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Downlink BER Simulation for IEEE 802.1 6e OFDM-PHY

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Abstract- **Now-a-days, with the rapid growth of digital wireless communication, the need for high-speed mobile data transmission has increased. Processing power has increased to a point where OFDM has become feasible and economical. Some of the current applications using OFDM include DVB (Digital Video Broadcasting) DAB (Digital Audio Broadcasting), HDTV (High-Definition Television) broadcasting, IEEE 802.11 (wireless networking standard).**

Orthogonal Frequency Division Multiplexing (OFDM) has become very popular, allowing high speed wireless communications. A basic OFDM modulator system consists of a QAM or PSK modulator, a serial to parallel, and an IFFT module. Using FPGA instead of an ASIC gives also flexibility for reconfiguration, which is a need for the Software Defined Radio (SDR) concept.

In this OFDM modulator will be implemented as per the 802.16 standard with full digital techniques.

Evaluation of synchronization scheme for Carrier Frequency Offset (CFO) and Timing Offset (TO) in IEEE 802.16e Subscriber Station (SS) and integrate both inner receiver and outer receiver to evaluate the performances under SUI-4 channel.

Keywords- **FEC encoder, Mapping circuit , IFFT, Guard Interval inserter, In Phase and Quadrature signal generators.**

I. INTRODUCTION

The IEEE standard 802.16e specifies the WirelessMAN air interface with mobility for broadband wireless access systems. The performance evaluation of the TDD mode for OFDM-PHY is focused in this. As we know, its performance is very sensitive to

Carrier Frequency Offset (CFO) induced from oscillators mismatch between the transmitter and the receiver. Impacted by frequency offset, the performance degrades due to (1) inter-carrier interference (ICI), (2) amplitude reduction of DFT output, and (3) introducing phase rotation to the sub-carriers. The phase shifts induced from CFO are considered identical on all sub-carriers if ICI is ignored due to the main part of CFO has been compensated after coarse compensation of frequency offset. The timing offset (TO) causes phase shift that is proportional to the sub-carrier index as well as the offset itself. It is popular to obtain the TO estimates by computing a slope from the phase differences versus sub-carrier. Accurate demodulation and detection of an OFDM signal requires carrier orthogonality. However, variations of the carrier oscillator, sampling clock or the symbol timing all destroy the orthogonality of the system. Hence, before an OFDM receiver can work properly, we should perform timing and CFO synchronization on the received signals.

II. SYSTEM MODEL

The mandatory channel coding supported in IEEE 802.16e OFDM-PHY is composed of three steps: randomizer, FEC, and interleaver. They should apply in this order at transmission. After the interleaver, the N encoded complex data are modulated to synthesize an OFDM symbol by employing inverse Fourier transform (IDFT), where N denote the number of samples for DFT. In order to reduce the effect of ISI, a Cyclic Prefix (CP) of Ng samples is inserted at the beginning of each symbol. The CP duration provides multi-path immunity and symbol time synchronization error tolerance, but still results in the overall SNR loss.

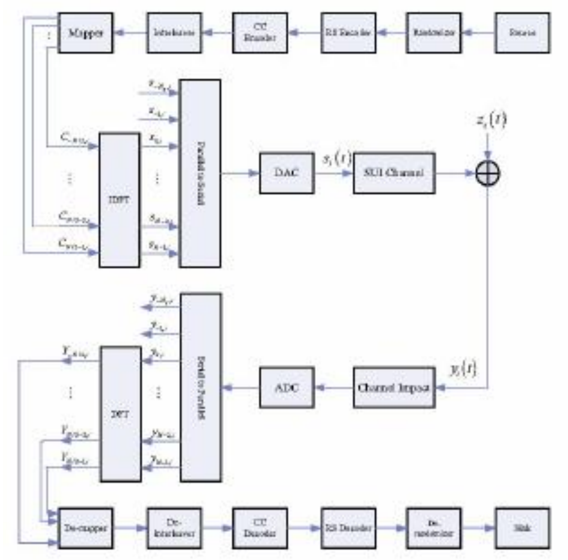


Fig. 1. System Model of IEEE 802.16e OFDM-PHY.

