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Uplink CFO compensation for FBMC multiple access and OFDMA in a high mobility scenario

Gustavo J. González [a,*], Fernando H. Gregorio [a], Juan Cousseau [a], Risto Wichman [b], Stefan Werner [b]

[a] CONICET-Department of Electrical and Computer Eng., Universidad Nacional del Sur, Av. Alem 1253, Bahía Blanca, 8000, Argentina

[b] Department of Signal Processing and Acoustics, Aalto University School of Electrical Engineering, P.O. Box 13000, 00076 Aalto, Finland

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ABSTRACT

We study in this work CFO compensation methods for two multicarrier multiple access techniques in a high mobility scenario. In particular, we consider orthogonal frequency division multiple access (OFDMA) and filter bank multicarrier multiple access (FBMC-MA). The main motivation for this study is not only the different sensitivity these multicarrier techniques have to CFO but also the different methods they use to reduce CFO effect. In a high mobility scenario the CFO is re-estimated to follow its variation. We show that the frequency at which the CFO is re-estimated has a strong influence in the performance and the complexity of the proposed compensation methods. Additionally, we present a low-complexity CFO compensation method for OFDMA that employs a better approximation of the intercarrier interference than previous approaches. Regarding FBMC-MA, we introduce an extension of a CFO-compensation method that allows to consider a multitap channel equalizer. Finally, using simulations, we compare the performance of the compensation methods over several channel and time-varying CFO conditions.

1. Introduction

Owing to their high data throughput for multimedia applications, spectral efficiency and flexibility, the most promising techniques for the new generation of wireless systems are based on multicarrier modulation schemes. However, the uplink of multicarrier access techniques is highly sensitive to carrier frequency offset (CFO) since it destroys the orthogonality among subcarriers producing intercarrier interference (ICI), and therefore, multiple access interference (MAI) between users. When comparing to downlink synchronization, uplink synchronization is more challenging because each user is characterized by its own particular CFO and channel parameters [1,2].

Uplink frequency synchronization is commonly divided into an acquisition stage followed by a tracking stage. In the acquisition, or coarse estimation, the CFO and the communication channel are estimated using a suitable training sequence at the beginning of each frame [1–3], or through a specific synchronization procedure [4]. In the tracking stage, the estimation of the residual CFO produced by user mobility (Doppler effect) or estimation errors in the acquisition is refined [5]. These estimates are used to compensate the CFO interference.

Even when other alternative schemes for the uplink exist [6], the two options considered in this work are: orthogonal frequency division multiple access (OFDMA) and filter bank multicarrier multiple access (FBMC-MA) [7,8]. FBMC-MA is the multiple access technique based on filter bank multicarrier (FBMC) modulation [9]. The main motivation for this study is not only the different sensitivity these multicarrier techniques have to CFO but also the different form they use to reduce CFO's consequences, considering a high mobility scenario.

* Corresponding author. Tel.: +54 2914595101.
E-mail addresses: ggonzalez@uns.edu.ar (G.J. González), Fernando.gregorio@uns.edu.ar (F.H. Gregorio), jcousseau@uns.edu.ar (J. Cousseau), risto.wichman@aalto.fi (R. Wichman), stefan.werner@aalto.fi (S. Werner).

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Some popular approaches for the acquisition stage of uplink CFO compensation in OFDMA use iterative interference cancellation [10,11] or linear suppression [12]. Despite its larger computational complexity, the latter compensation scheme is preferred due to its better bit error rate (BER) performance [13]. Although OFDMA demodulation has low complexity, linear CFO suppression requires the inversion of a huge interference matrix, resulting in a computational complexity that may be prohibitive. A banded approximation of the interference matrix that reduces the matrix inversion complexity at the expense of some residual MAI is proposed in [12].

The FBMC transmission technique can be regarded as an extension of the OFDM concept. The OFDM rectangular time window is replaced by a highly selective filter that, in a multiple access context, leads to a negligible MAI [8]. As a consequence, only intercarrier interference needs to be compensated in FBMC-MA. A low complexity method for CFO compensation in the acquisition stage for FBMC-MA is introduced in [8]. The compensation is equivalent to the post-demodulation compensation for OFDMA, derived in [14], although it performs better due to the lower MAI inherent to FBMC-MA. Even when a low complexity polyphase realization exists [9], the high complexity of the whole FBMC-MA system, i.e. symbol modulation, channel estimation and equalization, and CFO estimation and compensation, is still a problem as discussed in the following sections.

