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Secant Method based CFO Estimation and Correction for MC-CDMA Systems over Rayleigh Flat Fading Channel

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Abstract:
In this paper Multi-Carrier Code Division Multiple Access (MC-CDMA) has been proposed as one of the air interface possibility for the fourth era remote correspondence frameworks. Be that as it may, MC-CDMA frameworks endure a great deal of execution corruption because of transporter recurrence balances. In this paper proposes a Numerical Technique dependent on the secant strategy for dazzle Maximum-Likelihood (ML) estimation of transporter recurrence balance in MC-CDMA Systems over Rayleigh level fading channels. The proposed strategy is described by low multifaceted nature and quick union while keeping up the estimation precision.

***Keywords:** MC-CDMA, Numerical technique, ML-estimation, Rayleigh channel, carrier frequency offset (CFO).*

1. Introduction

Modern Communications Networks demand high to very high Data Rates because of Multimedia applications. In place of Single Carrier systems, this demand calls for a multiple carrier approach [9]. It is employed in European digital transmission radio system [10] and in wireless applications like digital broadcasting television [16] and mobile systems [8]. Improvement and investigation in the domain of digital signal processing and communication system have caused in wireless communication systems like MC-CDMA [1].

The frequency spectrum for wireless system is limited that needs to exploit the accessible spectrum and use it efficiently for all existing applications with future requirements. Therefore, innovative wireless methodology is necessary to function at High data rates by utilising Multi Carrier techniques. MC-CDMA technology is fundamental for multiple carrier systems which is playing a vital part in satisfying the above necessities.

MC-CDMA, identical to additional Multi-Carrier structures, suffers an excessive performance degradation caused through frequency offsets with minimization of preferred signal amplitude since the ***sin*** functions are moved and are no way tested at the peak amplitudes of sin function. Carrier Frequency Offset causes discrepancy of the oscillators in transmitter and receiver. The demodulation of a signal using an

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offset in the carrier frequency leads to bit errors and degrades the efficiency of a symbol synchronizer [17, 18]. The other negative effect is the loss of orthogonality among the sub-carriers that reduces threshold signal amplitude. ICI diminishes (SNR) and increases the error probability Bit Error Rate (BER). There also has been increasing interest in blind retrieval of CFO. Many reviews examined the performance understanding to the frequency offset for MC-CDMA systems [3] [15].

2. Need of CFO Estimation in MC-CDMA Model

Although MC-CDMA has many advantages, such as the ability to combat against the adverse effects pertaining to frequency selectivity of the radio channel, efficiency in bandwidth utilization, and the low complexity enjoyed in the implementation of transceivers, it also has drawbacks. MC-CDMA is very sensitive to CFO. The performance of MC-CDMA degrades rapidly with increasing CFO [2]. Accurate estimation and compensation for the CFO is important for MC-CDMA systems.

In this paper, the likelihood function for the CFO is derived depending on the maximum likelihood (ML) approximation approach for MC-CDMA systems for the downlink on Rayleigh flat fading channels. A gradient method is employed to evaluate and reduce the CFO in the AWGN environment. This paper ML-CFO blind estimation methodologies are focussed on Cyclic Prefix recurrence for MC-CDMA systems [5]. Therefore, a practical MC-CDMA system requires the CFO to be detected with adequate accuracy.

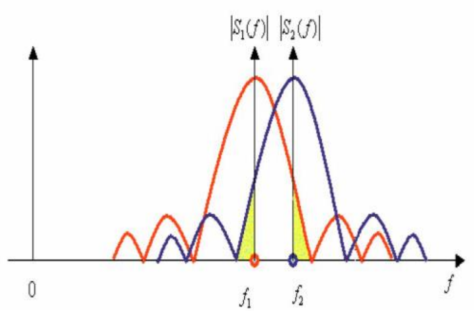

Fig 1: Illustration of ICI

3. Types of Carrier Frequency Offset Algorithms

In any broadcasting system, the received signal is CFO owing to the Doppler shift and local oscillator drift. The CFO causes a frequency change and a time-varying revolution of the data symbols to be detected for at the receiver prior to symbol retrieval. The evaluation of the CFO is a conventional issue, and could be evaluated through information accumulated or non-blind, semi blind approaches [14].

