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Carrier Frequency Offset Estimation for WLAN using Low-Complexity Decision Directed Method

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Abstract—**In this paper, a new carrier frequency offset (CFO) estimation algorithm is proposed for MIMO-OFDM based wireless local area network (WLAN) systems, IEEE 802.11ad. The existing hardware-efficient auto-correlation scheme which subsamples the short train symbol can be used for low complexity. However this method has a limitation of performance degradation. Therefore, we combine the subsampled auto-correlation scheme in a decision-directed (DD) method for the performance improvement. We show that the proposed scheme improves BER performance and SNR**.

Keywords—carrier freqency offset; MIMO-ofdm; WLAN.

I. INTRODUCTION

Recently, there has been increasing interest in millimeter wave WPANs for delivering high quality multimedia and data services. IEEE 802.11ad standard task group has worked on standardizing the 60 GHz spectrum. A key advantage of using the 60GHz band is the small sizes of radio frequency components, therefore, it is possible to employ multiple antennas on a small portable device, since it supports high data rate transmission over frequency selective fading channel [1][2]. Orthogonal frequency division multiplexing (OFDM) has been utilized as an effective transmission technique for various application areas. However, one of the main drawbacks of the OFDM system is that they are sensitive to CFO. Frequency errors usually originate from the frequency mismatch between the oscillators at the transmitter and receiver. The effect of CFO in OFDM system is the loss of orthogonality between sub carriers, which results in severe performance degradation caused by inter carrier interference (ICI). Therefore, the development of accurate CFO methods is very important for the synchronization of OFDM systems.

The previous work in [3] reduces the number of the arctangent operations by half using a novel range pointer method. By comparing the sign information of real and imaginary value of sample based auto-correlation with fine CFO estimation value, [3] removes the arctangent operation during the coarse CFO estimation. The algorithm estimates fine CFO value first and then based on the fine CFO value, Simple criteria is used for the boundary decision of integer CFO estimation. [4] proposed a hardware-efficient autocorrelation Scheme for the CFO estimation of MIMO-OFDM based WLAN system. An efficient correlation scheme is commonly required for the CFO estimation. To reduce the complexity of the system, [4] proposed a scheme to use subsampled auto-correlation and time-multiplexing technique for MIMO-OFDM systems. However, there is some performance degradation, since its complexity reduction is based on subsampling the inputs, short training symbols. In this paper, we propose a scheme to integrate the sample reduced auto-correlation scheme in a decision directed (DD) CFO estimation method for IEEE 802.11ad MIMO-OFDM based WLAN systems in order to improve the performance with ignorable complexity increase.

II. integration of low complexity auto correlation and decision directed method.

Range point method is a new low-complexity CFO estimaton scheme. This algorithm reduces the number of the arctangent operations by half using a novel range point method [3] by comparing the sign information of real and imaginary value of 16 sample based auto-correlation [4] with a fine CFO estimation value, and it can remove the arctangent operation during the coarse CFO estimation. Decision directed (DD) CFO estimation method [5] is widely used for reducing the overhead mostly in the tracking stage, since the tracking bandwidth is narrow enough to use the DD method.

A. Low-Complexity Range Pointer Method

In [3], a novel range pointer method is proposed for low complexity CFO estimation by simple comparison operations between real and imaginary values of the fine CFO value. Also, the number of arctangent operation is reduced from 2 to 1. Firstly, it divides the total CFO estimation region (±1.5) into two parts, Case I and II. The selection of the case depends on the fine CFO value. The reason why it divides the estimation region into two parts is to prevent severe error in the integer value of CFO. If an error occurs in the integer value of CFO, the performance of the CFO estimator will be dramatically decreased. For Case I, the coarse CFO result is obtained by comparing the normalized CFO value, $\varepsilon = 0$, 2 and ±1.0 value. Also, Case II is sensitive to integer value error near ε = 0, 2 and ±1.0 axes under low SNR. Therefore, the two cases, Case I and Case II, are combined to reduce the integer CFO error in [3].

