Chapter 9
Channel Compensation of Variable Symbol Timing Offset in Non-synchronized OFDM System

Jae-Ho Lee, Dong-Joon Choi, Nam-Ho Hur and Whan-Woo Kim

Abstract In this paper, we propose the method of channel compensation with phase rotator (PR) when there is variable symbol timing offset (STO) in non-synchronized orthogonal frequency division multiplexing (OFDM) system. Because the symbol timing of OFDM symbols is estimated within cyclic prefix (CP) interval, a STO occurs and makes the received quadrature amplitude modulation (QAM) symbols rotated. These rotated QAM symbols can be compensated with frequency domain equalizer (FEQ). However, because the drift of symbol timing occurs in non-synchronized OFDM system, symbol timing should be estimated every OFDM symbols. Thus, the STO of the first OFDM symbol can be different from it of other OFDM symbols. PR compensates the phase difference caused by STO differences of OFDM symbols before FEQ. We show that the uncoded-bit error rate (BER) between the synchronized OFDM system and the proposed non-synchronized OFDM system is the same under additive white Gaussian noise (AWGN) and multipath channel.

Keywords Cyclic prefix · Symbol timing offset · Phase rotator · Frequency domain equalizer

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9.1 Introduction

In an OFDM system, a transmitted frame consists of a preamble and a payload. Pilot symbols in a preamble are used for channel estimation and use sequences known to a transceiver. After IFFT, L samples are prepended to an OFDM symbol for a symbol timing estimation.

After a receiver estimates a frame synchronization, and then symbol timing is estimated within CP interval to avoid inter symbol interference (ISI) caused by multipath channel. Thus, STO occurs.

Because STO is constant in synchronized OFDM system, the received OFDM symbols have the same phase rotation in frequency domain. Thus, FEQ using least square (LS) algorithm can compensate the channel and phase rotation.

However, in non-synchronized OFDM system, symbol timing must be estimated every OFDM symbols to compensate a frequency offset of a sampling clock between a transmitter and a receiver. In this case, variable STO occurs within CP interval and the variable phase rotation occurs after the FFT. Therefore, this variable STO must be compensated before FEQ.

First, we introduce the general OFDM system, and then show the channel model and the proposed channel compensation to compensate the variable STO. As simulation results, we show the uncoded-BER between synchronized OFDM system and non-synchronized OFDM system.

9.2 Transmitter of OFDM System and Multipath Channel

The transmitter and frame structure are depicted in Fig. 9.1 [1].

As shown in Fig. 9.1, the transmitter consists of a QAM, serial-to-parallel (S/P) conversion, N-point IFFT, CP generator, and parallel-to-serial (P/S) conversion.

The mapped QAM symbols of lth OFDM symbol of mth frame, $X_{m,l,}(0)$, …, $X_{m,l,}(k)$, … $X_{m,l,}(N-1)$, are converted from serial to parallel, and are the inputs to the N-point IFFT. OFDM symbol with the L-prepended samples, s_{-L}, …, s_{-1}, s_0, …, s_{N-1}, are converted from parallel to serial.

A frame consists of a preamble and a payload and has q OFDM symbols. The preamble is used for channel estimation and pilots of preamble are inserted for every 6 subcarriers [2, 3].

The channel model includes multipath channel and AWGN shown in Fig. 9.2.

As shown in Fig. 9.2, $x_{m,l}(n)$ is passed through multipath channel, and added with AWGN. The multipath channel applies echo channel (EC) used in digital video broadcasting for cable systems (DVB-C2) whose maximum delay spread is 26 samples [2, 3].

