

Chapter 9

Frequency Synchronization for OFDM / OFDMA Systems

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ABSTRACT

Orthogonal frequency division multiplexing (OFDM) has been the focus of many studies in wireless communications because of its high transmission capability and its robustness to the effects of frequency-selective multipath channels. However, it is well known that OFDM systems are much more sensitive to a carrier frequency offset (CFO) than single carrier schemes with the same bit rate. Therefore, a frequency synchronization process is necessary to overcome this sensitivity to frequency offset. Synchronization is performed in two stages: acquisition and tracking. After a first estimation and correction of the CFO performed in the acquisition stage, there still remains a residual frequency offset (RFO) due to real system conditions. Therefore, the RFO tracking has to be performed for all the receiving data. Frequency synchronization is even more complicated for uplink communications in OFDMA (orthogonal frequency division multiple access) systems because the base station (BS) has to deal with signals from different users in the same bandwidth. Each user's data is affected by a different CFO. Because of this, estimation and correction of the CFOs cannot be accomplished by the same methods as in OFDM systems.

INTRODUCTION

OFDM has, with substantial progress in digital signal processing, become an important part of the telecommunications arena. This is because its ability to transform a wideband frequency-selective channel to a set of parallel flat-fading narrowband channels, which substantially simplifies the channel equalization problem. Several existing standards, among them WiFi 802.11g/n (802.11n, 2009), WiMAX 802.16d/e (802.16d, 2004; 802.16e, 2005) or DVB-T (DVB-T, 2004), are based on the OFDM concept. This chapter will focus on these standards when explaining the frequency synchronization process.

CFO synchronization turns out to be a critical issue for *multicarrier* systems. This CFO can appear because of two reasons: due to an offset between the frequencies of the local oscillator of the transmitter and the receiver or due to the Doppler effect. The CFO causes loss of orthogonality of the multiplexed signals that produces an *inter-carrier interference (ICI)* noise, an amplitude reduction and, also, a constant increment in the phase of the samples. Therefore a frequency synchronization process is necessary to overcome this sensitivity to frequency offset.

Frequency synchronization is often performed in two phases: *acquisition* and *tracking*. At the start of the sequence the acquisition stage is used to perform a first estimation of the CFO of the signal (Beek, 1997; Schmidl, 1997; Speth, 2001; Moose, 1994). In a circuit-switched system the acquisition phase can be fairly long since it only represents a small percentage of the total transmitted sequence. Some systems like DVB-T and cellular systems are circuit-switched. In packet-switched systems, as 802.16d and 802.11g/n, the acquisition phase is more important since the transmission sequences are short. The most common approach in such systems is to use a preamble for acquisition. As it will be shown, the acquisition stage is a well defined task that can be easily adapted to all standards being considered. Most of the CFO is

usually corrected at the acquisition stage, but there still remains the problem with the residual ICI and the increasing phase of the samples.

After acquisition, the tracking problem has to be solved. Since acquisition is never performed perfectly and real world conditions are not static, there still remains a RFO. If the RFO is not tracked and corrected, oscillator instabilities and/or Doppler effect can make the CFO estimation from the acquisition stage to become obsolete, thus increasing the residual ICI and decreasing the receiver performance. The constellation points will also suffer a rotation due to this RFO and will eventually cross the decisor boundaries, thus causing the system performance to become unacceptable. This rotation affects mostly to OFDM packet based systems as 802.11g/n or 802.16d/e. This is because, for these standards, the channel estimation is only performed at the beginning of the frame since the packet length is short enough to assume a constant channel during the length of the packet. Therefore, channel estimation can not correct the constant rotation produced by the CFO. In addition, the residual ICI will also affect the performance of the systems. It is mandatory to correct this impairment for all the technologies that use OFDM.

The tracking stage can be non data-aided (Kuang, 2005), when no extra information is included in the transmitted data (as in decision-directed methods) or data-aided (Speth, 2001; González-Bayón, 2007), when periodically transmitted training symbols and/or known pilot subcarriers are used.

The increasing demand for multimedia communications with variable data rates and different quality of service (QoS) requirements has recently led to a strong interest in OFDMA. This transmission technique has been chosen for mobile wireless metropolitan area network as in 802.16e-2005 (mobile WiMAX). In OFDMA, subcarriers are grouped into sets, each of which is assigned to a different user. Block, interleaved, random or clustered tiled assignment schemes can be used for this

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