

The Performance of Frequency Offset Estimation in DVB-C2 Receiver

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Abstract— In this paper, we show the performance of frequency offset (FO) estimation in Digital Video Broadcasting for Cable version 2 (DVB-C2) receiver which uses orthogonal frequency-division multiplexing (OFDM). In OFDM system, inter-carrier interference (ICI) occurs due to FO which is caused by an oscillator of a transmitter and receiver, and degrades the performance of a receiver. Thus, FO should be estimated and compensated to improve the performance of a receiver. FO can be normalized to subcarrier spacing in OFDM system, and consists of fractional frequency offset (FFO) and integer frequency offset (IFO) accordingly. FFO is estimated in time domain using cyclic prefix (CP), and IFO is estimated in frequency domain with unique synchronization sequence (USS) of preamble due to the structure of DVB-C2 frame. Because the estimation of FO is influenced by CP length and echo channels shown in the DVB-C2 specification, we simulate the mean square error (MSE) of FO estimation w.r.t CP length and echo channels. The results of simulation show that MSE is reduced as CP length is longer. In addition, MSE is improved as E_b/N_0 increases. However, MSE of the estimated FO tends to saturate at high E_b/N_0 when echo channels are used. In addition, it increases when the maximum delay spread between echo channels is longer.

Keywords— DVB-C2 receiver, Frequency offset, mean square error, unique synchronization sequence

I. INTRODUCTION

FO is caused by an oscillator of transmitter and receiver. In multicarrier system such as OFDM, FO causes ICI among subcarriers and degrades the performance of a receiver [1]. Thus, FO should be estimated and compensated to reduce the required E_b/N_0 of a receiver. FO is dependent on the accuracy of an oscillator and can be normalized to subcarrier spacing in multicarrier system. In general, the estimation of FO can be performed in time domain or frequency domain. To estimate FO in time domain, CP and the training symbols may be used. Because the training symbols are not used in the DVB-C2 frame, the estimation of FO in this paper is performed with CP. However, the estimation of FO using CP can extract only the FFO of FO. Thus, IFO is estimated using USS after FFT. In other words, IFO is performed in frequency domain. The MSE of the FO estimation is influenced by additive white Gaussian noise (AWGN) and echo channels. DVB-C2 specification

shows the two types of echo channels; echo channel 1 (EC1) and echo channel 2 (EC2) [2], [3]. Because EC2 has the longer maximum delay spread than EC1, EC2 is inferior to EC1. Thus, we simulate the MSE of the estimated FO under various channel conditions.

II. ESTIMATION OF FO

First, we introduce the simulation model of OFDM system and channel. Next, we explain the method of the estimation of FO. Last, we show the results of simulation.

A. OFDM System

Figure 1 shows the OFDM system we simulate.

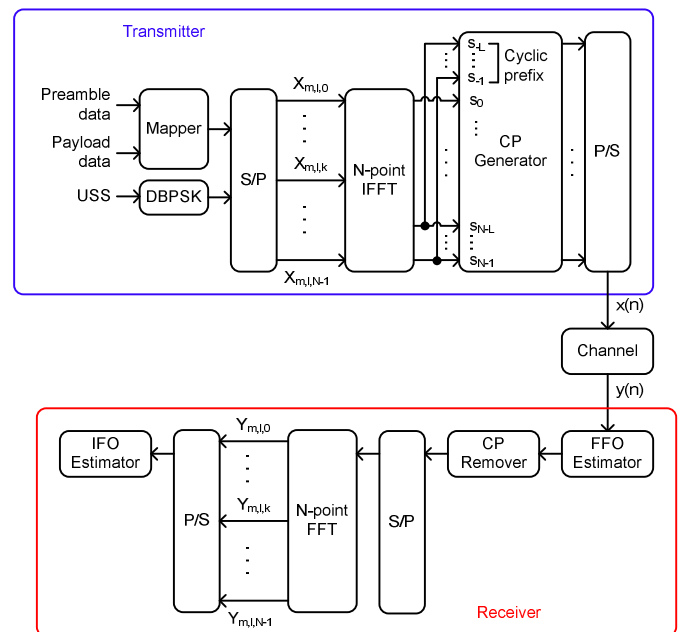


Figure 1. A block diagram of a OFDM transceiver.

