Estimation of Carrier Frequency Offset for OFDM Systems

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Abstract- **In this paper, proposed a Blind Maximum likelihood estimation (MLE) technique for the estimation of carrier frequency offset (CFO) in wireless orthogonal frequency division multiplexing (OFDM) systems. The proposed scheme is based on the assumption that the channel slowly changes in the time domain with respect to the OFDM symbol duration. Based on this assumption, cost function is derived and identity matrix is used at the higher order of the terms of cost function. We demonstrate that the proposed scheme has superior performance and having least significant of mean square error (MSE) at higher signal to noise ratios (SNRs). In the maximum likelihood technique, numerical iteration for blind estimation of carrier frequency offset gives low complex. It has fast convergence and achieves high accurate estimation.**

Keywords: Orthogonal frequency division multiplexing (OFDM); Carrier Frequency Offset (CFO); Mean square error (MSE); Signal to noise ratios (SNRs); Blind Maximum likelihood estimator (MLE).

I. INTRODUCTION

With the increasing demand for wireless multimedia applications, it is desirable to design wireless system with higher data rates. Furthermore, the frequency spectrum has limited and valuable source, making it necessary to utilize the available spectrum efficiently and co-exist with other wireless systems. Thus future wireless technology is required to operate at high data rates, at high carrier frequencies under the environment of high mobility and large spectrum interference, while the data transmission still remains reliable and supports multiple users. Orthogonal frequency division multiplexing (OFDM) technology is at the core of multicarrier systems that play a crucial role in fulfilling the above requirements [1].

In a communication system based on OFDM technique, a receiver needs to synchronize with a transmitter in frequency, phase and time to faithfully reproduce the transmitted signal. Frequency offset in OFDM system is introduced by the mismatch between transmitter and receiver sampling clocks and misalignment between the reference frequency of transmitter and receiver stations. The sampling clock errors appear in two ways.

- A slow variation in sampling time instant causes rotation of sub-carriers and subsequent loss of signal-to-noise ratio (SNR) due to inter carrier interference (ICI) and
- It causes the loss of orthogonality among sub-carriers due to energy spread and adjacent sub-carriers.Let us defined the normalized sampling error as

$$t_\Delta = \frac{T' - T}{T} \qquad (1)$$

Where T and T' are transmit and receive sampling periods respectively and the power is approximated by

$$Pt_\Delta \approx \frac{\pi^3}{3}(Kt_\Delta)^2 \qquad (2)$$

where K = sub-carrier index.
Hence, the degradation grows as the square of offset t_Δ and the sub-carrier index K. this means that the outer most sub-carriers are most severely affected. The OFDM system with a large number of sub-carriers is very sensitive to the sampling offset.

II. WIRELESS COMMUNICATION CHANNEL

The wireless channel is the defined as a link between a Transmitter and a receiver and classified considering the coherence bandwidth and coherence time. The multipath channel generally has a bandwidth where channel variations are highly correlated. This bandwidth is called the coherence bandwidth $(\Delta f)c$. When signal is transmitted through a channel, if (Δf) c of the channel is small compared with the bandwidth of the transmitted signal, the channel is called to be frequency selective. In this case, the signal is severely distorted by the channel. And, if (Δf) c is much larger compared with the bandwidth of the transmitted signal, the channel is called to be frequency nonselective or flat. For the measure of frequency selectivity of the channel, there are two important parameters;

- The average excess delay
- The root mean square (RMS) delay spread.

The Rayleigh distribution is commonly used to describe the statistical time varying nature of the envelope of a frequency non selective (flat) fading signal, or the envelope of an individual multipath component. In this case, the channel is called a Rayleigh fading channel. On the other hand, when a direct path is available or the channel signal reflectors. In this case the envelope as a Rice distribution and the channel is called, a Ricean fading channel. Rayleigh distribution and Ricean distribution describes the envelope fluctuation for an individual multipath component in the channel, the multipath intensity profile or spaced-frequency correlation function determines the frequency selectivity of the channel, and the Doppler power spectrum or spaced-time correlation function determines the time selectivity of the channel. Multipath delay profiles are used to describe frequency selectivity of a channel. There are a fixed number of paths with equidistant delays and the average received powers of multipaths are exponentially decaying. It is an exponentially decaying profile.

