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Joint time-frequency synchronization and channel estimation in two-way relay networks

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Abstract

This work investigates joint time-frequency synchronization and channel estimation in two-way relay networks (TWRN) that utilize amplify-and-forward (AF) relay strategy. A two-way transmission model for joint time-frequency synchronization and channel estimation in TWRN is provided. Due to the high dimension and complexity of the model, the maximum likelihood (ML) algorithm is over complex and a standard Markov chain Monte Carlo (MCMC) algorithm is ineffective. We instead develop a hybrid Metropolis–Hastings–Gibbs algorithm in order to facilitate joint time-frequency recovery and effective channel estimation. In particular, we present a reparameterized model to facilitate Gibbs sampling with respect to the self-interference channel. Then the second order truncated Taylor series approximation is adopted for carrier frequency offsets (CFOs) estimation. Furthermore, a heuristic way of determining update order of parameters is proposed and initial value of the Markov chain is discussed as well. To test the robustness and objectivity of our proposed algorithm, two MCMC estimators, each with its own prior distribution, are compared against each other. Numerical results are provided to verify the effectiveness and robustness of proposed algorithm in terms of both mean-square errors (MSE) and estimation bias. The bit error rate (BER) performance results are further offered for comparison.

1. Introduction

Two-way relay network (TWRN) has been a highlighted research topic in recent years since it can potentially achieve higher spectral efficiency over traditional one-way relay network

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(OWRN) [1–5]. Specifically, by allowing two terminals to transmit signals simultaneously, a two-way amplify-and-forward (AF) relay can reduce the relay time from 4 packet time-slots to 2 by exploiting the broadcast nature of the wireless medium and by letting each terminal cancel its own transmission from the relay signal [1] as shown in Fig. 1.

Although the transmitted data are available to cancel the own transmission with each node, self-interference cancelation and message demodulation are possible only if time-frequency synchronization as well as channel estimation are implemented at receivers. Therefore the joint time-frequency synchronization and channel estimation are essential for two-way relaying in practice. Motivated by the practical need for symbol timing information and carrier frequency offset and channel estimate, this work addresses the problem of joint time-frequency synchronization and channel estimation for TWRN that utilizes AF relay protocol.

The problem of joint time-frequency synchronization and channel estimation in TWRN is complex because the joint estimation of up to eight real variables is involved, and only a complex-valued channel is linear with respect to the model. We note that the problem is similar but different from the joint time-frequency synchronization and channel estimation in the uplink of a two-user system, since the autocorrelation function of the noise at terminals depends on channel gains and transmitted data of the self-interference signals are known at receivers.

Among related works in the literature, Gao et al. [6] proposed a maximum likelihood (ML) channel estimation schemes for two-way relaying with AF relays under quasi-static flat fading channels. In [7], the authors analyzed least-square (LS) based channel estimators for OFDM modulated TWRN with AF relays in quasi-static frequency-selective fading channels. Also in [8], the authors generalized estimation of MIMO channels for TWRN with AF relays, whereas Wang et al. [9] investigated TWRN channel estimation in time-varying systems. For carrier frequency offset (CFO) estimation, Feifei Gao and Liang [10] developed a joint estimator of the CFO and the channel for a OFDM-based TWRN. Nevertheless, these works all assumed perfect symbol timing synchronization. We note that none of these works considered the issue of joint time-frequency synchronization and channel estimation in a simple AF TWRN.

In our previous work [11], the joint symbol timing synchronization and channel estimation was tackled by a Markov chain Monte Carlo (MCMC) based algorithm. Specifically, BMH and MH-ML estimators which are both essentially based on a Metropolis–Hastings algorithm were proposed. Nevertheless, it assumed an impractical perfect frequency synchronization. Surprisingly, these two estimators cannot be directly extended to a more practical imperfect frequency synchronization scenario, due to the high nonlinearity of the transmission model with respect to the carrier frequency offset (CFO). In particular, we found that the pure Metropolis–Hastings based algorithm cannot work anymore if CFO is further taken into consideration in a TWRN.

We have developed a hybrid Metropolis–Hastings–Gibbs algorithm in this paper. Specifically, our joint time-frequency synchronization and channel estimation is based on a hybrid form of

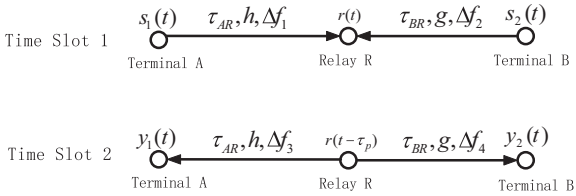

Fig. 1. A typical two-way relay system with one relay node and working under AF mode.