As shown in Figure 1, the transmitter in OFDM system consists of mapper, serial-to-parallel (S/P), IFFT, CP generator and parallel-to-serial (P/S). Preamble and payload data are mapped into various QAM symbols by mapper. USS is generated by two pseudo random binary sequences (PRBS) and is mapped by differential binary phase shift keying (DBPSK) for preamble pilot symbols. The position of

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preamble pilot symbols is shown in Figure 2 [2], [3].

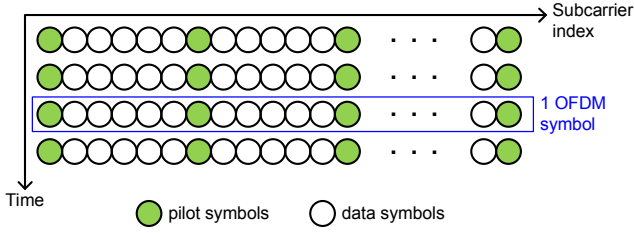


Figure 2. The position of preamble pilot symbols

As shown in Figure 2, preamble pilot symbols have a comb structure and are inserted for every 6 subcarriers.

CP generator copies the last L samples of IFFT output and appends them to it. Thus, one OFDM symbol has the length of N plus L .

The receiver shown in Figure 1 consists of FFO estimator, CP remover, S/P, FFT, P/S and IFO estimator.

Table 1 shows the parameters for 8MHz channel bandwidth [2], [3].

TABLE 1. PARAMETERS OF DOWNSTREAM TRANSMITTER

Number of total subcarriers per OFDM symbol, N	4096
Number of used subcarriers per OFDM symbol, N_{USED}	3409
Number of CP, L	32 or 64 samples
Number of pilot subcarriers per OFDM symbol in preamble, N_{PRP}	569
Subcarrier spacing, Δf	2.232 kHz
IFFT/FFT period, T_{FFT}	448 μs
Echo channel	EC1 and EC2

B. The channel model

Figure 2 shows the block diagram of channel we apply.

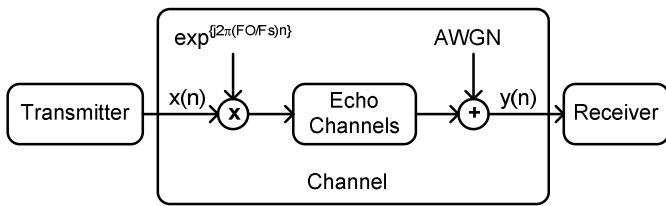


Figure 3. The block diagram of channel for simulation.

As shown in Figure 3, the channel consists of FO, echo channels and AWGN. F_s in Figure 3 is a sampling frequency and is $\Delta f \times N$

FO can be normalized to Δf and is expressed as equation (1).

$$\frac{FO}{\Delta f} = \epsilon = \epsilon_f + \epsilon_i \quad (1)$$

where ϵ is normalized FO, ϵ_f is FFO and ϵ_i is IFO.

Figure 4 and Figure 5 shows the power delay profile for EC1 and EC2 respectively [2], [3].

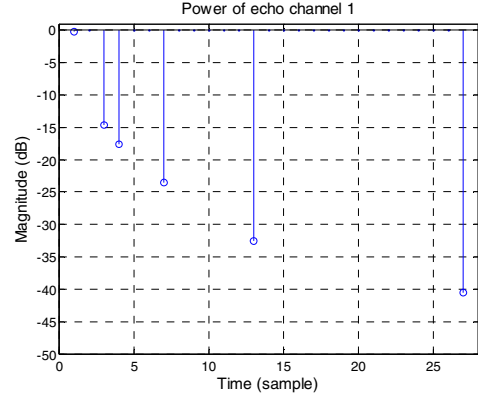


Figure 4. Power delay profile of EC1.

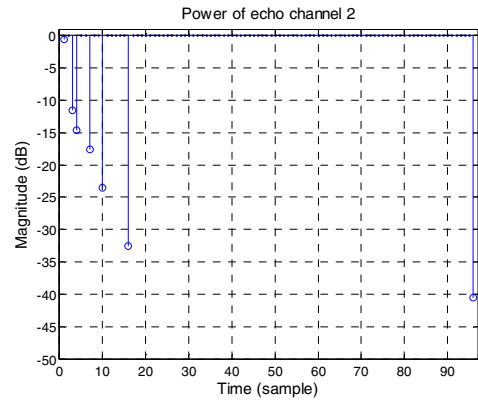


Figure 5. Power delay profile of EC2.