Synchronization comprises of a number of step ladders, containing frame identification, CFO and sampling error rectification [7]. Frame identification is employed to limit the symbol boundary desirable for accurate de-modulation. Between each frame, the frequency offset amongst the transmitter and the receiver accomplishes an unidentified phase shift factor [13].

Semi blind methodologies suggest the prime uncertain stage to advance the bandwidth competence [14]. Those frequently reliant are on numerous assumptions like a distinct pilot symbol, two equals' successive OFDM data blocks, or certain definite schemes inside the OFDM symbol [11].

Among various categories of blind techniques, subspace dependent techniques [14] [15] are currently found to be resulting in near performance to ML estimator [3] [4]. Those approaches are specified through the summary rank signal prototype obtained with either certain virtual carriers or unmodulated carriers at boundaries of MC-CDMA block, aims at reducing the interference attained due to neighbouring MC-CDMA systems. Even though MC-CDMA systems are matched by constructing a multiple path transmission, numerous existing CFO evaluators deal only with flat frequency channels. Blind methods do not waste bandwidth to communicate on pilot tones [14]. Nevertheless, they employ fewer data at the expense of additional complication and minimized performance [12].

In the blind CFO Estimator sub channels are completely employed to transfer actual information and the CP is not to be extended for guard intervals. The blind estimators are assumed to be bandwidth effective. These estimators of CFO in the MC-CDMA system designed on the

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root of the arrangement of the MC-CDMA frame or its elements are: Blind CFO estimators depending on the employed carriers, VC dependent blind CFO estimators, and CP dependent blind CFO estimators.

3.1 Carrier Frequency Offset (CFO)

In communications if the transmitter frequency does not match with the received frequency is called CFO. This is because of the Doppler Effect at transmitter or receiver. The transmitted signal to be received with optimal threshold, received design by means of FFT has to be modelled accurately. This outcome is characterized by phase rotation and Inter Carrier Interference that causes orthogonal collapses and oscillations. An unstable oscillator or drift presents severe inter-symbol and inter carrier interference [9]. This is evaluated using existence of Doppler fading in wireless channels. The performance diminishing results in minimization in signal amplitude of preferred sub-carrier and ICI from adjoining subcarriers, as given in Figure 2. Adjacent sub-carriers are reason for interference since they are not detected at their zero crossings.

The global influence of CFO on SNR is studied as degradation in decibels as

$$SNR_{loss}(dB) \approx 10/3ln10(\pi T\Delta f)_2 Es/No \quad (1)$$

hereΔf =frequency offset, T=sample period. CFO

affects Information

x (t) and y_n as given

$$y_n = \sum_{k=0}^{N-1} H_k.X_k.e^{i2\pi\frac{K+\varepsilon}{N}} + Z_n \quad (2)$$

CFO's effect is phase rotation in time domain. ICI occurs as the effect in frequency domain and the equation (2) is given as

$$Y_p = \sum_{m=0}^{N-1}\sum_{n=0}^{N-1} H_{k,m}.X_{k,m}.e^{i2\pi\frac{K+\varepsilon}{N}}.e^{-i2\pi\frac{m}{N}} + Z_p$$

$$= H_p.X_p e^{i2\pi\varepsilon p} + \sum_{\substack{m=0\\ m\neq k}}^{N-1}\sum_{n=0}^{N-1} H_{k,m}.X_{k,m}.e^{i2\pi\frac{K-m}{N}}.e^{i2\pi\frac{\varepsilon}{N}} + Z_p \quad (3)$$

If distinct signal among transmitter and receiver is misled, phase rotation and ICI occur similar to (4.3). $Z_p$is sampled AWGN. $\varepsilon$is regularized CFO

that is specified as Doppler frequency divided by carrier spacing.

