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# Analysis of Timing and Frequency Offset Estimation of OFDM System using Scaled Precision Model

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## Abstract

Orthogonal Frequency-Division Multiplexing (OFDM) is a robust multi carrier modulation system most commonly used in many wireless communication standards. The overall OFDM system performance is stable over signal distortions caused by multipath fading channels but synchronization problems caused significant quality degradation at receiver side. In recent years many papers have been published to mitigate this synchronization problem still the overall system performance is getting worsened due error caused by fixed point model. In this paper we analyzed the limitations of the fixed point computations in timing and frequency offset estimation and its performance in terms of error rate. Here we carry out both analytical approach and statistical results obtained through extensive numerical simulations and the bit length of floating point IEEE 754 standard single precision formats is optimized with the required degree for an accurate offset estimation to reduce OFDM design complexity. Also, a unique floating point precision model for error less FFT computations for all mapping levels used in OFDM system. The proposed scaled floating point precision model is compared over full precision model and its efficiency against fixed point model in OFDM synchronization process is proved through MATLAB simulations. Finally through FPGA hardware synthesis the complexity reduction of proposed scaled precision model is proved in basic arithmetic models such as adder and multiplier against single precision format. Here we proved the resource utilization rate is reduced by half as compared to standard full precision models without compromising any quality degradations. The computational error free nature of proposed scaled precision model in both timing and frequency offset estimation process and its overall OFDM system performance in terms of BER rate is proved.

**Keywords:** Customization, Fast Fourier Transform, Floating Point Aithmetic, OFDM, Synchronization

## 1. Introduction

OFDM is most commonly used in recent wireless standards like WLAN, DVB, and 3GPP etc. for its robustness against multipath fading[1,2]. Even when the entire channel is subject to frequency selective fading each sub channel will experience only flat fading. Though it has several advantages over all other multicarrier modulation technique still OFDM has some potential drawback because of its high sensitivity towards receiver synchronization imperfections that leads time[3] and frequency errors[4]. In recent years many works described the problems over synchronization process. But in all these methods they were proved the efficiency only through numerical simulations. In most cases they are not considering numerical errors happened during hardware

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implementation of OFDM systems in real time. Since the arithmetic complexity floating-point computation is very high fixed-point computation is highly desirable for arithmetic computations where truncation errors are unavoidable.

Only through baseband modulated sequence both timing and frequency estimation is carried in all methods[5]. Through FFT only sampled finite length trained sequences are converted into baseband signal for transmission. During FFT computations twiddle factors are optimized into integers after quantization this will leads quantization errors.

Many works have already been published to minimize the truncation error caused in fixed point arithmetic computation but error caused by quantization is unavoidable since fractional parts are not covered in integer arithmetic based FFT computation. All these quantitative errors have major impact in estimating offset levels at receiver side.

In hardware implementation of FFT modules base band modulated complex symbols were used for representing input sequence, where the symbol size of 32- bit will be used to cover all possible dynamic ranges during computations.

The primary goal of this research is to optimize the bit size of IEEE floating point single precision format to equalize its complexity similar to as that of fixed point arithmetic in FFT computation and to prove its performance in accurate estimation of timing and frequency offsets over fixed point arithmetic. In this paper, comparative implementations of customized floating point core over single precision IEEE 754 is carried out to prove the efficiency in terms area and power, quality improvements over fixed point computation to prove the errorless computation.

## 2. OFDM Synchronization

### 2.1 Preamble

In OFDM synchronization data aided schemes performance well and exhibits accurate offset estimation results over blind estimations process. In data aided methods standard training sequence were used for offset estimation called preambles as shown in Figure 1. The 802.11a standard preamble types consists of identical training symbols which is repeated over period of time. Here each preamble is transformed into a complex symbols using IFFT computation as shown in Figure 1.