As shown in Figure 4, Figure5, EC2 has the longer path than EC1. In other words, EC2 has the worse frequency characteristic than EC1

C. Estimation of FO

When there is FO (ϵ), the input (y) and output (Y) of FFT can be expressed as equation (2) and equation (3).

$$y(n) = \sum_{k=0}^{N-1} X(k)H(k)e^{\frac{j2\pi(k+\epsilon)n}{N}} \quad (2)$$

$$\begin{aligned} Y(p) &= \sum_{n=0}^{N-1} y(n)e^{-\frac{j2\pi np}{N}} \\ &= \sum_{n=0}^{N-1} \left[\sum_{k=0}^{N-1} X(k)H(k)e^{\frac{j2\pi(k+\epsilon)n}{N}} \right] e^{-\frac{j2\pi np}{N}} + Z(p) \\ &= \sum_{n=0}^{N-1} \sum_{k=0}^{N-1} X(k)H(k)e^{\frac{j2\pi(k-p+\epsilon)n}{N}} + Z(p) \end{aligned}$$

$$\begin{aligned}
&= \sum_{k=0}^{N-1} H(k)X(k) \sum_{n=0}^{N-1} e^{\frac{j2\pi(k-p+\epsilon)n}{N}} + Z(p) \quad (3) \\
&= H(p)X(p) \left(\sum_{n=0}^{N-1} e^{\frac{j2\pi\epsilon n}{N}} \right) + \\
&\quad \sum_{k=0, k \neq p}^{N-1} H(k)X(k) \sum_{n=0}^{N-1} e^{\frac{j2\pi(k-p+\epsilon)n}{N}}
\end{aligned}$$

where k and p is subcarrier index, n is sample index, $Z(p)$ is noise, and $H(k)$ is the frequency response of channel.

In equation (3), the first term corresponds to $k = p$, and the second term corresponds to $k \neq p$ and represents ICI.

If ϵ_f is not zero and ϵ_i is zero, equation (3) can be expressed as Figure 6.

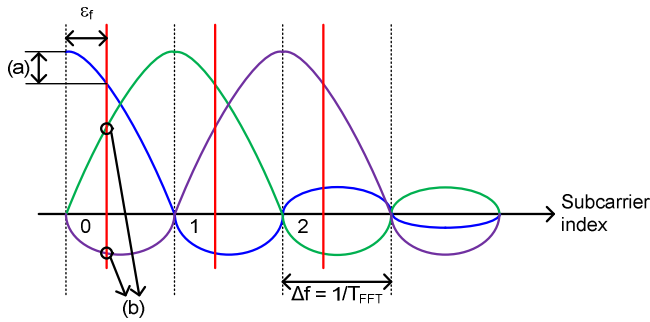


Figure 6. The effect of FFO.

As seen in Figure 6, (a) represents the change of magnitude and phase and (b) shows ICI.

To estimate ϵ , the FFO estimator using CP of OFDM symbols is shown in Figure 7 [4], [5], [6].

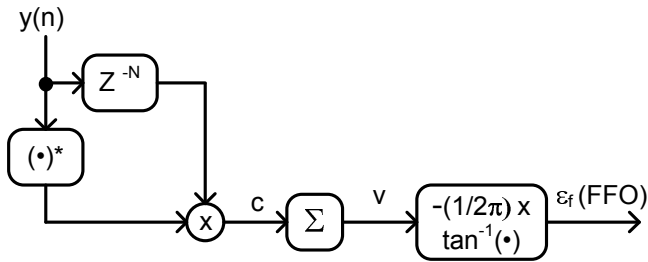


Figure 7. The structure of FFO estimation

The estimation of ϵ_f in Figure 7 can be expressed as equation (4).

$$\begin{aligned}
y(n) &= x(n)e^{\frac{j2\pi\epsilon n}{N}} + z(n), \\
c(n) &= y^*(n)y(n-N) \\
&= x^*(n)x(n-N)e^{\frac{-j2\pi\epsilon n}{N}}e^{\frac{j2\pi\epsilon(n-N)}{N}} + z'(n) \\
&= |x(n)|^2e^{-j2\pi\epsilon} + z'(n)
\end{aligned}$$

$$\begin{aligned}
v(n) &= e^{-j2\pi\epsilon} \left(\frac{1}{L} \sum_{n=0}^{L-1} |x(n)|^2 + z'(n) \right) \quad (4) \\
&= Ae^{-j2\pi\epsilon} + \text{noise}
\end{aligned}$$

$$-2\pi\epsilon = \tan^{-1} \left\{ \frac{\text{Imag}(v)}{\text{Real}(v)} \right\} < \pm \pi \rightarrow |\epsilon| < 0.5$$

where $z(n)$ and $z'(n)$ are noise.