$$\varepsilon = \frac{f_d}{carrier\ spacing}, f_d = \frac{v.f_c}{c}$$

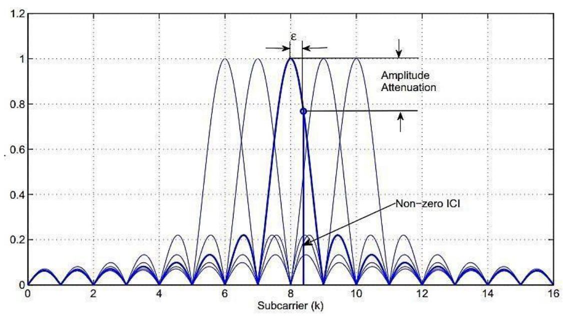

Fig 2: Carrier Frequency Offset

4. Carrier frequency offset estimation Techniques

A modified CFO estimator to improve the global system performance is suggested. In recent survey, numerous data assisted and non-data assisted CFO estimators have been communicated for multicarrier systems e.g., [7, 11, 12, 13, and 19]. Nevertheless, little attention is shown to manipulate unseen pilots for the CFO estimation. This inspired to build a CFO estimator by means of concealed pilots. It is essential to evaluate the CFO that demonstrates alteration in the broadcasted symbols and henceforth at the receiver it can be replenished by means of information in time or frequency domain.

4.1 Time-Domain Estimation

Training symbol or CP is employed to evaluate the CFO in time-domain. *CFO Estimation Methods by means of CP*: CFO (ε) with a faultless

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symbol synchronization outcome in a phase rotation of $\frac{2\pi n\varepsilon}{N}$in received signal. Whenever,

considered below insignificant channel effect, phase difference amongst the N samples apart spaced of an OFDM symbols and CP caused by CFO (ε) becomes$\frac{2\pi N\varepsilon}{N} = 2\pi\varepsilon$, CFO could be

obtained from phase angle which is the result of N samples spaced apart of an OFDM symbols and CP.

$$\hat{\varepsilon} = \frac{1}{2\pi}\arg\{y_1{}^*[n]y_l[n-N]\} \quad n = -1, -2, \ldots\ldots\ldots -N_g \tag{4}$$

Now, its mean can be considered on the samples in the CP interval so as to minimize noise effect

$$\hat{\varepsilon} = \frac{1}{2\pi} arg\{\sum_{n=-N_G}^{-1} y_1{}^*[n]y_l[n-N]\} \tag{5}$$

In Equation (5), $\arg()$ is accomplished by means of $\tan^{-1}()$, as the CFO acquisition range is $\frac{[-\pi,+\pi)}{2\pi}$ = [-0.5, +0.5), i.e. < 0.5. When there is no

frequency offset that becomes real but in fact to estimate CFO [76] for imaginary part of in this situation, the estimation error is given as:

$$e_\varepsilon = \frac{1}{L}\sum_{n=1}^{L} lm\{y_1{}^*[n]y_l[n-N]\} \tag{6}$$

Here, *L* indicate quantity of samples employed for averaging. The expectation of error function e_ε

can be estimated as:

$$E(e_\varepsilon) = \frac{\pi_d{}^2}{N}\sin\frac{2\pi\varepsilon}{N}\sum_{k\ corresponding\ to\ useful\ carriers}^{L}|H_K|^2 \approx K_\varepsilon \tag{7}$$

Also, transmitted signal power ($=\pi_d{}^2$), comprises

transmit and channel power (=K), and channel frequency response of K^{th} sub-carriers($= H_k$) .

The equation (7) is used to control Voltage Control Oscillator (VCO) which in turn the frequency synchronization can be maintained.