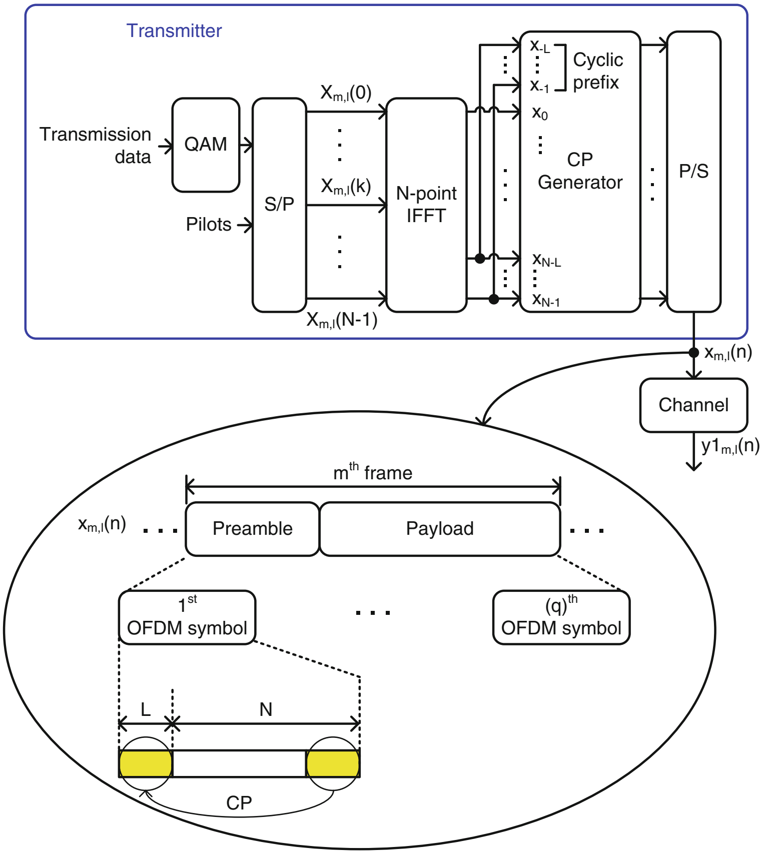
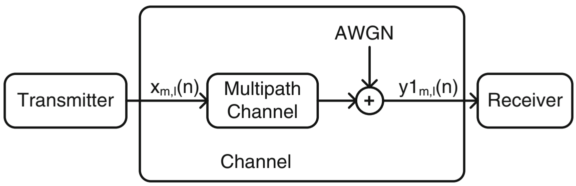


Fig. 9.1 Transmitter of an OFDM system and frame structure

Fig. 9.2 Channel model which includes AWGN and multipath channel



9.3 Channel Compensation of Variable STO

Next, we introduce the proposed method of channel compensation of variable STO in non-synchronized OFDM system. The proposed channel compensation applied to non-synchronized OFDM system is shown in Fig. 9.3.

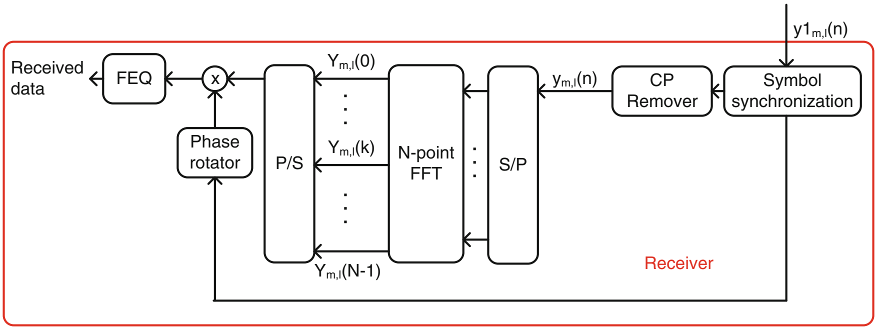


Fig. 9.3 Proposed channel compensation of variable STO in non-synchronized OFDM system

The proposed channel compensation consists of symbol synchronization, CP remover, parallel-to-serial (P/S) conversion, N-point FFT, parallel-to-serial (P/S) conversion, PR and a FEQ [1, 4, 5].

Because the transmitted OFDM symbols have CPs, the correlator is used in symbol synchronization. The symbol timing is estimated within CP interval to avoid inter symbol interference caused by maximum delay spread of multipath channel [6, 7].

CP remover eliminates the L samples of CP and the FFT input is N samples which correspond to FFT window. The output of CP remover, $y_{m,l}(n)$, is expressed as Eq. (9.1).

$$\begin{aligned} y_{m,l}(n) &= \sum_{k=0}^{N-1} X_{m,l}(k)H(k)e^{\frac{j2\pi k\left(n+\delta_{m,l}\right)}{N}} + z_{m,l}(n) \\ &= \sum_{k=0}^{N-1} X_{m,l}(k)e^{\frac{j2\pi kn}{N}}\underline{H(k)e^{\frac{j2k\pi\delta_{m,l}}{N}}} + Z_{m,l}(n) \end{aligned} \tag{9.1}$$

where m is frame index, l is OFDM symbol index, k is subcarrier index, n is sample index, $z_{m,l}$ is noise, and $\delta_{m,l}$ is STO.

If we define underlined term of Eq. (9.1) as the frequency characteristics of estimated channel such as Eq. (9.2), the frequency characteristics of estimated channel are changed by STO.

$$\widehat{H}(k) = H(k)e^{\frac{j2\pi k\delta_{m,l}}{N}} \tag{9.2}$$

The FFT output, $Y_{m,l}(p)$, is expressed as shown in Eq. (9.3)

$$
\begin{aligned}
Y_{m,l}(p) &= \sum_{n=o}^{N-1} y_{m,l}(n) e^{\frac{-j2\pi pn}{N}} + Z_{m,l}(p) \\
&= X_{m,l}(p)\widehat{H}(p) + Z_{m,l}(p) \\
&= X_{m,l}(p) e^{\frac{-j2\pi p \delta_{m,l}}{N}} + Z_{m,l}(p) \\
&= \underline{X_{m,l}(p) e^{\frac{-j2\pi p \delta_{m,l}}{N}}} H(p) + Z_{m,l}(p) \quad p = 0, \ldots, N-1.
\end{aligned}
\tag{9.3}
$$