As shown in equation (4), the estimation of FO using CP can extract only the FFO (ϵ_f) of FO (ϵ) and is affected with CP length.

Therefore, IFO (ϵ_i) of FO (ϵ) is estimated in frequency domain after FFT and IFO estimator is shown in Figure 8 [3].

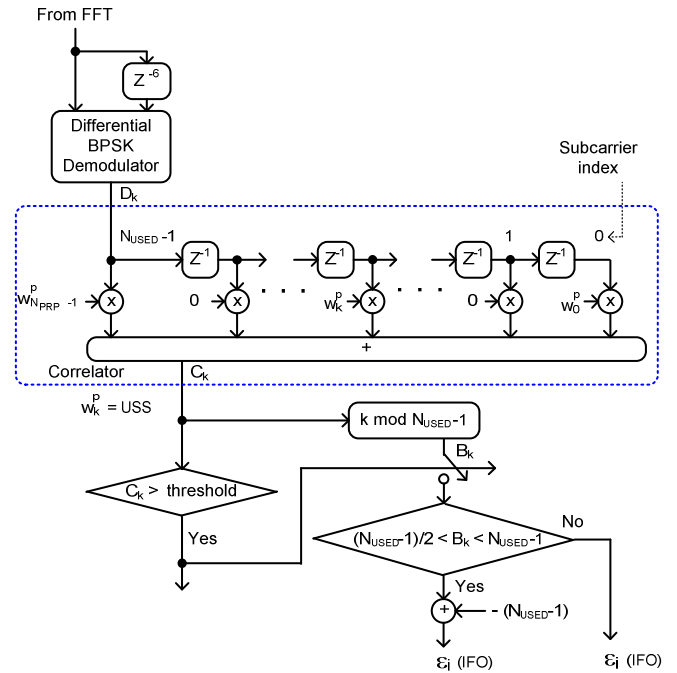


Figure 8. The structure of IFO estimation.

In Fig. 8, 0, 1, ..., $N_{\text{USED}}-1$ represent the subcarrier index and $w_k^0, \dots, w_{N_{\text{PRP}}-1}^p$ represent USS. The pilot symbols of preamble are demodulated by DBPSK demodulator and then the output (D_k) of it is correlated with USS (w_k^p). Only when the output (C_k) of correlator exceeds a threshold, the estimation of ϵ_i is performed. Figure 9 shows the examples of various ϵ_i .

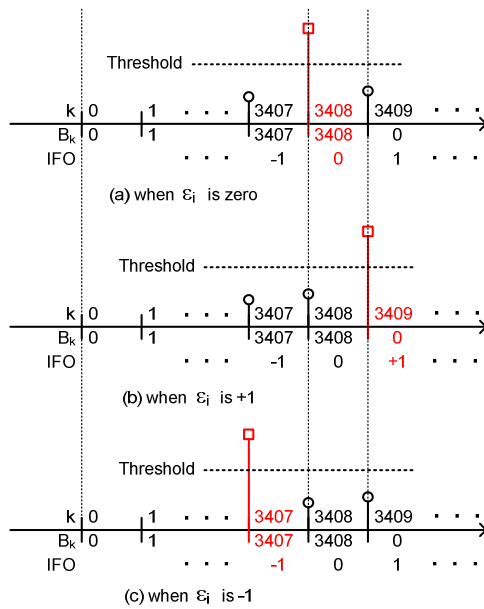


Figure 9. Examples of the estimation of IFO.

When there is no IFO, the peak occurs at $k = 3408$ with preamble detection. If the peak occurs at $k = 3409$ and $k = 3407$, the IFO equals 1 and -1, respectively. From our simulation, the max/min of the IFO is found to be ± 63 .