CFO estimation techniques by means of Training Symbol: To know within the range of $\{|\varepsilon| < 0.5\}$, the above method is valid for the

estimation of CFO. The distance amongst two blocks of samples for correlation can be reduced through increasing the range of CFO approximation. This is only possible if only the technique where training symbols which are iterative using certain shorter period are applied. Let *D* be an integer that indicate ratio of OFDM symbol length to length of iterative pattern. Suppose transmitter is transmitting the training symbols using *D* iterative patterns in the time-domain which could be formed by captivating the IFFT as:

$$X_l{}^K = \begin{cases} A_m, if\ K = D.i, i = 0,1, \ldots.(\frac{N}{D-1}) \\ 0, \quad Otherwise \end{cases} \tag{8}$$

Here, A_m =*M*-ary symbol and $\frac{N}{D}$is an integer. As

$x_l[n]$ and $x_l[n+D]$ are identical

then,$y_1{}^*[n]y_l\left[n-\frac{N}{D}\right] = |y^*{}_l|^{2e^{j\varepsilon\pi}}$ a receiver can

produce CFO, estimation as given [6,13].

$$\hat{\varepsilon} = \frac{D}{2\pi}\arg\{\sum_{n=0}^{\frac{N}{D}-1} y_1{}^*[n]y_l\left[n-\frac{N}{D}\right]\} \tag{9}$$

In this case range covered for the CFO estimation is $\{|\varepsilon < D/2|\ \}$ which becomes extensive as *D*

upsurges. In other hand the performance of the MSE might degrade as the samples for

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computational of correlation is minimized by *1/D.* It is proved that the range of CFO estimation but there causes a negative effect in MSE performance. Thus it is concluded that as MSE performance becomes worse when estimation range increases, the approximations is averaged with the recurring patterns with smaller period such as:

$$\hat{\varepsilon} = \frac{D}{2\pi}\arg\sum_{m=0}^{D-2}\sum_{n=0}^{\frac{N}{D}-1} y_l^*\left[n+\frac{mN}{D}\right] y_l\left[n+\frac{(m+1)N}{D}\right] \quad (10)$$

4.2 Frequency-Domain Estimation

When two training symbols are broadcasted uninterruptedly, then

$$y_2[n] = y_1[n]e^{\frac{j2\pi N_\varepsilon}{N}} \leftrightarrow Y_2[k] = Y_1[k]e^{j2\pi\varepsilon} \quad (11)$$

Using above relationship, the CFO estimation is given as:

$$\hat{\varepsilon} = \frac{1}{2\pi}\tan^{-1}\{\sum_{k=0}^{N-1} lm[Y_1^*[k]Y_2[k]] / \sum_{k=0}^{N-1} re[Y_1^*[k]Y_2[k]]\} \quad (12)$$

This equation (12) is a renowned methodology given in [4]. The range for the CFO estimation is $|\varepsilon| \le \frac{\pi}{2\pi} = \frac{1}{2}$, it could be augmented *D* times by

means of training symbol using *D* recurrent arrangements. In this situation Equation (12) is functioned on subcarriers having non-zero values and formerly averaged over sub-carriers. In this case also, MSE performance may degrade owing to minimized non-zero trials taken during averaging in frequency domain and also preamble period is required for the estimation of CFO

5.Multi carrier – code division multiple access model in presence of CFO

This approach considers a CP aided MC-CDMA model using 'M' subcarriers and accepting a maximal of 'k' energetic operators. As portrayed in Figure.3, every user transfers the symbols $s^k$the outcome of the CDMA generator, on entire subcarriers. Earlier than broadcasting, the symbols $s^n$are initially clustered into M×1 block,

$$S^{(n)}(n_1) = \{[S^{(n)}(n|M), S^{(n)}(n_1M+1) \ldots.., S^{(n)}(n_1M+M-1)]^T\}. \quad (13)$$

These blocks are given to the modulator to generate

$$x^{(n)}(n_1J+i) = \frac{1}{\sqrt{M}}\sum_{m=0}^{M-1} s^{(n)}(n_1M+m) \times C^{\frac{j2\pi n(i+M-P)}{M}} \quad 0 \le i \le j-1,$$

$$j=M+P \quad (14)$$

here 'n₁' represents block index, 'm' indicates subcarrier index, 'i' indicates sample index, and 'p' indicates number of trials in CP. Formerly x^n moves over the transmitted channel $h^{(n)}$ with the higher boundary of channel sequence $L_h(\le P)$ and knowledge's the frequency offset in addition to the propagation delay τ.

