 0$ and $a_1 = 1$. In our proposed model, the nonlinear GMSK signal $s(t)$ has been decomposed into sums of amplitude modulated (AM) pulses in two dimensions and the two pulse shaping filters $\delta(f)$ and $\delta(t)$ have been employed. The impulse shaping filter has been obtained as [10] $\delta(f) = \frac{1}{T} \text{rect}\left(\frac{f}{2T}\right)$ for $f \in [0, 3/T]$ and $\delta(t) = \frac{1}{T} \text{rect}\left(\frac{t}{T}\right)$ for $t \in [0, T]$,

where the variable $\delta(f)$ refers $\delta(f) = \cos(\pi f T)$, $\delta(t) = \text{rect}\left(\frac{t}{T}\right)$, $\delta(f) = \frac{1}{T} \text{rect}\left(\frac{f}{2T}\right)$ (6)

In case of the GMSK signals, $\delta(f)$, which is the frequency pulse represents the convoluted output of a low-pass Gaussian filter having a rectangular pulse in the duration of T and magnitude $1/(2T)$. Mathematically, it is represented as follows: $\delta(f) = \frac{1}{T} \text{rect}\left(\frac{f}{2T}\right)$ (7)

In (7), $\delta(f)$ represents the 3 dB bandwidth of the implemented Gaussian low-pass filter and $\delta(t) = \frac{1}{T} \text{rect}\left(\frac{t}{T}\right)$ (8)

Here, the sampler of the received signal is denoted by $s[n]$ while, nT represents the noise at time nT is nT + nT , where N signifies the OSR value and $T_s = T$ sampling time. In fact, the linear presentation of the GMSK scheme is equivalent to the PAM modulation except with the inclusion of inter-symbol interference (ISI). In the case of no ISI, the signal may be reduced to the MSK signal. These features motivate us to develop certain enhanced synchronization scheme for GMSK by amalgamating these approaches for MSK so as to reduce noise of interference to a significant level. In this paper, we have proposed a joint synchronization paradigm to enhance BER performance. A brief of the proposed synchronization schemes for symbol timing, phase and frequency is discussed in the following sections.

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Thus, the right-hand side of (24) is obtained by $?? \text{ } ??[?? \text{ } [??|??(??)] = ?? \text{ } ??|?? \text{ } ???? \text{ } ????1, ? \text{ } , ? ? 1 \text{ } , ? ? 0 \text{ } ???? (??) = ? \text{ } ?? \text{ } ???? \text{ } ????1 \text{ } ?? = 0 \text{ } ?? \text{ } ?? \text{ } 1 [?? \text{ } ?? \text{ } |?? \text{ } ?? \text{ } 1 (??)](25)$

Where $?? \text{ } ?? \text{ } (??) = ???? \text{ } ?? \text{ } , ? \text{ } , ? ? 1 \text{ } , ? ? 0 \text{ } ? \text{ } , ??(??)(26)$

Here, the estimation of the factor $?? \text{ } ???? \text{ } | ? ? \text{ } ?? \text{ } 1 [?? \text{ } ?? \text{ } |?? \text{ } ?? \text{ } 1 (??)]$ depends on the channel model and modulation scheme, which in our proposed system are Gaussian and Rayleigh fading channel and GMSK modulator respectively. Now, here we consider that the computation does rely primarily on $?? + 1$ symbols associated with a trellis possessing $?? \text{ } ??$ states. During the formation of trellis and for any trellis branch, the individual feasible symbol at certain specified time is exclusively characterized by the starting and ending states of the subsequent branch at that time. Hence, in our proposed SBS algorithm there is a 1-to-1 connection between the input symbols sequence $??(??) = \{?? \text{ } 1 (??) \text{ } ? \text{ } ?? \text{ } ????1 (??)\}$ and the state transition sequence $??(??) = \{(?? \text{ } ? \text{ } , ??) \text{ } 0 (?? \text{ } ? \text{ } , ??) \text{ } 1 (?? \text{ } ? \text{ } , ??) \text{ } ????1 \}$, where $\{(?? \text{ } ? \text{ } , ??) \text{ } ?? \}$ states the initial and end (i.e., starting and ending) states for $??$ th hypothesis at certain time $??$. In our developed algorithm $?? \text{ } ?$ at time $??$ is equivalent to that of $??$ at time $(?? \text{ } ? \text{ } 1)$. Consider, $?? \text{ } ?? \text{ } (?? \text{ } ? \text{ } , ??) = ? \text{ } ?? \text{ } ???? \text{ } ??(??+1)1 \text{ } ?? = ???? \text{ } ?? \text{ } ?? \text{ } 1 [?? \text{ } ?? \text{ } |?? \text{ } ?? \text{ } 1 (??)](27)$