Thus, there are N Ng samples during one OFDM symbol. In IEEE 802.16e OFDM-PHY , each OFDM symbol contains 256 samples with a variable CP length. Fig. 1 illustrates the system model with transmitter and receiver. The time-domain symbol waveform contains the duration of data part Tb and CP part Tg. The value of Tg/Tb might be 1/4, 1/8, 1/16, 1/32, depending on the transmission environment. Thus, the n-th time-domain sample of the i-th symbol can be expressed as

$$S_{n,i} = \sum_{\frac{N}{2}-1}^{\frac{N}{2}-1} C_{k,i} \exp(jn \frac{2\pi}{N}) \qquad (1)$$

where Ck,i is the modulated data to be transmitted on the i-th OFDM symbol with the k-th sub-carrier. In a practical transmission simulation, we usually use an interpolator to change the transmission sampling rate by an appropriate factor. In this we increase the sampling rate by 4. To avoid ISI effect on the band-limited channel, we use Square Root Raised Cosine (SRRC) filter. Thus, we need a FIR filter with a gain of 4, cut off frequency $\pi/4$ and roll off factor 0.21875 in the discrete-time domain simulation. At the receiver, the demodulation of the OFDM symbols is performed by applying DFT to calculate the complex value of the sub-carrier after timing synchronization which finds the precise start point of OFDM symbols for DFT operation. The demodulated frequency-domain sample on k-th sub-carrier of i-th symbol is expressed as

$$Y_{k,i} = \frac{1}{N} \sum_{n=0}^{N-1} y_{n,i} \exp(-jk \frac{2\pi n}{N}) \qquad (2)$$

where $\{y_{n,i}\}$ denote the time-domain received samples. Here, we assume there is no ISI due to adequate choice of CP.

III. BASEBAND INNER RECEIVER ARCHITECTURE

The overall block diagram of the proposed IEEE 802.16e SS baseband receiver is illustrated in Fig. 2. We can partition the receiver into two subsystem, one is the inner receiver and the other is the outer receiver. The inner receiver needs to accomplish numerous function blocks such as energy detection, Automatic Gain Control (AGC), diversity selection, Frame Detection (FD), timing and frequency

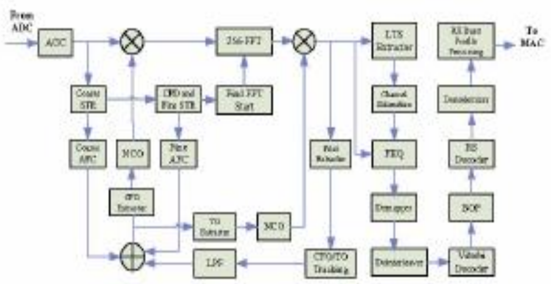


Fig. 2. Block diagram of the proposed inner and outer receiver for IEEE 802.16e OFDM-PHY.

synchronization, CP length detection, channel estimation and equalization during the preamble period in order to detect the data symbols correctly. The outer receiver processes the soft information obtained from de-mapping the output of inner receiver, the complete bit-processing tasks composed of de-interleaving, channel decoding, de-randomization and receive data burst handler.
Fig. 3 illustrates the preamble structure in time domain and the associated functions of receiver in our target system. The preamble consists of two OFDM symbols preceded by CP. The former comprises four short training symbols (STSs) and the later comprises two long training symbols (LTSs). After a SS is switched on, energy detection starts to monitor whether radio signals exist in the surrounding. In addition, we adopt a digital AGC approach with careful timing budget to reduce circuit complexity.

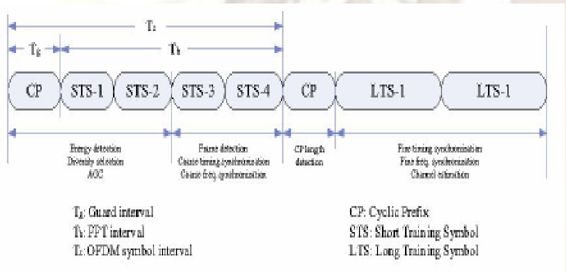


Fig. 3. The structure of preamble and timing budget plan.

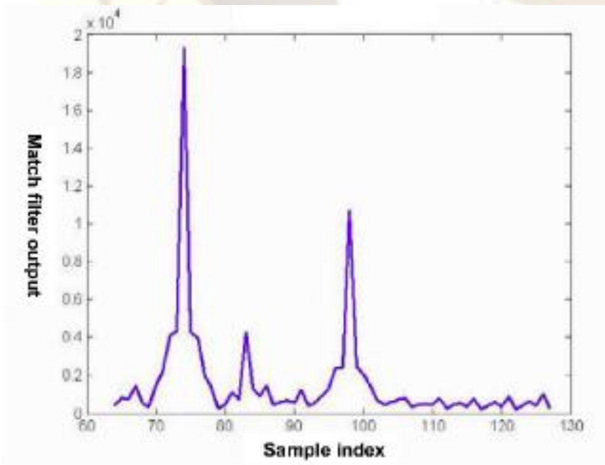


Fig. 4. Match filter output of the proposed coarse TO estimation algorithm under SUI-4 channel model.