B. Subsampled Auto-Correlation Technique

A hardware efficient auto-correlation scheme needs to be developed for the CFO estimation of MIMO-OFDM systems. The main issue of the auto-correlation is the optimization of the calculation scheme while reducing the number of samples and their bit-widths [4] [6] [7]. The key idea of these techniques is that the frame detection and timing synchronization only require the argument of the maximum correlation value, whereas CFO estimation requires precise correlation value itself.

In OFDM system, the auto-correlation is used to calculate the phase difference between two successive training symbols to estimate CFO value. For MIMO system, these autocorrelation values can be simply combined using a maximal ratio combining (MRC) which provides better performance due to the improved receiver diversity [8]. In MIMO-OFDM WLAN system, the auto-correlation and the CFO estimation are defined as equations in (1) and (2)

$$A(n) = \sum_{j=1}^{N_r} \sum_{k=0}^{L_x - 1} r_j(n+k) r_j^*(n+k-L_x) \quad (1)$$

$$\varepsilon = \frac{N}{2\pi L_x} \tan^{-1}\left(\frac{\mathrm{Im}\{A(n)\}}{\mathrm{Re}\{A(n)\}} \right), \quad (2)$$

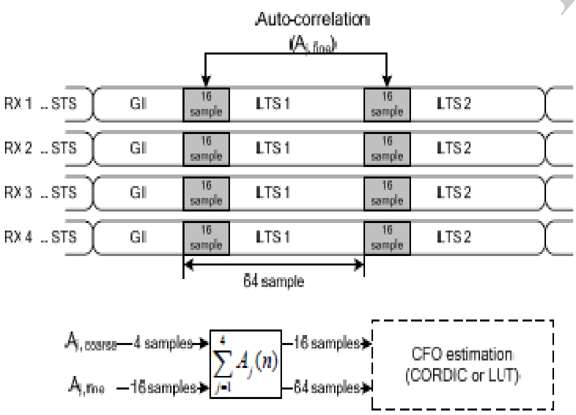

Figure 1. Subsampled auto-correlation

Where *Nr* is the number of receive antenna, *Lx* is the length of short and long training symbol, 16 and 64, respectively. N is an FFT size, ε is normalized CFO value. In [9],even though the delay registers for coarse CFO estimation (16 samples) and fine CFO estimation (64 samples) are shared for efficient design of a conventional SISO based WLAN, IEEE 802.11a, at least 64 delay registers are required for real and Imaginary part, respectively. When the number of receiving antenna , *Nr* , is 4, 256 delay registers are required for IEEE 802.11n legacy preamble, extension of 802.11a preamble, in Order to perform the auto-correlation in (1). An example of the straight-forward implementation of (1) without architectural transformation is shown in Fig. 1.

From the analysis of auto-correlation schemes, the high complexity block in auto-correlation is the FIFO based delay shift register. By increasing the number of receiving antennas in MIMO systems, the delay registers at each *R*x branch will be increased linearly. To solve this problem, it proposes a MIMO architecture requiring the almost same hardware complexity as SISO systems with reasonable performance loss. By keeping the system performance as that of SISO performance, we can use the fixed number of the delay registers regardless of the number of the receiving antennas. The auto-correlation method proposed in [4] is expressed in (3).

$$A(n) = \sum_{j=1}^{N_r} \sum_{k=0}^{\lfloor L_x / N_r \rfloor - 1} r_j(n+k) r_j^*(n+k-L_x) \quad (3)$$

In (3), we can easily see that the number of the multiplications and delay registers are reduced by 75%. The auto-correlation for coarse process is the same as the fine process except the number of samples.

C. *Decision-Directed (DD) CFO Estimation Method*

DD method uses a preamble or a pilot signal to estimate an initial CFO estimation value, and then applies the data signal detection technique to track the changes of the CFO value. If data decisions are available, they are used to improve the performance of CFO estimators. Reliable data decisions are available after the receiver has acquired some channel information based on the inserted pilots. Therefore, DD schemes can be utilized to improve the tracking performance of CFO synchronizers [10]. The received time domain signal, *Y'*n is transformed to the frequency domain by a DFT operation, leading to the signal, *Y'*k .