Now, substituting equation (27) into (25) gives

Where $\{?? \text{ } ?? \text{ } ((?? \text{ } ? \text{ } , ??))\}$ is independent of the hypothesis $??$ as the estimation of $?? \text{ } ???? \text{ } ?? \text{ } ?? \text{ } 1 [?? \text{ } ?? \text{ } ?? \text{ } ?? \text{ } 1 (??)]$ depends only on $?? + 1$ successive symbols. Now taking into consideration of the equations, (23, 24, 28), the numerator of (22) becomes $?? \text{ } ???? \text{ } ? = ??(??) \text{ } ? \text{ } . ???? (?? \text{ } ? = ??(??)) = ? \text{ } ???? \{?? \text{ } ? \text{ } ?? = ?? \text{ } ?? (??) \} . ?? \text{ } ?? \text{ } (?? \text{ } ? \text{ } , ??) \text{ } ????1 \text{ } ????1 (29) == ? \text{ } ? \text{ } ?? \text{ } (?? \text{ } ? \text{ } , ??) \text{ } ????1 \text{ } ????1$ Where $? \text{ } ?? \text{ } (?? \text{ } ? \text{ } , ??) = ???? \{?? \text{ } ? \text{ } ?? = ?? \text{ } ?? (??) \} . ?? \text{ } ?? \text{ } (?? \text{ } ? \text{ } , ??)$.

As the sequence of multiplicative branch weights is a function of the hypothesis $??$, individual multiplicative branch weight $? \text{ } ?? \text{ } (?? \text{ } ? \text{ } , ??)$ are not functions of the hypothesis $??$ due to the reason that the individual branch is connected to certain specific symbol and hence all those hypotheses which pass through certain specific branch encompasses the specific symbol in that duration. Thus, finally, the state transition probability, as defined in equation (21) becomes $\text{Pr}\{?? \text{ } ????1 = ?? \text{ } ? \text{ } ; ?? \text{ } ?? = ???? \} = ? \text{ } ? \text{ } , ? \text{ } ?? \text{ } (?? \text{ } ?? \text{ } (??)) \text{ } ????1 \text{ } ?? = 0 \text{ } ???? \text{ } ?? \text{ } (?? \text{ } ? \text{ } , ?? \text{ } ??) \text{ } ? \text{ } ? \text{ } ?? \text{ } (?? \text{ } ?? \text{ } (??)) \text{ } ????1 \text{ } ?? = 0 \text{ } ?? (30)$

Where $?? \text{ } ?? \text{ } (??)$ represents the $??$ th element of the hypothesized path through the trellis $??(??)$. For the purpose of signal demodulation in GSM (GSM Standard GSM 05.03), we are interested in estimating $???? \{?? \text{ } ?? = ???? \}$ where $??$ refers one of the Q-ary input symbols, which is input to the SBS MAP demodulator. In our proposed decoder, it has been estimated by adding the overall transition probabilities corresponding to those all branches allied with the symbol $??$ at certain time $??$. In this paper, computations based on soft as well as hard decisions based demodulation has been done, where decoding using hard decision has demonstrated better performance as compared to soft decision process. The final decoded signals have been used for bit error ratio analysis. The results obtained for BER analysis with different SNR and E_b/N_0 are discussed in the following section.

12 VI.

13 Results and Discussion

In this paper, a novel synchronization scheme for Gaussian Minimum Shift Keying (GMSK) algorithm has been developed for low SNR, GSM system. To simulate GSM system, a burst mode transmission scheme has been developed for GSM simulation, where a single GSM data block with 260 random bits has been employed as input data sample. The overall simulation model has been developed using MATLAB software and GSM 05.05 (3GPP TS 05.05 standard) standard. The overall developed transmitter and receiver components comprises data generator, differential coding, interleaver, multiplexer, GMSK modulator and GMSK demodulator, demultiplexer, de-interleaver, SBS based decoder, respectively. Here for simulation, $BT=0.3$ (GSM standard), oversampling rate (OSR) of 4 and sample time $?? = 3.692 \times 10^{-6}$ has been considered. In this paper we have proposed a joint synchronization scheme that intends to synchronize symbol time offset, carrier frequency offset and carrier phase offset altogether. Unlike other GSM synchronization schemes, in this paper we have used three variables (time, frequency and phase) based synchronization altogether. In this paper, we have developed a symbol by symbol (SBS) maximum a posteriori probability (MAP) algorithm, named SBS-MAP algorithm for signal decoding, which has been followed by Bit Error Ratio (BER) analysis. Figure ?? represents the BER performance of our proposed GMSK modulation based synchronization scheme for GSM system. Figure ?? depicts signal to noise per bit (E_b/N_0) for the developed system. GSM 05.05 and other standards for GSM communication system suggests low SNR up to 7dB for mobile communication. These hard decision based SBS decoding affirms better performance. Following figure affirms the standard requirements (Figure ?? and Figure ??) for GSM systems. Figure 4 represents the BER performance with varying block size or data frame, where the results obtained assures better performance with decreasing SNR slope as per increase in number of data blocks.