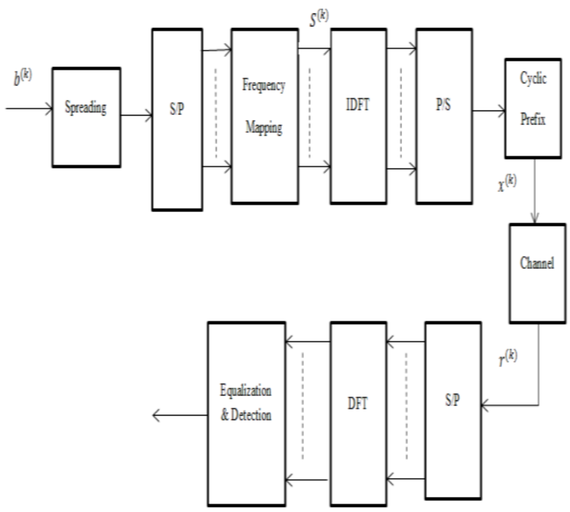

Figure.3 Block Diagram of MC-CDMA system

The obtained discrete-time comparable signal is

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$r(n_1, j+i) = \sum_{n=1}^{n} e^{\frac{j2\pi v^{(n)}\left(\frac{nj}{i}\right)}{M}} r(n) \times (n_1 J + i) - \mu^{(n)} + v(n_1 J + i)$ (15)

Here, $r^{-(k)}$ is the signal for n^{th}user and is written as

$r^{-(n)}(n_1 J + i) = \sum_{i=-\infty}^{\infty} x^{(n)}(i) h^{(n)}(n_1 J + i - 1)$ (16)

V is zero mean Gaussian noise, the regularized frequency offset is specified as $V^{(n)} = \left(\frac{\delta f}{\Delta f}\right) = n_0 + \varepsilon$, where $\Delta f$is sub-channel's bandwidth. $n_0$is an integer and $0 < \varepsilon < 1$. Let suppose that, however solitary, that entire active users are finely coordinated i.e.$V^{(n)} = 0, \mu^{(n)} = 0$, (k=1, 2, 3… K-1).

Receiver abandons cyclic prefix (CP) fragment and executes the DFT on achieve the frequency-domain form of the acknowledged signal

$\bar{r}(n_1 M + m) = \sum_{n=1}^{n} \tilde{h}^{(n)}(m) s^{(n)}(n_1 M + m) + \bar{v}(nM + m), 0 \leq m \leq M - 1$ (17)

Where

$$\tilde{h}^{(n)}(m) = \sum_{l=0}^{L_n} h^{(n)}(l) \exp\left(-\frac{j2\pi lm}{M}\right)$$ (18)

$\bar{V}$ isthe frequency-domain form of the noise.It is observed that obtained signal is superposition of entire dynamic individuals. Symbol identification desires the channel state information along with the appropriate plan of $s^{(k)}$. In the existence of CFO, obtained signal is multiplied with Φ (where $\Phi = \mathrm{diag}(1, e^{j\phi}, , , , , , , , e^{j(N-1)\phi})$, where $\Psi = 2\pi\varepsilon/N$ then

$$r = \Phi W_p H X + n_1$$ (19)

orthogonality amongst subcarriers is not preserved at receiver side, $(so\ W_p^H \Phi W_p \neq I)$ ICI rises.

Setting $\bar{X} = HX$ becomes

$$r = \Phi W_p \bar{X} + n_1$$ (20)

Unknown parameters are $\bar{X}$and Φ.