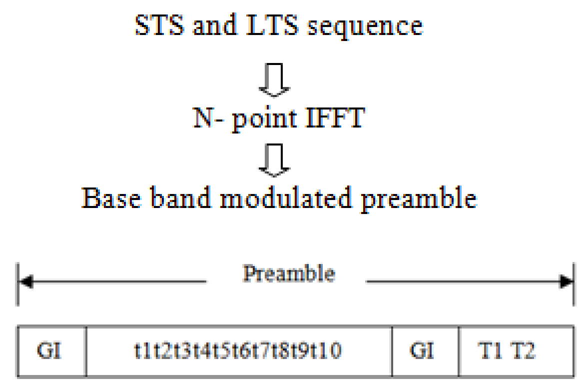


**Figure 1.** IEEE 802.11a Preamble.

### 2.2 Timing offset Estimation

Timing synchronization is always achieved through symmetrical properties of shot and long sequence in the time domain. At the receiver side the received signal is correlated with a delayed version of the same signal. Through this autocorrelation the beginning of the frame is estimated since only the autocorrelation output will be higher only for preamble while ordinary OFDM symbols don't have this periodic structure. Though only simple arithmetic Equations are required for timing offset estimation as shown in Figure 2but it is accomplished using several multipliers as described in Hamed Abdzadeh et al[7]. From the periodic structure of training sequence frame detection is easily carried out from the peak values at the cross correlation output. But this peak magnitude is highly sensible to multipath propagations in wireless channels, which makes timing estimation task is a difficult process.

$$Y(n) = yr\ LTS(n) * y\ LTS(-n). \tag{1}$$

Where * is the convolution operator, yr LTS is the received sequence and y (n) is the output.

$$Ck = \sum_{n=0}^{L-1} rk - m * Xm \tag{2}$$

Where L is the length of the cross-correlation

### 2.3 Frequency offset Estimation

Since frequency offsets are completely discrete parameters, for an accurate carrier frequency an offset unique method has been used as mention in Zoran Cvetkovic et al[8]. As we discussed earlier any fixed point model based offset estimation always cause numerical errors. Accurate CFO estimation can be done using full precision arithmetic model rather than fixed point model but full precision is not feasible solution due to its high complexity. OFDM received sequence changed its form due to CFO as shown in Equation (3).

$$\mathrm{rm} = e^{j2\pi f\epsilon n} \sum_{n=0}^{L-1} \mathrm{sm} - \mathrm{nhn} + \mathrm{wn}, \qquad 0 \le m \le N-1 \quad . \tag{3}$$

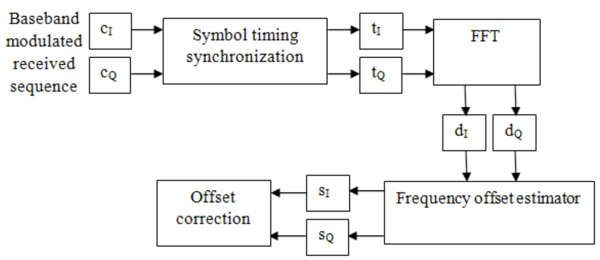


**Figure 2.** Architecture of Timing and Frequency Offset Estimator.

## 3. Performance of Base Band System over Precision Level

### 3.1 Fixed vs. Floating-point

As we discussed earlier 32 bit complex symbols are used in FFT computations. Here for basic arithmetic computation 16 bit MAC units are required. A natural tradeoff is always exists between bit widths required for maximum computational accuracy over hardware resources utilized. But in the case of fixed point computation quantization errors are unavoidable. So here overall precision is driven by quantization. For the inclusion of fractional bit width IEEE 754 single precision floating point is required.

Here exponents are used to cover dynamic range during arithmetic computation. By knowing outcome dynamic range one can reduce bit width required for exponent. Mantissa is used to represent fraction part of the number which decides overall precision level. Number of bits used in mantissa can be optimized at the expense of precision.