A. Coarse CFO/TO Estimation

The task of the CFO estimation is to estimate the frequency offset and compensate the received signal for it. By calculating the phase of the output of the delay correlation $P_{n,CFO}$, the coarse CFO estimates can be obtained. The delayed correlation can be computed by

$$P_{n,CFO} = \sum_{m=0}^{\frac{N}{4}-1} y^*_{n+m} y_{\frac{N}{4}+n+m} \qquad (3)$$

and the CFO is then given by

$$\Delta f = \frac{f_S \angle P_{n,CFO}}{2\pi \frac{N}{4}} \qquad (4)$$

where f_S, is the sampling frequency.

The task of the coarse STR is to find a reference location by which the length of Guard Interval (GI) can be estimated. There are two steps in the proposed STR method: 1) Find out the most significant arriving path from the received signal, and 2) locate the transition boundary of the STS and the LTSs with that path. To find the most significant path, the received signal is passed through a matched filter which is constructed of the conjugated and reversed STS. The output of the matched filter, q_n, is expressed as

$$q_n = \sum_{m=0}^{\frac{N}{4}-1} S_{m,STS} y_{n+m} \qquad (5)$$

where $\{s_{m,STS}\}$ denote the samples of 64-sample STS. The absolute values of the last 64-sample presented by matched filter output at $\frac{E_b}{N_0}$ = 10 dB over the channel model SUI-4 is shown in Fig. 4, which demonstrates that the first peak happen at n = 74.
The boundary of the STS and the LTS within the most significant path can be estimated by the normalized delayed correlation Rn which can be written as

$$R_n = \frac{|P_{n,CFO}|^2}{Q_n Q_{n+\frac{N}{4}}} \qquad (6)$$

where Qn = $\sum_{m=0}^{\frac{N}{4}-1} |y_{n+m}|^2$.

By $R_{n+\frac{lN}{4}}$ for l = 1,2,, the boundary is chosen at the first l that $R_{n+\frac{lN}{4}}$ is smaller than a specified threshold.

B. Fine CFO/TO Estimation and CP Detection

The fine symbol timing boundary is detected by a match filter. This method is performed by calculating the correlation of received samples {yn} and the known 128-sample LTS, {Sm,LTS}. For AWGN channel, the fine symbol timing boundary is performed in the period of LTS and can be estimated as

$$\hat{t}_S = \arg\max \left| \sum_{m=0}^{L_{LTS}-1} y_{n+m} S^*_{m,LTS} \right|^2 \qquad (7)$$

where L_{LTS} is the period of LTS and is set to 128.

For fading channel case, to handle the situation that the first path may be not the strongest path, we use a threshold to find the peak. The threshold is set to ∝,

$$\max\left|\sum_{m=0}^{L-1} y_{n+m} S^*{}_{m,LTS}\right|^2$$

where α is a fractional number.

From Fig. 3, CP length can be calculated by that the boundary between CP and LTS 1 subtracts the coarse boundary between STS4 and CP. Note that coarse boundary between STS4 and CP is obtained from the detection of coarse symbol boundary. And the boundary between CP and LTS 1 is estimated step by step as follows:

1) Find some timing indexes whose relative output of match filter is large enough, and set them as candidate boundaries.

2) Define candidates of CP lengths to be the calculated candidate-boundaries from step 1 subtract the coarse boundary between STS4 and CP.

3) Take the candidates of CP lengths from step 2 to match the legal CP length, i.e., 8, 16, 32 and 64, and choose the most likely one.

The procedure of estimating fine CFO is the same as coarse CFO estimation, but take different parameters as follows,

$$P'_{n,CFO} = \sum_{m=0}^{\frac{N}{2}-1} y^*{}_{n+m}\, y_{\frac{N}{2}+n+m} \qquad (8)$$

$$\Delta f' = \frac{fs\angle P'_{n,CFO}}{f\pi \frac{N}{2}} \qquad (9)$$

This CFO refinement is performed in the period of LTS in order to fine tune the residual frequency offset after coarse frequency offset estimation.

C. Channel Estimation

In view of the preamble structure, the second OFDM symbol in the log preamble consists two identical LTSs with length 128.Both LTSs are summed and transformed into the frequency domain to obtain the LS channel estimates. Note that there are totally two hundred sub-carriers utilized as useful sub-carriers.