Underlined term in Eq. (9.3) means that the received QAM symbols are rotated by STO. If STO is not zero in Eq. (9.3), $Y_{m,l}(p)$ has the phase rotation proportional to STO and is expressed such as Eq. (9.4).

$$
Y_{m,l}(p) = X_{m,l}(p)\widehat{H}(p) + Z_{m,l}(p) \tag{9.4}
$$

The received QAM symbols are estimated by FEQ using LS algorithm and is expressed as shown in Eq. (9.5).

$$
\widehat{X}_{m,l}(p) = \frac{Y_{m,l}(p)}{\widehat{H}(p)} = X_{m,l}(p) + \frac{Z_{m,l}(p)}{\widehat{H}(p)} \tag{9.5}
$$

In Eq. (9.5), the estimated QAM symbols are the transmitted QAM symbols added by noise if STO must be constant in one frame.

In synchronized-OFDM system, because STO is constant within one frame, received QAM symbols can be estimated correctly such as Eq. (9.5) with FEQ.

However, because there is a frequency offset of transceiver clock in non-synchronized OFDM system, the variable STO between the first OFDM symbol and the other OFDM symbols occurs. Therefore, PR compensates the phase difference between the first STO and the other STO before FEQ to compensate for variable STO as shown in Eq. (9.6).

$$
Y_{m,l}(p) \times e^{\frac{j2\pi p\left(\delta_{m,1} - \delta_{m,l}\right)}{N}} \quad l = 2, \ldots, q \tag{9.6}
$$

In Eq. (9.6), m is the frame index, l is the OFDM symbol index, $\delta_{m,l}$ is STO of lth OFDM symbol of mth frame.

9.4 Simulation Results

We have studied uncoded-BER performances between synchronous OFDM system and non-synchronized OFDM system using a computer simulation.

The major parameters of simulation are shown in Table 9.1 [1].

In addition, pilots in preamble are inserted every 6 subcarriers, and the first order interpolator is used in FEQ.

Figure 9.4 shows the BER between synchronized OFDM system and non-synchronized OFDM system under AWGN and multipath channel [1. 2].

Table 9.1 Simulation parameters

Parameter	Value
Number of total subcarriers per OFDM symbol, N	4096
Number of used subcarriers per OFDM symbol, N_{sub}	3409
Number of CP, L	32 samples
Subcarrier spacing, Δf	2.232 kHz
QAM order	4096

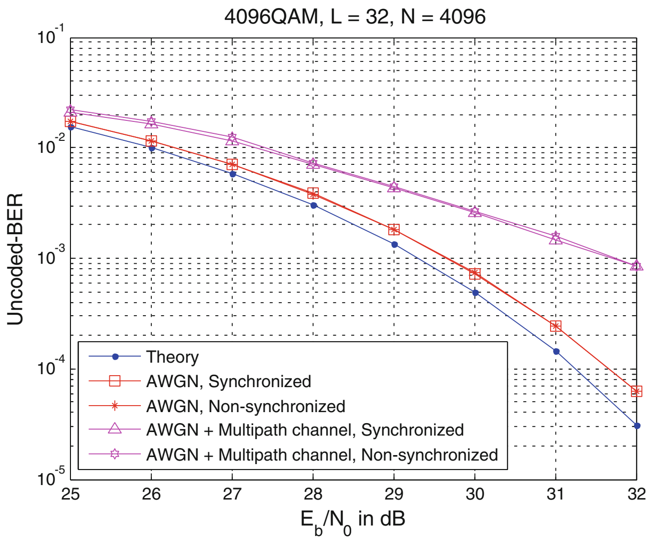


Fig. 9.4 Uncoded-BER of 4096QAM under AWGN and AWGN plus multipath channel

As can be seen in Fig. 9.4, "Theory" represents the theoretical uncoded-BER of 4096QAM.

In case of AWGN, the uncoded-BER is worse than "Theory" because of interpolator of FEQ. In case of multipath channel, because the estimated STO is shorter than maximum delay spread and ISI occurs, the uncoded-BER is higher than "Theory". However, the performances between synchronized and non-synchronized OFDM system is the same under AWGN and AWGN + multipath channel. Therefore, the proposed channel estimation can be available in non-synchronized OFDM system.

9.5 Conclusions

We propose channel estimation of variable STO in non-synchronized OFDM system which compensates the phase rotation with respect to variable STO before FEQ. In addition, the simulation results show the uncoded-BER is the same between synchronized and non-synchronized OFDM system. Therefore, the proposed channel compensation is expected to be available in non-synchronized OFDM system.

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