**Table 1.** Bit size model for various arithmetic

**Fixed point arithmetic:**

| Sign | Integer part | Fractional part |
|---|---|---|
| 1 | 15 | 0 |

**Floating point arithmetic (single precision model):**

| Sign | Integer part | Fractional part |
|---|---|---|
| 1 | 8 | 23 |

**Customized arithmetic (scaled precision model):**

| Sign | Integer part | Fractional part |
|---|---|---|
| 1 | 5 | 10 |

### 3.2 Analyzes of Dynamic Ranges

In any real time digital implementation to reduce the design complexity and memory requirements computation results are always truncated to keep the word length same using appropriate groups of operations, but the word length size is increased linearly after each computations by fixed number of bits and need additional bits to accommodate accurate final results. Here through MATLAB simulations dynamic ranges of various mapping orders are calculated and its absolute difference is analyzed over full precision model as shown in Figure 3. Behavior of overall system performance with proposed model over channel offset estimation is also verified and accuracy level is measured through MATLAB simulation as shown in Figure 4.

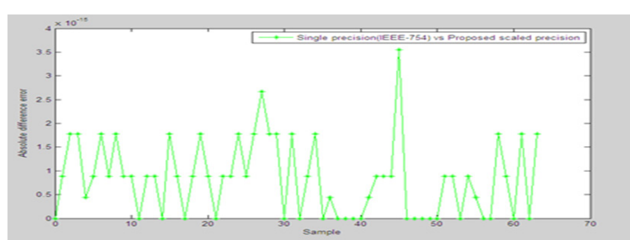


**Figure 3.** Computational Error Abs Differences Full Precision vs. Scaled Precision Model.

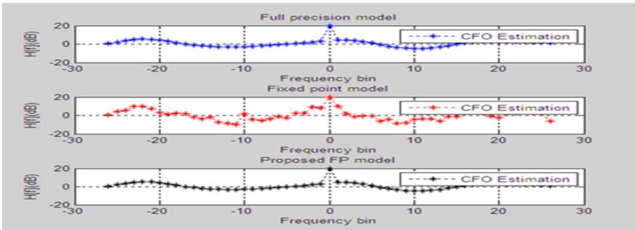


**Figure 4.** Performance Analyzes of Channel Estimation.

## 3.3 Timing offset Cancellation

In this work we focus only on how the baseband modulated systems at the transmitter part which includes IFFT leads the overall timing estimation. The following considerations help us to study the importance of errorless arithmetic computation. With fixed point baseband modulated system due to the presence of numerical computational errors misdetection is happened as shown in Figure 5.

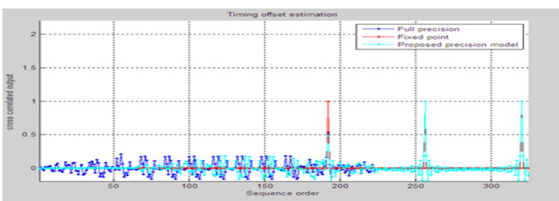


**Figure 5.** Timing offset Correlator Performance Analyzes over Various Computation Arithmetic.

This will leads symbol-timing offset errors which have to correctly estimated and compensated. More specifically, if we include fractional part of twiddle factors and truncation free baseband system the frame boundaries are detected with accurate peak value at the cross correlation output which is obtained at the receiver side.

## 3.4 Frequency offset Cancellation

Frequency synchronization is the most crucial thing in OFDM communication system. In particular, OFDM is highly sensible to Carrier Frequency Offset (CFO), which may be introduced by oscillator mismatch between Transmitter (Tx) and Receiver (Rx) and/or Doppler shift. If any numerical errors occurs during estimation of frequency offset CFO will not get compensated fully at the Rx which leads accumulated phase rotation, amplitude degradation, and Inter Carrier Interference (ICI) with all these things the overall system performance is severely degrade as shown in Fig. Thus, accurate CFO estimation is indispensable for OFDM systems.

The possibilities of numerical computation error occurrence in frequency estimation is quite high as compared timing estimation since FFT computation is involved in the receiver side. The need of error less arithmetic computation is relatively high for frequency estimation.

## 3.5 Customizable Floating Point Format

In full precision model dynamic ranges during computation is covered by exponent bit-width. Here we derived the maximum word length required for various modulation types with maximum possible FFT size from Table2.

From our simulation results, we found that the accuracy level of FFT computation is not degraded when reducing the bit-size of exponent and mantissa. This bit width optimization range over the standard IEEE floating point models will lead the way to use full precision model in all wireless applications with low complexity. The optimized model has the exponent bit-width requirement as given in Table 2, and finally we derived the statistical model with modified precision which has 10 bit mantissa and 5 exponent bit width.