6.Numerical approach for estimation of carrier frequency offset using Secant method

The presence of CFO disturbs signals in the systems with increased distortion and causes ICI that reduces the efficiency of Multiple Carrier CDMA systems. Therefore, it is essential to estimate the CFO that is present in system and correct the Offset or Adjust the Offset within the model. In this section, a numerical methodology is suggested for evaluation of CFO in the MC-CDMA model. The Frequency Offset is estimated using the ML approach and incorporating the mathematical ***secant*** method for near estimation in the Likelihood. The numerical generation for blind evaluation of CFO provides fewer problems.

6.1 Maximum Likelihood Estimation (MLE)

For MLE, the complicated Gaussian noise vector is considered using the covariance matrix σ^2. The likelihood/ probability function (L) of $\bar{X}$ and Φ is defined as [4].

$$L(\Psi, \bar{X}) = \frac{1}{(\pi\sigma^2)^N} . e^{-\frac{1}{\sigma^2}(r - \Phi W_p \bar{X})^H (r - \Phi W_p \bar{X})}$$ (21)

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The ML estimates of $\bar{X}$ and Φ maximizes likelihood function or diminishes score function.

$$S(\Phi,\bar{X}) = (r - \Phi W_p \bar{X})^H (r - \Phi W_p \bar{X}) \quad (22)$$

So as to evaluate $\bar{X}$, gradient score function pertaining to $\bar{X}$ need to be set to zero.

$$\nabla_{\bar{X}} S(\Phi,\bar{X}) = 0 \Leftrightarrow W_p^H \Phi^H (r - \Phi W_p \bar{X}) = 0 \Leftrightarrow \bar{X}_{ML} = W_p^H \Phi^H r \quad (23)$$

The estimate of $\bar{X}_{ML}$ has the similar form of Φ, thus estimation of X might be substituted in (23) that consequences as

$$L'(\Psi) = L(\Psi,\bar{X}_{ML}) = \frac{1}{(\pi\sigma^2)^N} \cdot e^{\frac{1}{\sigma^2} r^H (I - \Phi W_p W_p^H \Phi^H) r} \quad (24)$$

6.2 Traditional Secant Approach

Newton's methodology depends on employing the line tangent to the arc of $y = f(x)$, having the point of tangency$(x_0, f(x_0))$. Whenever$x_0 \approx \alpha$, the plot of the tangent line is roughly similar to the plot $y = f(x)$ around$x_0 = \alpha$.

Benefits of secant approach

- It converges fast than the bisection methodology.
- It does not need the derived function, something which is not obtainable in numerous applications.
- It needs merely single function estimation per repetition.

The secant approach is faster even though the number of iterations may be higher.

6.3 Numerical Technique aided on Secant Method

So as to attain the ML estimation of CFO (ϕ), numerical approach is employed in this section. The suggested methodology for the numerical results of the ML evaluation issue depends on the Secant approach.

Therefore, it is obvious that the complication of repetitive technique is very little. Multiple initial points are employed, covering the complete range of probable CFO values, one potential selection is group of {(0.1, 0.2), (0.2, 0.3), (0.3, 0.4), (0.4, 0.5), (0.5, 0.6), (0.6, 0.7), (0.7, 0.8), (0.8, 0.9), (0.9, 1.0)}. Initiating from this group of preliminary points, procedure is implemented in parallel, starting from these initial values and tending to a local minimal or maximum. Probability function is formerly estimated at the points ensued from the repetition process so as to obtain the evaluation of ML solution. A localized maximum would tend to minimum value of probability function. Henceforth, it is prohibited. Assuming fewer initiating points would additionally diminish complication.

7. Experimental results and its analysis

The Simulation Results for the suggested Secant Methodology depending on Numerical Technique of CFO Estimation are given in this section. This approach is simulated in the Multi Carrier CDMA Model along with CFO into the System.