14 Conclusion

Being a very potential candidate for mobile communication system, GSM has emerged with varied communication facilities and supporting services. The ultimate service qualities of GSM systems are undoubtedly influenced by the efficiency of modulation techniques and signal decoding. In addition, synchronization of signals can be a

significant approach to enhance efficiency of the communication system. Considering these as motivation, in this paper, a Gaussian Multiple Shift Keying (GMSK) synchronization scheme has been developed for GSM systems. The novelty of this paper is the implementation of symbol time offset estimation, carrier frequency offset estimation and carrier phase offset estimation altogether for an efficient synchronization. Furthermore, the implementation of symbol by symbol (SBS) demodulator for signal decode has also resulted better performance. The developed burst mode transmission paradigm based GSM system and its efficient synchronization has enabled it to be efficient for low SNR environment. In future, the comparative performance analysis of the proposed scheme can be done with other modulation techniques and synchronization approaches for GSM systems.



Figure 1: Figure 1 :

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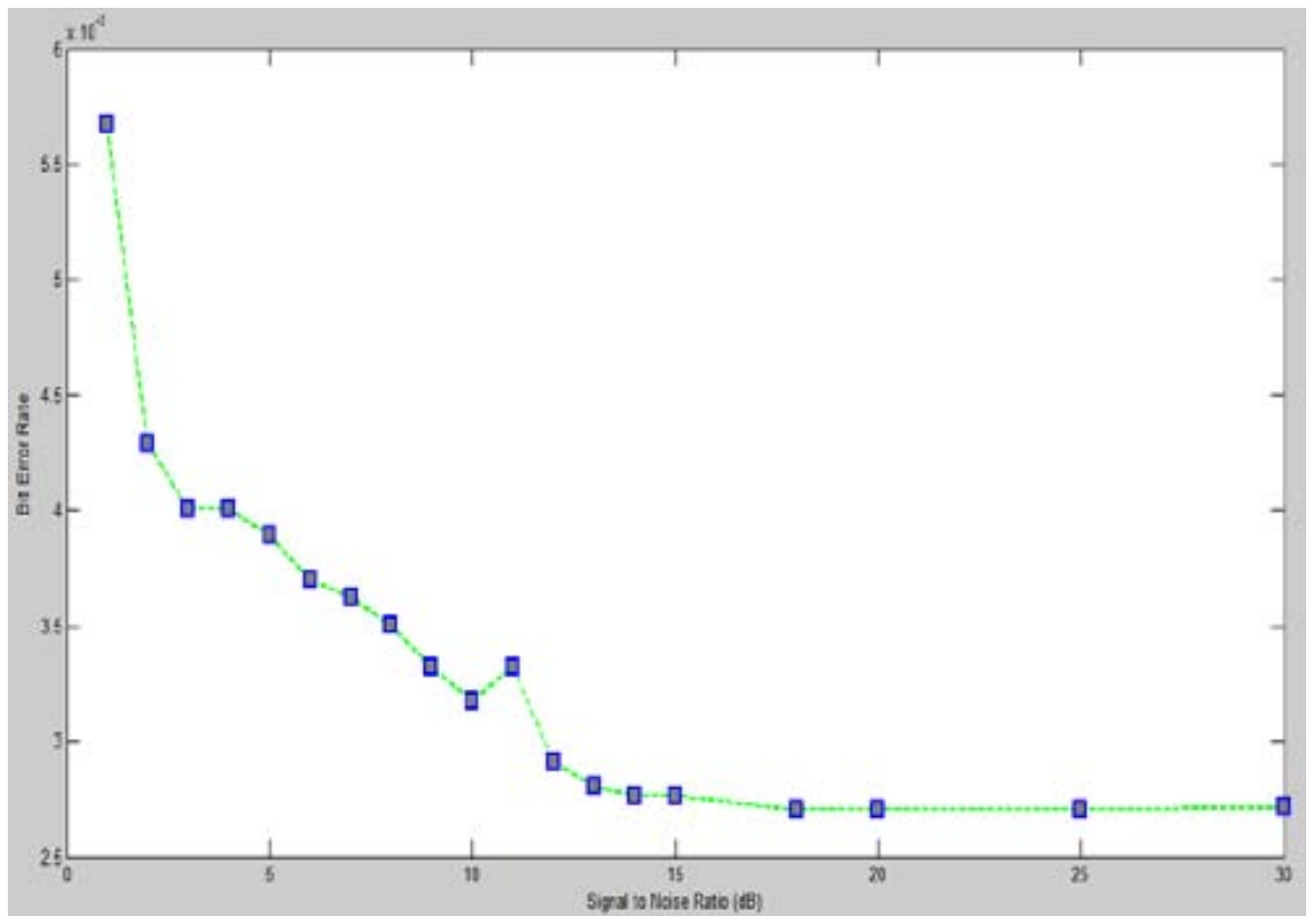