D. Simulation results

We simulate to evaluate the MSE of FO estimation under CP length and various channels which can be expressed as equation (5).

$$MSE = \frac{\sum_M |\epsilon_{given} - \epsilon_{estimated}|^2}{M} \quad (5)$$

where M is the number of simulation iteration, ϵ_{given} is given frequency offset and ϵ_i is the estimated frequency offset.

Figure 10 shows the MSEs under AWGN with respect to CP length.

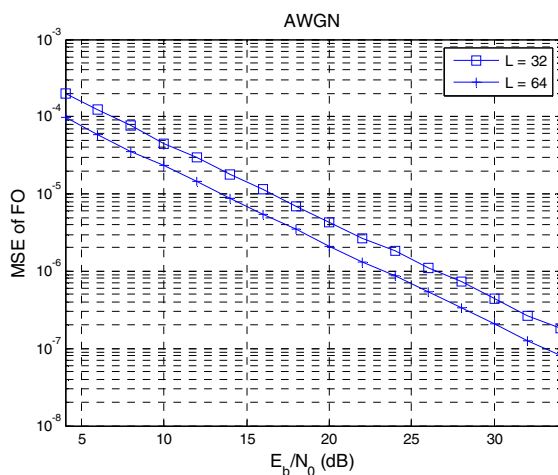


Figure 10. MSE of the estimated FO with respect to CP length when the given FO is 1.25 and channel is AWGN.

As CP length and E_b/N_0 increase, the MSEs decrease monotonically.

Figure 11 shows the MSEs under EC1 with respect to CP length.

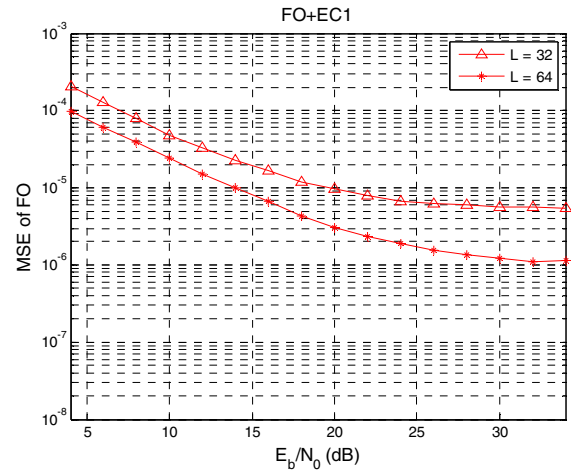


Figure 11. MSE of the estimated FO with respect to CP length when the given FO is 1.25 and channel is EC1.

As shown in Figure 11, the MSEs are saturated at high E_b/N_0 . As CP length is longer, the MSE is smaller.

Figure 12 shows the MSEs under EC2 with respect to CP length.

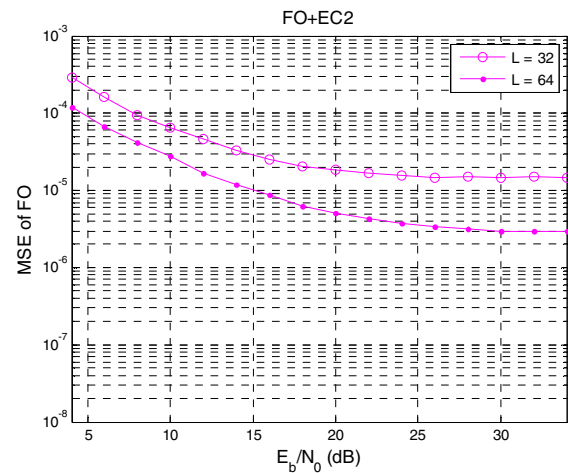


Figure 12. MSE of the estimated FO with respect to CP length when the given FO is 1.25 and channel is EC2.

The pattern of MSEs is the same as the Figure 11, but the MSEs are worse than them shown in Figure 11.

III. CONCLUSION

Because FO causes ICI in OFDM system, FO must be estimated and compensated to improve the performance of a receiver.

Thus, we have investigated the performance of FO estimation w.r.t CP length and echo channels. FFO and IFO

are estimated in time domain and frequency domain individually according to the structure of DVB-C2 frame.

The results of simulation show that MSE decreases as CP length is longer. In addition, MSE is better as E_b/N_0 increases. However, the MSE of the estimated FO tends to saturate at high E_b/N_0 when echo channels are used. In addition, it increases when the maximum delay spread between echo channels is longer.

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