The three factors to describe the fading characteristics that a transmitted signal experiences in a channel, the p.d.f. of the envelope, frequency selectivity, and time selectivity. They are independent, so there are many combinations to consider. For instance, when no line-of-sight component is available in a channel, the data transmission rate is very high. The receiver is installed in a high-speed cruising vehicle, the channel will be a frequency selective fast Rayleigh fading channel,the data transmission rate is very low. Then the receiver is installed in a stationary terminal, the channel will be a frequency nonselective slow Ricean fading channel. Figure I shows the relation among the number of sub-carriers, frequency selectivity, and the time selectivity. The OFDM systems are more sensitive to frequency error than the single carrier frequency systems. Carrier frequency offset is the difference in carrier frequency at the transmitter and receiver. Carrier frequency offset due to Doppler frequency shift or frequency mismatch between the transmitters and receivers

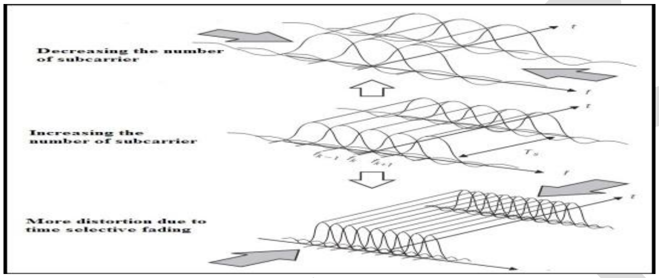

Fig. 1 Relation Among Number of Subcarriers, Frequency Selectivity and Time Selectivity [1].

III. CARRIER FREQUENCY OFFSET

Oscillators introduce severe inter-symbol and inter-carrier interference into OFDM system [1].This effect becomes more severe when compounded by the presence of Doppler fading in wireless channels. The degradation is caused by the reduction in the signal amplitude of the desired sub-carrier and the ICI from the neighboring sub-carriers, as shown in Figure I. The amplitude loss occurs because the desired sub-carrier is no longer sampled at the peak of the equivalent sinc function of the DFT. Adjacent sub-carriers cause interference because they are not sampled at their zero crossings. The overall effect of carrier frequency offset effect on SNR is analyzed as degradation in decibels is

$$SNR_{loss}\,(dB) \approx 10/3\ln 10(\pi T\Delta f)^2\ Es/No \qquad (3)$$

where, Δf=frequency offset T=sample period.

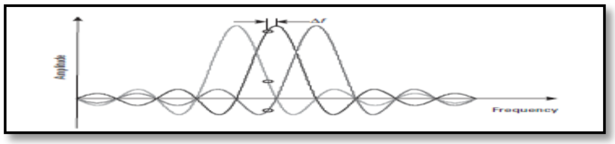

Fig. 2 Loss of Orthogonalitiy due to Sampling Offset [1]

It is required to reduce this offset to a minimum for proper performance. There are two offset estimation techniques has been proposed.

A. Blind estimation:
B. Semi Blind estimation

IV. BLIND ESTIMATION

Blind estimation is such technique which did not required any training symbol of pilot sub-carriers and performed well in frequency selective channels. This technique has low complexity due to use of minimum number of operations of multiplication and division. It has rapid time selectivity because it requires only short duration for channel staionarity. Maximum likelihood scheme is able to decode with probability close to one. It has fast convergence and achieves high accurate estimation [2].

The blind detection blind channel estimation based on the cyclic prefix is that this channel estimation concept is standard-compliant and can be applied to all commonly used OFDM systems that use a cyclic prefix. The blind detection without the necessity of pilot symbols for coherent detection is possible when joint equalization and detection is applied. This is possible by trellis decoding of differentially encoded PSK signals where the trellis decoding can efficiently be achieved by applying the Viterbi algorithm.

Typical algorithm structure includes stochastic gradient algorithm, recursive estimator, prediction error filtering, sub space algorithm and iterative techniques for maximum likelihood estimation. The main design goal of a blind estimation are fast convergence to an operating point where the detection of information symbols is reliable as well as low computational complexity.

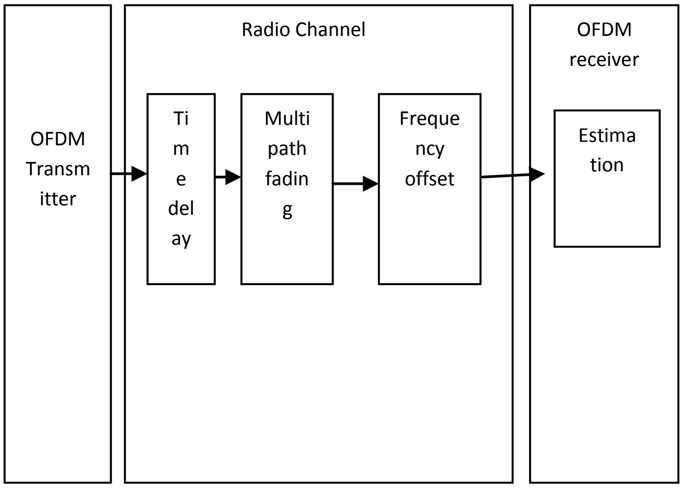

Fig. 3 Blind System Model

V. SIMULATION RESULTS AND PLOTS

The system performance is assessed using Monte Carlo simulation over white Gaussian noise (AWGN) and frequency-selective multipath fading channels. In each simulation run 10^6 OFDM symbols are used. The performance is evaluated by means of normalized MSE, where the MSE of CFO estimates is normalized with respect to the subcarriers, frequency spacing. The OFDM system considered in this paper has N=256 subcarriers modulated using quaternary phase-shift keying, Ng=64.