Figure 2:

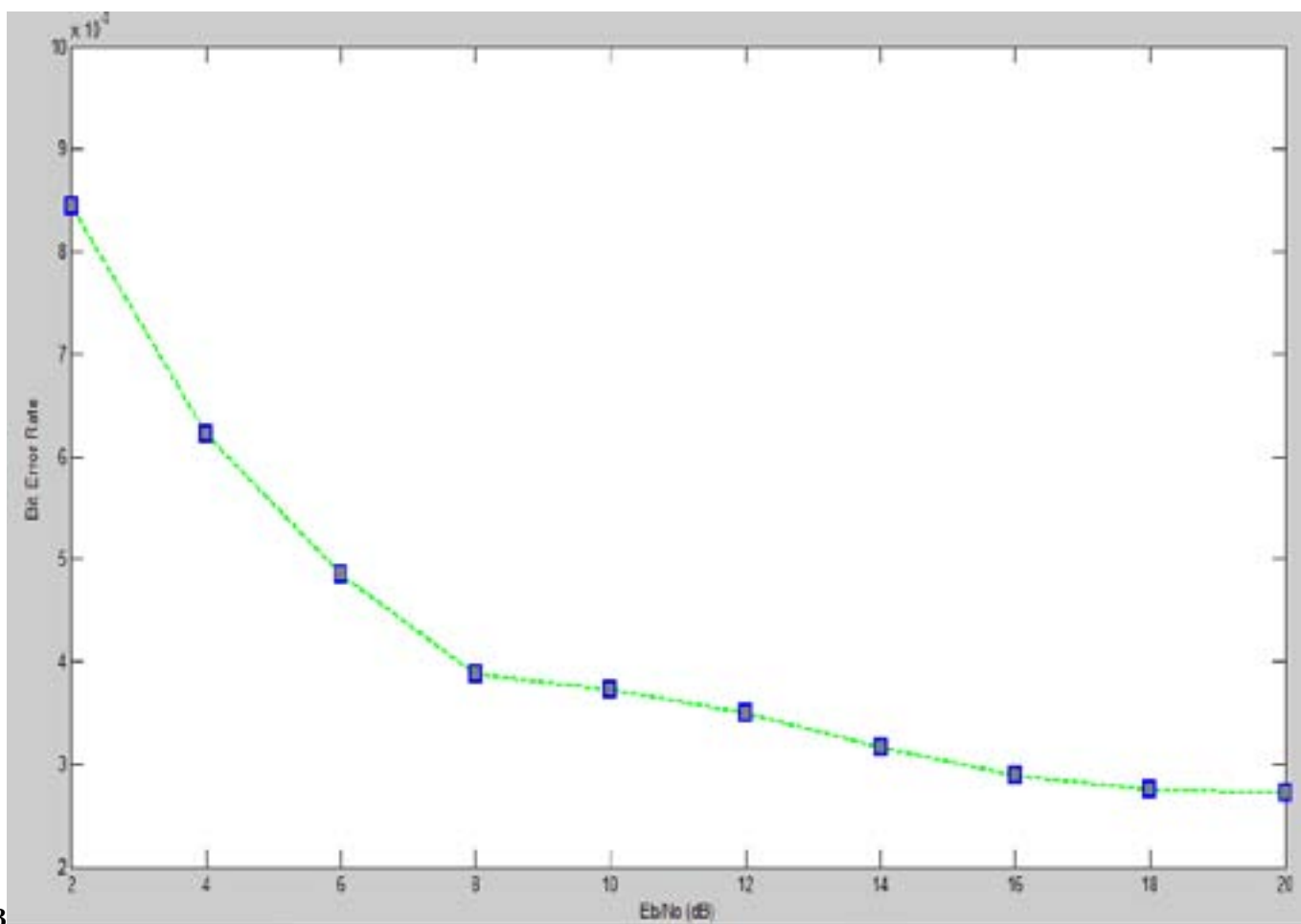


Figure 3: Figure 2 :FFigure 3 :