The DD estimation of the carrier frequency offset can be implemented using the following equations [10].

$$\Delta\hat{f} = \frac{N}{2\pi MT} \arg\{\varepsilon\} \quad (4)$$

$$\varepsilon = \sum_{n=0}^{N-M-1} \bar{S}'_{n+M} \bar{S}'^{*}_{n} \bar{S}_{n+M} \bar{S}^{*}_{n} \quad (5)$$

Suppose additive noise and channel estimate errors do not exist, then the difference between r (n, ε 0) and r ˆ (n) is determined by the decision errors, which caused only by the inter carrier interference.

D. Proposed CFO Estimation.

There are two ways to compensate CFO in time-domain: by using a cyclic prefix and by using a training symbol. In [6], the algorithm target is low-complexity range pointer method which reduces the number of arctangent operations. But hardware complexity is increased, since it uses each arctangent table for coarse and fine CFO estimation. In [8], a subsampled synchronization technique is proposed. It reduces the complexity of the auto-correlation operations. But it can not be applied to the CFO estimation efficiently, since the CFO estimation requires more precise correlation value, and the effect of CFO in OFDM system is more sensitive than that of the timing synchronization error. DD CFO estimation [10] provides more accurate estimation result with ignorable Complexity increase. In this paper, we utilize the DD CFO method by incorporating the low-complexity computation schemes, low-complexity range pointer method for the phase rotation [3] and subsampled autocorrelation method [4].

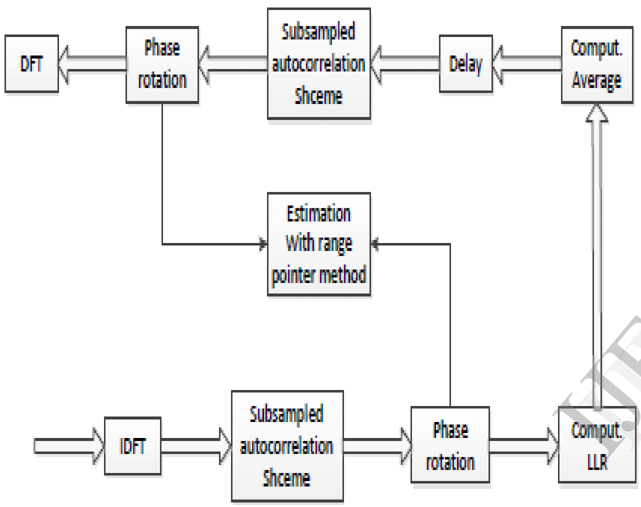

Figure 2 . Block diagram of the proposed algorithm

The proposed algorithm uses the equation (5) for DD based CFO estimation. For the frequency offset estimation, the input data is subsampled for the complexity reduction. Combining equations (3) and (5), the proposed algorithm can be written in the subsampled form of equation (6).

$$\varepsilon = \sum_{j=1}^{N_r} \sum_{n=0}^{\lfloor L_x / N_r \rfloor - 1} \bar{r}_j(n+L)\bar{r}_j^*(n)\bar{r}_j(n+L)\bar{r}_j^*(n) \qquad (6)$$

III. Simulation Results And Analysis

We performed the simulation of the proposed algorithm. The bit errors rate (BER) of the proposed algorithm and the signal to noise ratio(SNR) [4] are shown in Fig. 3. Since both algorithms use range pointer boundaries to estimate the integer part of CFO, that the performances of both algorithms under low SNR (0 dB) are severely degraded near each boundary. It means the performance of both algorithms depends on the estimated CFO value. Simulation result shows that BER improve with increase the value of SNR compare to without carrier frequency offset compensation. In figure 4 it is clear that the percentage carrier offset estimated error (CO) has maximum at 3% of carrier offset.