7.1 Simulation Parameters

The simulation constraints for the suggested method are given in the Table 1. The CP is supposed to be lengthier compared to the channel's impulse responses so as to evade ISI in the MC-CDMA system. The sub-channels considered are 64, each of them carrying their information and the signal is communicated over a time-invariant channel and along with the impulse response. Further Normalized CFO is considered with the AWGN noise and Rayleigh fading Channel.

Table.1: Simulation Parameters

Parameter Name	Value
Modulation Scheme	BPSK
Sub-channels(N)	64
Number of samples in CP (P)	52
Number of Symbols	192
Number of Pilot sub carriers	8
impulse response of the channel(h)	[0.227 ,0.46, 0.688, 0.46, 0.227]
Normalized CFO (ε)	0.66
Signal to Noise Ratio(SNR)	10dB
Noise	AWGN
Fading	Rayleigh fading
$\phi_{CFO} = \frac{2\pi\varepsilon}{N}$	0.0648

7.2 Suggested Secant Method aided ML estimator with the Traditional ML estimator

The Normalized Mean Square Error (NMSE) was evaluated for suggested Maximum Likelihood estimator with the equation given as:

$$MSE = \frac{1}{N_t}\sum_{i=1}^{N_t}\left(\frac{|\hat{\phi}-\phi_{CFO,i}|}{2\pi/N}\right)^2 \qquad (25)$$

Here, N_t signifies number of Monte Carlo trails, $\hat{\phi}$ and $\phi_{CFO,i}$ signifies approximated and authentic values of CFO. The obtained NMSE values for the developed system with suggested Secant Method aided ML estimator are shown in figure.4.

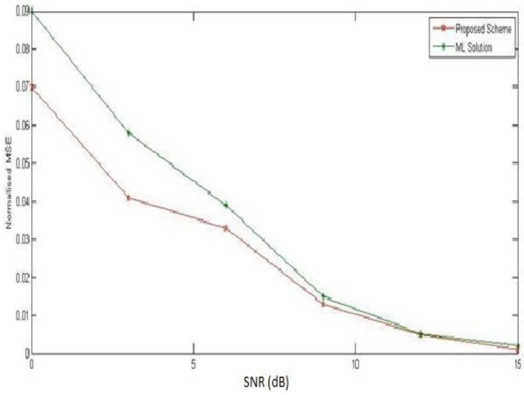

Figure.4: Comparison of suggested Secant Method aided ML estimator with the Traditional ML estimator

By the secant method, the procedure is skilled within five iteration phases, iteration might also halt whenever the ensued approximations remain similar with the evaluations of the previous phases that evades lavish iterations and saves time. From the figure.4 it is shown that, the NMSE of the suggested Secant Method aided ML estimator is less compared to traditional ML estimator. This is achieved by the iterative MSE evaluation. Table.2 illustrates the comparative analysis of suggested Secant Method aided ML estimator with existing ML estimator through NMSE.

Table.2 NMSE Comparison of suggested Secant Method

SNR(dB)	NMSE	
	Suggested	ML
0	0.07	0.09
2	0.06	0.08
4	0.04	0.06
6	0.035	0.05
8	0.03	0.04
10	0.01	0.03
12	0.005	0.01
14	0.002	0.005

8. Conclusion

In this paper, the approximation and rectification of occurrence offset for an MC-CDMA system for the downlink over Rayleigh flat fading channels in AWGN noisy approach is explained. The suggested approach primarily focuses on Maximum Likelihood (ML) CFO blind approximation procedures depending on the numerical secant approach with little numeral iterations for MC-CDMA systems. This approach

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decreases the complexity by means of the numerical technique during CFO estimation and also succeeded in reducing the MSE for the CFO estimator. The results indicate substantial enhancement in the system performance.

In this paper, both mathematical analysis and simulation results simulated that CFO violates the orthogonality principle, and hence introduce MAI, decreases the SNR of the signal and increases the bit error rate. The Numerical Secant based estimation technique has the best performance in this paper in terms of their MSE.

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