Only a few results are available in the literature considering specifically a high mobility scenario. Blind algorithms for the tracking stage are proposed in [15,16]. A data-aided CFO tracking algorithm is presented in [11], although the CFO compensation procedure does not receive much attention. None of these methods consider a realistic CFO model. In [17] is shown that Rician-fading channels in the mobile context produce time-varying CFO, and a realistic model for this variation is proposed. LTE includes a similar model for the Doppler shift in high speed trains [18, Appendix B].

We study in this work uplink CFO compensation techniques for OFDMA and FBMC-MA systems for the tracking stage. We propose a low complexity alternative for uplink CFO compensation in OFDMA that can be seen as a generalization of the ideas presented in [12]. Comparing with [12], our solution features lower interference for the users at the edges of the band. We also present an algorithm for CFO compensation in FBMC-MA, that includes a multitap channel equalizer. We find that the CFO-compensation technique introduces a phase rotation term that has to be taken into account.

Furthermore, considering a high mobility scenario, we show that the frequency at which the CFO estimation is updated affects the performance and complexity of compensation methods proposed. In our study, we consider separately the operations associated with CFO update and CFO compensation. That allow us to obtain a more realistic complexity measure. To validate the proposed compensation schemes, a detailed simulation study that takes into account several time-varying CFO conditions is included.

The paper is organized as follows. In Section 2 we describe the high mobility scenario and the signal models for OFDMA and FBMC-MA. The CFO compensation schemes for OFDMA and FBMC-MA are derived in Section 3. In Section 4 we present a detailed comparison of the computational complexity for both systems. Numerical simulations and a general discussion are presented in Section 5. Finally, Section 6 concludes the paper.

2. Multicarrier multiple access system model

We consider a centralized system where a base station (BS) controls the information flux from (uplink) and toward (downlink) the users [7,19]. The multicarrier symbol has N subcarriers, where $M < N$ subcarriers are used for data transmission and the remaining $(N - M)$ are virtual subcarriers (VS) located at the edges of the band. Virtual subcarriers avoid frequency leakage to the neighbor bands [7]. Useful subcarriers are divided into K subchannels, where each subchannel containing M/K subcarriers corresponds to a different user. Considering the carrier allocation scheme (CAS), each subchannel is usually composed by an entire number of tiles of size N_t [5]. The tiles of each user can be contiguous to form a subband CAS (SCAS), equispaced to form an interleaved CAS (ICAS), or it can follow a more sophisticated rule, such as maximization of the link quality for every user, to form the generalized CAS (GCAS).

The subcarrier indicator set of each user is $\mathcal{I}^{(k)} = \{\mathcal{I}_0^{(k)} \ldots \mathcal{I}_{N-1}^{(k)}\}$, whose components are defined as

$$\mathcal{I}_m^{(k)} = \begin{cases} 1 & \text{if } m \text{ is allocated to user } k \\ 0 & \text{if } m \text{ is not allocated to user } k \end{cases} \tag{1}$$

where $(\cdot)^{(k)}$ denotes to user k and $0 \le m \le N - 1$. The subcarrier indicator sets of different users are disjoint and the union of all sets is complete, i.e. contains the M subcarriers. The components $\mathcal{I}_m^{(k)}$ are defined according to the chosen CAS. The user k transmits symbols

$$X_m^{(k)}(\ell) = \begin{cases} A_m^{(k)}(\ell) & \text{if } \mathcal{I}_m^{(k)} = 1 \\ 0 & \text{otherwise} \end{cases} \tag{2}$$

where $A_m^{(k)}(\ell)$ is a QAM symbol transmitted at subcarrier m, at time ℓ, by user k. We denote the time-varying impulse response of the L-tap wireless channel between user k and the base station as $h_q^{(k)}(n)$, where q is the tap index and n the time index. We also assume that the channel remains constant within a multicarrier symbol (block fading).

2.1. High mobility scenario

Even for a high mobility scenario, the CFO must be below 1% of the intercarrier spacing in order to maintain a negligible degradation [17,20]. We consider two main sources of CFO: user's mobility CFO $\xi_d^{(k)}(\ell)$, related to Doppler effects, and local oscillator drift $\xi_{lo}^{(k)}$.[1] As a consequence, the overall CFO is $\xi^{(k)}(\ell) = \xi_{lo}^{(k)} + \xi_d^{(k)}(\ell)$. Note that in this model the CFO is assumed fixed within a multicarrier symbol and that the CFO terms $\xi_{lo}^{(k)}$ and $\xi_d^{(k)}(\ell)$ are normalized to the intercarrier spacing. During the time

[1] The local oscillator is assumed to have negligible phase noise [21].