Since only one hundred sub-carriers with data are embedded in LTS, the channel estimates for the remaining one hundred null sub-carriers are determined using interpolation. Thus, we can rewrite the channel estimate formula with the help of LTS as

$$H_{k,LTS} = \frac{Y_{k,LTS}}{S_{k,LTS}} \qquad (10)$$

In order to qualify channel estimation, we adopt decision directed channel estimates to make the number of erroneously detected data low. Thus, the detected data can be substituted as training data to form the channel estimate. It can be expressed as

$$\hat{H}_{k,l+1} = \lambda \tilde{H}_{k,l} + (1-\lambda)\hat{H}_{k,l} \qquad (11)$$

where the decision-directed channel response is estimated by

$$\tilde{H}_{k,l} = \frac{Y_{k,l}}{D_{k,l}}, l \geq 1 \qquad (12)$$

where $D_{k,l}$ is obtained from the hard-decision results of $Y_{k,l}$, and the initial channel estimate can be obtained from $\hat{H}_{k,l} = H_{k,LTS}$. The weighting factor λ determines the effective channel memory used in the current channel estimate. When the channel varies slowly, the channel estimate with a smaller A would achieve better performance.

D. CFO/TO Tracking

We know that the CFO and TO can be compensated mainly with CFO and TO estimates. But the residual CFO and TO still need to be tracked after the essential estimates has been conducted in the second preamble symbol. The eight equally spaced pilot sub-carriers embedded in the data symbol can be utilized for residual CFO and TO tracking. It is assumed that the frequency and clock offsets during adjacent symbols are kept constant.

IV. NUMERICAL RESULTS

Two numerical experiments are conducted in this section to test the performance of the proposed IEEE 802.16e baseband receiver scheme. With the consideration of practical implementations, we evaluate the performance impact due to the proposed synchronization and channel estimation algorithms under SUI-4 channel. In both experiments, we target at carrier frequency of 3.5 GHz, the OFDM symbol is assumed to have N = 256 subcarriers spaced 26.875 kHz apart.

Experiment 1: Synchronization test.

The goal of experiment 1 is to evaluate the proposed synchronization algorithms, including CFO/TO acquisition, CP length detection and CFO/TO tracking. In order to avoid too many effects are mixed up, perfect channel estimation is assumed in this experiment. In this simulation, an N/4-sample CP is chosen, and the system performances of several combinations of modulations and coding rates under SUI-4 channel with CFO of 33.6 kHz are evaluated. All BER are evaluated by averaging over 20000 frames, and each frame has 20 OFDM symbols. As shown in Fig. 5, the BER loss between the ideal synchronization and the proposed synchronization algorithm is about 0.2dB. Therefore, with the proposed synchronization algorithm, the system performance will have very little performance degradation compared with the ideal case system.

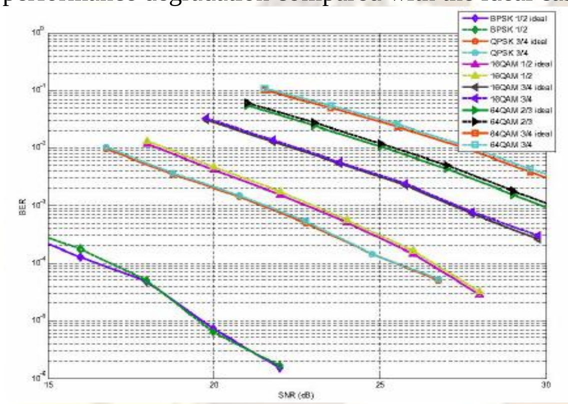


Fig. 5. BER performance of the proposed synchronization algorithm under SUI-4 channel.

Experiment 2: Integration test.

In addition to the impact of CFO and TO, we would like to test the proposed channel estimation algorithm. Similarly, we evaluate the performance degradation with different combinations of modulation schemes and code rates. The BER performance is shown in Fig. 6. With higher order modulation, we observe error floor induced from the interpolation error of channel estimation.

