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Particle filter based automatic frequency control scheme by combining the two-step structure

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Abstract

In this paper a new automatic frequency control (AFC) scheme was proposed, which could be used for the receiver of low earth orbit (LEO) satellite communication system in continuous transmitting scenario. By employing the time varying characteristic of particle filter technique, the new scheme combined the preamble based estimating step and data based estimating step to provide initial probability density recursively. Theoretical analysis proved that the proposed AFC scheme could provide better performance than the two-step scheme. The same conclusion was achieved by computer simulations with the criteria of root-mean square (RMS) frequency estimating performance and bit error rate performance.

Keywords satellite communication, Doppler effect, automatic frequency control, particle filter

1 Introduction

Global seamless personal communications is one of the most important characteristics of the next generation communication system. Low earth orbit satellite communication system has been considered as an important way to meet this requirement due to its short propagation delay and low propagation path loss [1]. However, its performance suffers from large and time-variant frequency offset caused by the satellites' fast speed and the jitter of receivers' oscillators, which is often larger than symbol rate.

The classical approach to cope with frequency offset and its time variation is analog implemented second-order or higher order phase locked loop (PLL) [2]. In addition, several efficient schemes have been developed to combat frequency offset, such as a dual-pilot tone calibration [3] and the method using discrete Fourier transform [4]. Specifically, the authors in Ref. [5] proposed a two-step Kalman filter based frequency control scheme to remove large frequency offset in burst transmitting scenario for LEO receiver. The first step called course estimator coarsely estimates and compensates the Doppler offset during preamble while the second step called fine estimator removes the residual frequency offset by employing the decision feedback loop approach during user data packets. However, the performance of the second step may suffer from the hang-up phenomena. Furthermore, due to the limitation of Kalman filter technique, the channel noise should be additive white Gaussian noise. The authors in Ref. [6] exploited differential quadrature phase shift keying (DQPSK) modulation to cope with the hand-up phenomena and particle filter technique to perform frequency offset estimating in both the two steps while retaining the two-step structure. Recently, there has been a surge interest in particle filter for solving sequential Bayesian estimation problems [7], especially for non-linear and/or non-Gaussian model. The growing popularity comes from that particle filter is often the only viable computing techniques in the situations which should be processed sequentially. The uniform convergence of this technique w.r.t its initial distribution was proved in Ref. [8] under rather strong assumptions. And in Ref. [9] the convergence was proved under weaker assumptions. Due to the advantage of particle filter technique, the channel

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noise considered in Ref. [6] can be non-Gaussian. Literature [6] also showed that the new scheme can achieve better performance than Ref. [5] in accuracy.

The two-step structure exploited by Refs. [5–6] makes it necessary to reset both the course and fine estimators for every packet, thus the accuracy is lost because of the absentation of the initial probability density function (PDF) of frequency offset for both the two estimators. Furthermore, the first several symbols of the data packets suffer from larger frequency estimating error. Therefore, the estimating performance could be improved by providing the initial PDF to each estimator. This paper proposes a new frequency offset estimating scheme which combines the above coarse and fine estimators to reach this motivation in continuous transmitting scenario. The new scheme essentially passes the estimated initial PDF iteratively between the coarse estimator and the fine estimator. Our study shows the proposed scheme outperforms the two-step scheme, especially during the first several symbols in data based estimating, and extra computation complexity is unnecessary.

The organization of this paper is as followers. Sect. 2 describes the system model and the channel model. Sect. 3 presents the basic frequency estimating principle in the context of DQPSK modulation. Then, the particle filter technique and the proposed AFC scheme are illustrated in Sect. 4 and Sect. 5, respectively. Sect. 6 discusses the simulation results. Sect. 7 concludes this paper.

2 System model

2.1 Transmitter and channel

The block diagram shown in Fig. 1 is the transmitter model exploiting DQPSK. The information bits is differentially encoded, and then modulated by Quadrature phase shift keying (QPSK) modulator with symbol rate R_s. Then, the modulated signal is shaped by the root Nyquist filter. A preamble with N QPSK symbols is added at the ahead of each user data packet. Finally, the user data packet with preamble is up-converted to carrier frequency f_c.

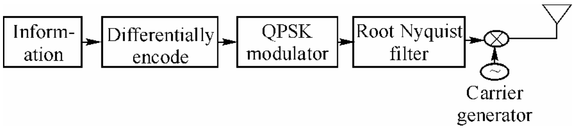

Fig. 1 Transmitter model

The LEO satellite communication channels hereafter are modeled as an additive white Gaussian noise channels with frequency offset. However, thanks to the non-Gaussian advantage of particle filter technique, the noise can be non-Gaussian, e.g., additive impulsive noise [6].

The frequency offset of an LEO channel can be divided into a constant term and a time-variant term

$$f(t) = f_0 + n_f(t) \tag{1}$$

where f_0 is the constant term and $n_f(t)$ is the time-variant term which is assumed to be zero-mean additive Gaussian white noise with variance δ_f^2.

2.2 Receiver

Fig. 2 shows the block diagram of the receiver employing differential detection (DD). The received signal is firstly filtered by the band pass filter (BPF) with bandwidth W centered at nominal center frequency f_c, then down-converted by local carrier generator and band-limited by a low pass filter (LPF) followed by analog-to-digital conversion (ADC). The output digital stream is split into two directions as shown in Fig. 2. During preamble the received signal is differential detected and then inputted into the estimator which coarsely evaluates the frequency offset. At the end of the preamble, the estimator starts to control the first compensator to compensate the Doppler effect and switches into data based estimating mode. The output of the compensator is shaped by the shaping filter with ideal symbol timing. Then the data stream is passed though differentially decoder, and is departed into two directions, one of which is fed into the nonlinear translator. After nonlinear translator, the QPSK modulation is removed, and the data stream is inputted into the estimator to perform data based frequency offset tracking. During data stream, the estimator controls the second compensator to delete the residual Doppler frequency offset and also controls the first compensator for coarsely compensating.

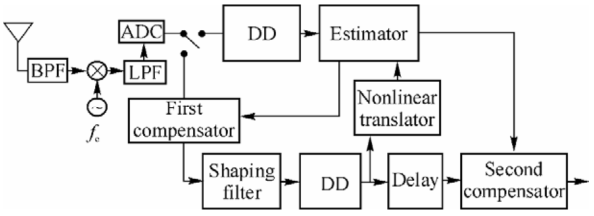

Fig. 2 Receiver model

As discussed above, the estimator shown in Fig. 2 can