In figure 1, the MSE of the proposed ML estimator is compared with the MSE of the estimator in Kurtosis. It may be seen that the MSE of both estimator decreases for SNR ≤ 22 dB but at higher SNR that means SNR > 22 dB, the ML estimator outperforms with respect to Kurtosis- type scheme. The MSE difference becomes least significant at higher SNRs. For the evaluation of MSE in moderate frequency-selective fading channels, uses the channels 1 and 2, which have mean square delay spreads σ^2(τ) = 1.74 and σ^2(τ) = 6.37 respectively. Figure 2 shows the mean square error performance of the proposed method and comparison with a technique reported in [7]. The MLE outperforms for the entire range of SNRs over both channels for zero Doppler shifts as compared to [7].

To evaluate the MSE performance of the proposed system over time-varying frequency-selective fading channels, consider the two different maximum Doppler shifts, fd = 50 Hz and fd = 200 Hz which correspond to vehicle speeds of approximately 24.5 and 98 km/h, respectively. The MSE of the MLE and that of the estimator in [7] start to converge for vehicle speeds ≥ 100 km/h, figure 3 shows that the MLE maintain its efficiency at higher SNRs even in time-varying channels.

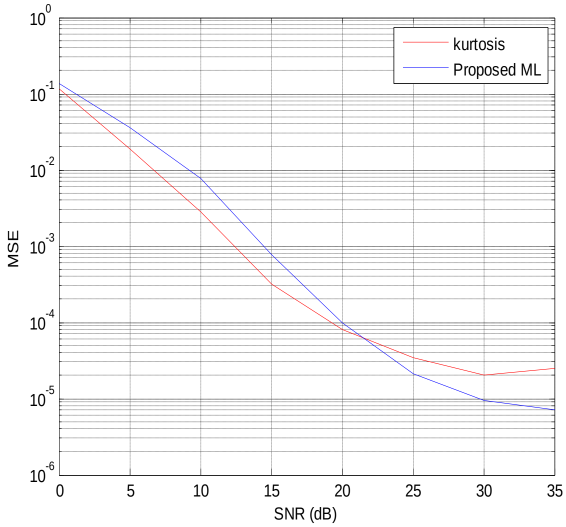

Fig. 4 MSE versus the SNR over AWGN channel: L=1

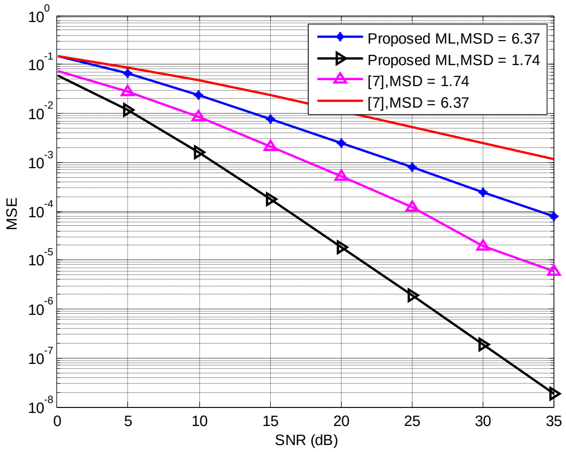

Fig. 5 MSE versus the SNR for frequency-selective fading channels with different delay spreads, L=1, and fd = 0.

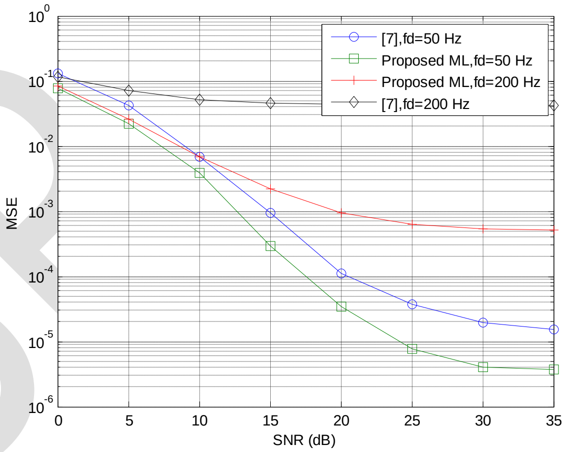

Figure 6 MSE versus the SNR for different Doppler shift values, L=1, σ^2(τ)= 20, fd=50, and 200 Hz.

V. CONCLUSION

In this paper, we have proposed a blind ML estimator of frequency offset in OFDM systems. In the proposed scheme identity matrix is used at the higher order of the cost functions and decreases MSE at higher SNRs. It has rapid time selectivity because it requires only short duration for channel stationarity. The MSE performance of the proposed algorithm is compared with that of Kurtosis- type scheme and technique in [7]. The proposed estimator is shown to yield a better performance compared to the existing techniques.

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