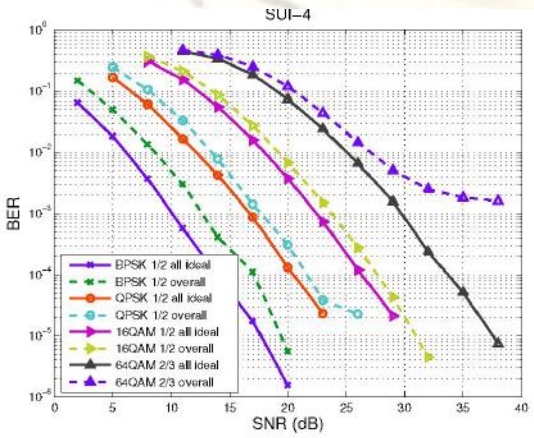
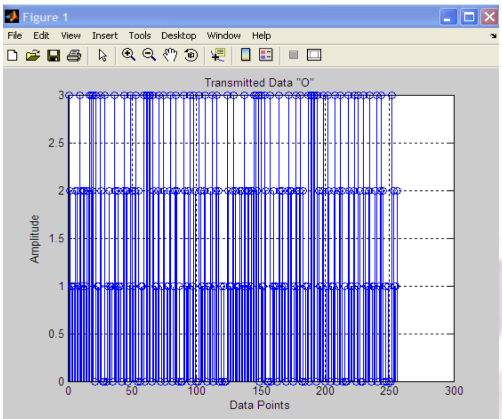


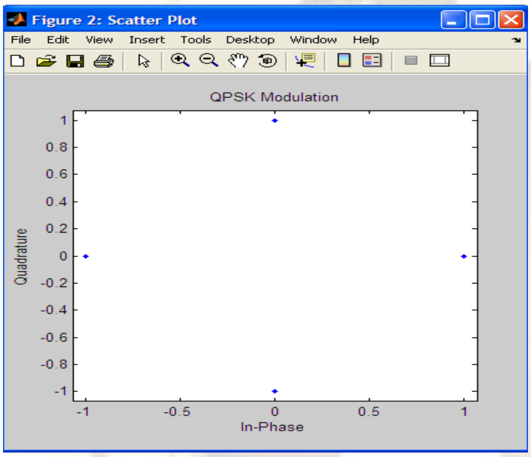
fig 6: Integrated BER Performance under SUI-4 channel.

V.SIMULATION RESULTS

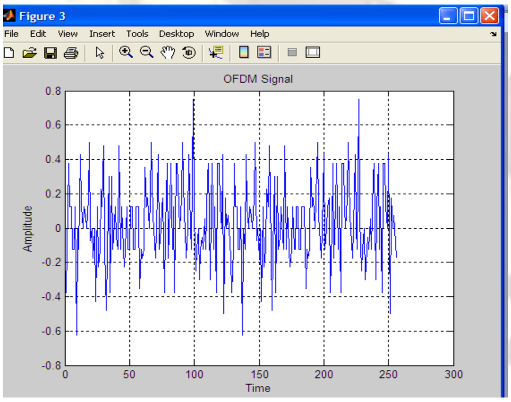
1.INPUT DATA IS SHOWN IN THE FIGURE BELOW



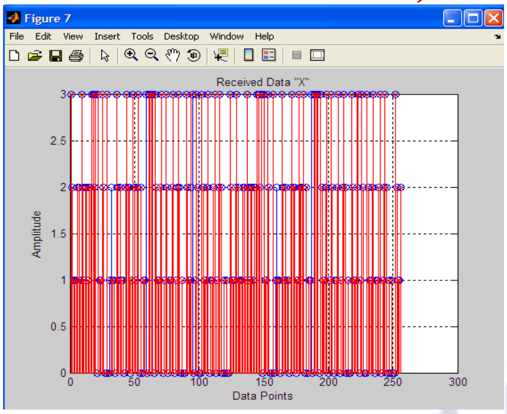
2.The constellation of the input data is shown in figure below:



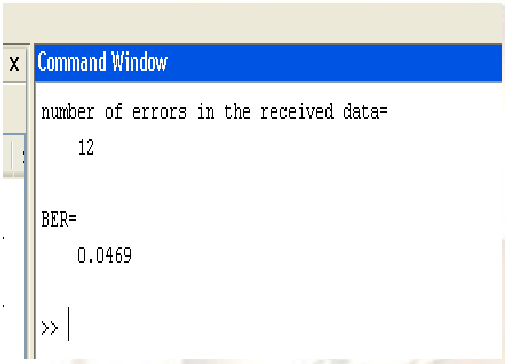
3.The figure below shows the generated OFDM signal



4.The following figure shows the receiver output compared with the original symbols.



5.BER analysis after comparing input and output



V. CONCLUSION

There are some synchronization schemes for compensating CFO and TO in the IEEE 802.16e subscriber station. We also propose the algorithms of channel estimation and frequency equalizer to correctly detect the received data after synchronization. In the numerical experiments, we demonstrate the integration performance of combining both inner receiver and outer receiver under SUI-4 channel. According to the simulation results, the proposed algorithms resolve CFO and TO effectively
with low complexity.

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