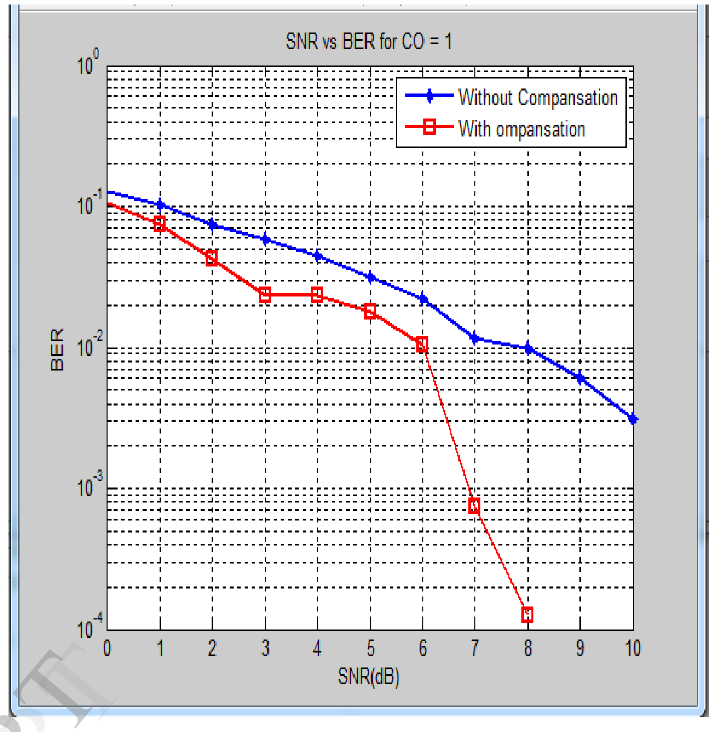

Figure 3: BER v/s SNR plot for Carrier offset

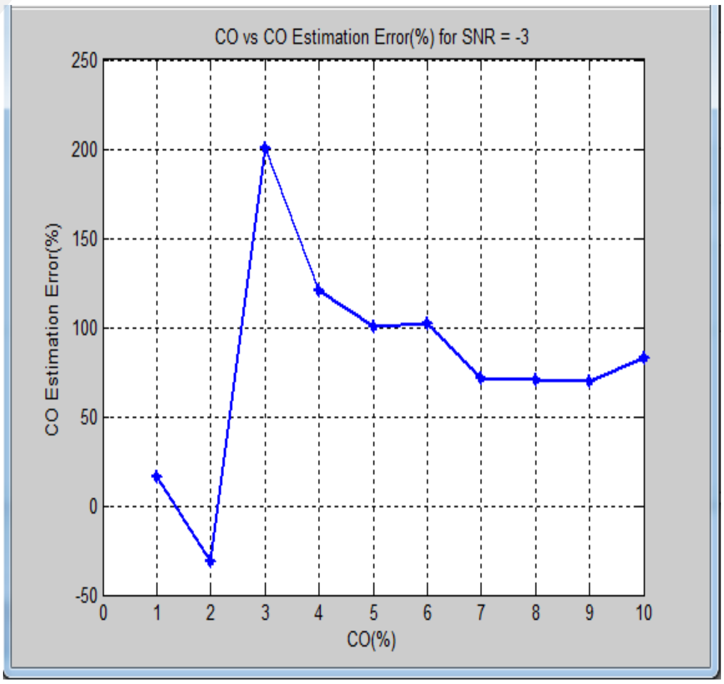

Figure 4: Carrier estimation error v/s Carrier offset% plot

Table 1. Complexity analysis

CFO estimation procedure	Operation	Requirement		
		Using all STS	[4]	Proposed algorithm
Coarse CFO	Auto-correlation (D=16)	Y	Y	Y
	Tan^{-1}	Y	N*	Y
	CFO compensation	Y	N**	N**
Fine CFO	Auto-correlation (D=64)	Y	Y	Y
	Tan^{-1}	Y	Y	Y
	CFO compensation	Y	Y	Y

* simple boundaries, ** joint compensation, Y: required, N: not required

IV. CONCLUSIONS

In this paper, we proposed the new CFO estimation algorithm using the DD algorithm with the subsampled low complexity CFO operations. The proposed CFO estimation algorithm improves the performance with reasonable complexity increase compared to conventional low complexity CFO estimation algorithm. The proposed algorithm is suitable to hardware implementation of next generation MIMO-OFDM based IEEE 802.11ad WLAN systems.

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