**Table 2.** Dynamic range of modified FP unit

| Format | Bit width (bits) | Sign (bits) | Exponent (bits) | Mantissa (bits) | Bias | Min | Max |
|---|---|---|---|---|---|---|---|
| Single precision | 32 | 1 | 8 | 52 | 127 | $1.4 .10^{-45}$ | $3.4 .10^{38}$ |
| Double precision | 64 | 1 | 11 | 23 | 1023 | $4.9 .10^{-324}$ | $1.8 .10^{308}$ |
| Customized FP | 16 | 1 | 5 | 10 | 15 | $2.9 .10^{-8}$ | $6.6 .10^{4}$ |

## 4. Results and Analysis

### 4.1 Simulation Results and Analysis

In this section, the BER performance analyzes of OFDM system is carried out over timing and frequency offset estimation using proposed scaled precision model with IEEE 754 full precision model using MATLAB. Here OFDM system has following parameters, number of subcarriers - 64, modulation - 16-QAM, Guard length-N/4, and for synchronization 802.11a prescribed short term and long term sequence are used as a preamble structure. As shown in Figure 5 for lower SNR range there is no significant performance gap between proposed scaled precision models over full precision model. From this simulation results we can conclude that the proposed model can be used for loss less arithmetic in OFDM system.

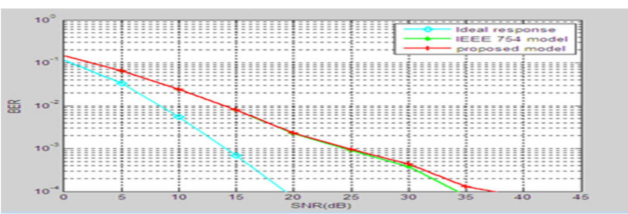


**Figure 6.** BER Performance Analyzes of Proposed Scaled Precision Model

### 4.2 Hardware Synthesis Results

The OFDM design complexity for an accurate synchronization scheme fully depends on bit-width used to represent the training symbols and arithmetic model used for computation. In this paper, we compare the area efficiency of our proposed scaled precision model over full precision floating point units to prove the complexity reduction. The proposed arithmetic models are described using the Verilog HDL and synthesized using FPGA synthesizer tool. As shown in Table3and Table 4, the proposed scaled precision model consumes lesser hardware as compared to full precision model. The attainable complexity reduction is more in time synchronization module since number of arithmetic computation units required is very high, and its performance metrics is more in CFO estimation process since transformation is used both transmitter and receiver for frequency offset estimation.

**Table 3.** Complexity Analyzes for Addition.

| Area utilization | IEEE 754 single precision model | Fixed point model | Customized model |
|---|---|---|---|
| LE's used(ALTERA) | 347 | 49 | 154 |

**Table 4.** Complexity Analyzes for Multiplication

| Area utilization | IEEE 754 single precision model | Fixed point model | Customized model |
|---|---|---|---|
| LE's used(ALTERA) embedded multiplier | 97<br>7 | 49<br>2 | 27<br>2 |

## 5. Conclusions

Here we reduced the complexity of floating point computation using scaled precision and its error free arithmetic computation by comparing it with IEEE 754 precision model. The impact of numerical computational error in OFDM system cause severe damages in frequency offset estimation process than timing model since CFO estimation is carried out from FFT transformed symbols. To overcome this issue high precision arithmetic is required for an accurate frequency offset computation. The proposed scaled precision can able to cover all possible outcomes during base band modulation and its error rate efficiency and hardware complexity reduction over standard model is verified. The results proved that scaled precision model based OFDM system will consume lesser hardware and provide effective solution for accurate OFDM synchronization as compared to standard fixed point and single precision models. Here it is also proved that there is no change in performance level in scaled precision model for both time and frequency offset estimation. To extend this bit width optimization for further complexity reduction one can achieve tradeoff between systems performance over complexity by reducing the mantissa bit sizes with negligible QoS reduction

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