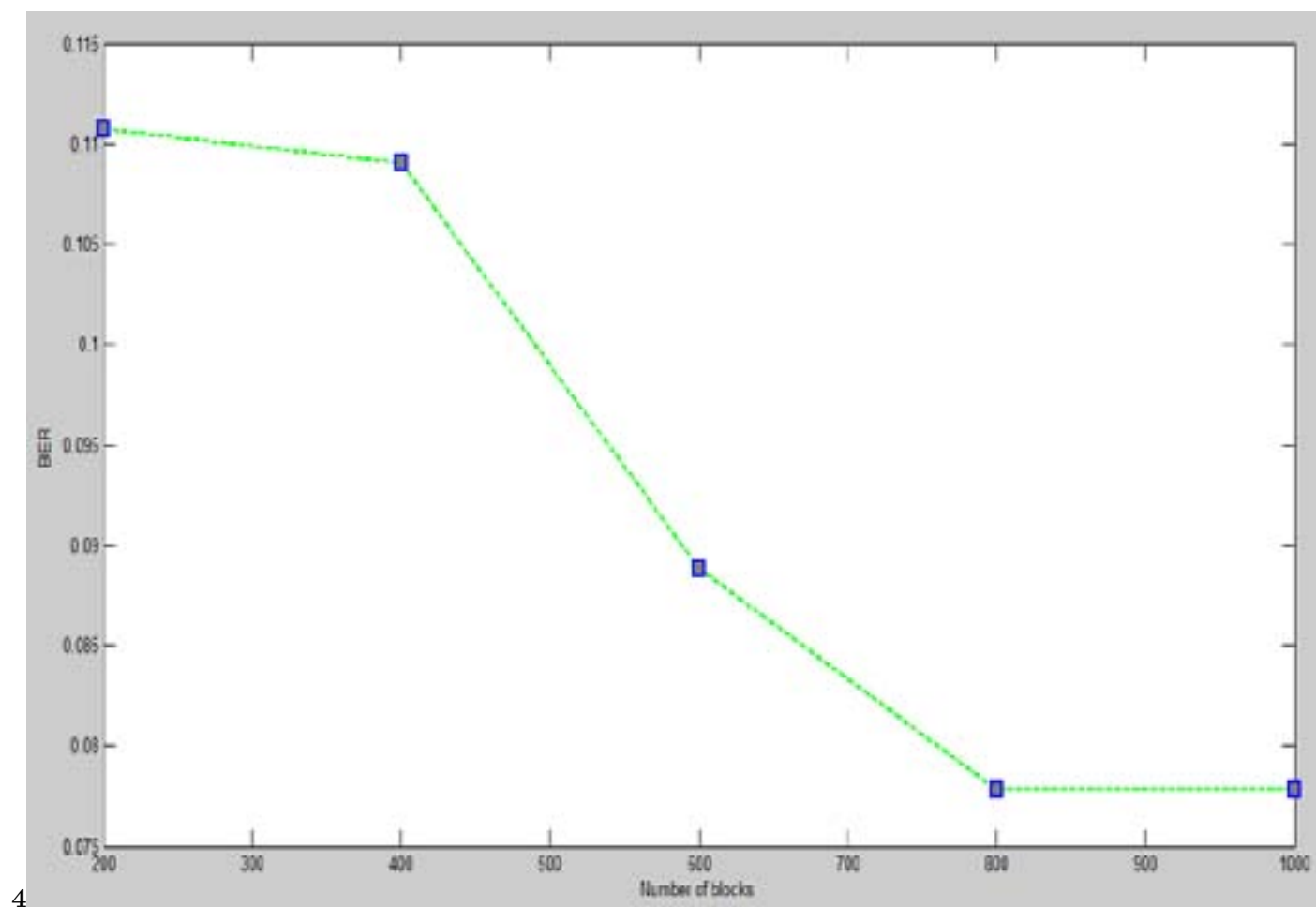


Figure 4: Figure 4 :

B? Transition Probabilities of the states

Q? Number of data symbols

N?The length of data block, in symbol periods;

M? number of states in trellis at a given time;

K?hypothesis;

R?number of samples/symbol

T?discrete-time index, in symbol periods;

U? transmitted symbols; X? transmitted symbol samples; Y? received symbol samples;

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Figure 5:

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