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Performance analysis of PSK systems with phase error in fading channels: A survey

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ABSTRACT

Communication system designers need to formulate an accurate and thoroughly reproducible error model for wireless mobile channels in order to assess the quality of communication with different modulation schemes. The task is relatively easy when an ideal situation is assumed, and is covered exhaustively in standard text books. However, the random time-varying nature of radio propagation renders estimation of different channel state information (CSI) very difficult and when these non-idealities (e.g. imperfect phase/frequency/timing information) are considered, the formulation complexity increases manifold. In this paper, we have set our attention on phase shift keying (PSK), which suffers mostly from phase synchronization error when proper CSI is not available at the receiver. The article surveys various error modelling methods for a PSK system operating over a slow flat Nakagami-*m* distributed wireless fading channel perturbed with additive white Gaussian noise (AWGN) in the presence of phase error. The phase distortions are considered to be random, unbiased, i.e. having zero mean, and may be represented by either Gaussian or Tikhonov distribution. We also provide a novel approach to classify these schemes that are surveyed, and summarize the major contributions of related works. Further, we identify the method that requires lesser mathematical operations and thus proves to be less complex, more stable and accurate than others. Apart from this, simple alternative approaches for calculating analytical bit error rate (BER) through Hermite's method of integration for Gaussian distributed phase error and through moment generating function (MGF) for Tikhonov distributed phase error have been proposed. Both of these methods have wider applicability, are able to furnish reproducible results, and show significant improvement in accuracy regarding theoretical BER calculation as seen from the graphical comparisons. Extensive Monte Carlo simulations were performed to validate the theoretical results.

1. Introduction

To cope with an ever increasing demand for higher data rates, M-ary schemes are frequently used in current wireless systems. The coherent M-ary schemes provide better error performance or require a lesser signal to noise ratio (SNR) to achieve a target BER when compared to their non-coherent or differentially coherent counterparts. Out of the coherent schemes, M-ary PSK (MPSK) is often preferred over M-ary frequency shift keying (MFSK) due to better bandwidth efficiency and over M-ary quadrature amplitude modulation (MQAM) as MPSK has a constant envelope which facilitates use of efficient non-linear power amplifiers [1]. Despite these advantages, PSK systems suffer from various problems, the most prominent one being imperfect phase estimation at the receiver.

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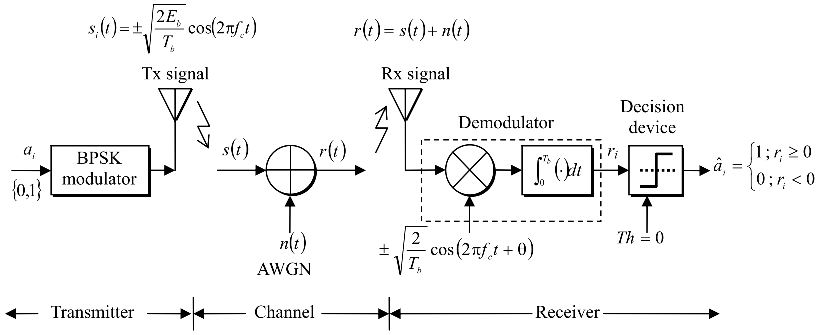

Fig. 1. Generic transmission model for BPSK modulated signal perturbed with AWGN and phase error.

Apart from synchronization errors, the wireless channels are subjected to random multipath fading, and Nakagami-m distribution serves as the most general distribution to characterize such fading effects. For PSK transmission through wireless medium, fading and phase error are the two major factors responsible for signal degradation, and error performance evaluation of PSK with Nakagami-m fading and phase error is of considerable interest. This can be substantiated by citing error performance characterizations of PSK systems with imperfect phase recovery by different researchers in the last five decades [2–11].

In our paper, a detailed survey as well as a comparative study of the earlier works related to BER calculation of PSK over AWGN/Nakagami-m fading channel with imperfect phase estimation has been presented. Two newly derived approaches, to tackle a more generalized form of the phase jitter problem, have also been incorporated. The results are derived through Hermite's method of integration for Gaussian distributed phase error and through simple MGF method for Tikhonov distributed phase error. Later, the MGF method has been extended through a weighted sum approach to derive symbol error rate (SER) of general MPSK systems under phase error. The corresponding BER/SER plots show perfect overlapping with simulation results. Moreover, the associated percentages of error (with respect to direct numerical integration) are much lesser compared to previous works.

The rest of the paper is organized as follows. Model of a system using binary PSK (BPSK) with imperfect phase estimation and operating over a wireless fading channel is detailed in Section 2. In addition, this section also describes the Gaussian and Tikhonov distribution functions for modelling the phase error random variable (RV) and introduces generic integral forms for calculation of error rates. In Section 3, the related works in this field are discussed and a comparative study between the corresponding approaches is made available in graphical form on the basis of percentage of error. The overall simulation methodology, giving more stress on different algorithms for generating Tikhonov PDF, is also explained. Two simpler approaches for BER calculation with both Gaussian and Tikhonov distributed phase error are presented next, in Sections 4 and 5 respectively. In Section 6, SER of MPSK for Nakagami-m fading channel models has been derived, assuming Tikhonov distributed phase error. The paper finally ends in Section 7 with some concluding remarks and a discussion on future scope of the work.

2. Modelling phase error

2.1. Transmission model in the absence of channel fading

PSK is a digital modulation scheme that uses a finite number of phases; each assigned to a unique pattern of binary bits. An MPSK signal set is defined as

$$s_j(t) = \sqrt{\frac{2E_s}{T_s}}\cos\left(2\pi f_c t + \varphi_j\right); \quad 0 \leq t \leq T_s,\ j = 1, 2, \ldots, M \tag{1}$$

where f_c is the carrier frequency chosen in a way such that it becomes an integer multiple of the symbol rate $R_s\,(= 1/T_s)$, and $\{E_s, T_s\}$ denotes energy and duration of any transmitted waveform respectively. Usually M is chosen as a power of 2, i.e. $M = 2^p; p =$ integer. Accordingly, the binary data stream is divided into p-tuples and each of them is represented by a symbol $\left\{s_j(t)\right\}_{j=1}^{M}$ with a particular initial phase, $\varphi_j = (2j-1)\pi/M$.

Fig. 1 illustrates block diagram of a communication system employing BPSK ($M = 2$) modulation. The effects of both AWGN and phase error are shown separately. The BPSK modulator in the transmitter (Tx) operates on binary information $a_i = \{0, 1\}$ and during the signalling interval $iT_b \leq t < (i+1)T_b$ produces an output signal

$$s_i(t) = \pm\sqrt{\frac{2E_b}{T_b}}\cos(2\pi f_c t); \quad iT_b \leq t < (i+1)T_b \tag{2}$$

where the sign of $s_i(t)$ is directed by the current input binary bit a_i, i.e. positive for '1' and negative for '0' and E_b, T_b denote the bit energy and bit duration respectively. The transmitter sends the modulated signal $s(t) = \sum_{i=-\infty}^{\infty} s_i(t - T_b)$ through a transmission medium where it is perturbed with AWGN and a noisy replica of the transmitted signal, $r(t)$, reaches the receiver (Rx). At the receiver, the received signal is first multiplied with the carrier. Ideally the carrier at receiver should be synchronous with the carrier at transmitter end, i.e. the