ESTIMATION OF CARRIER FREQUENCY OFFSET IN OFDM SYSTEM BY USING ADAPTIVE MODULATION TECHNIQUES

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ABSTRACT: In this paper we have implemented CFO correction under the influence of the CFO on OFDM transmission over AWGN channels. OFDM is very much sensitive to carrier frequency offset, which attenuates the desired signal & causes inter carrier interference, thus reducing the SNR. In this paper we have analyzed the Adaptive modulation with CFO and compared the average spectral efficiency with non-adaptive modulation methods. proposed adaptive modulation algorithm with CFO=0.05 achieves average spectral efficiency of 5.45% higher than the conventional adaptive modulation techniques.

Keywords: Orthogonal Frequency Division Multiplexing, Carrier Frequency Offset, Inter Carrier Interference, Channel State Information, Bit Error Rate.

1. INTRODUCTION

Orthogonal frequency division multiple access (OFDMA) is an extremely popular multiple access scheme that can support high data rate [1]. As OFDAM inherits many advantages of orthogonal frequency division multiplexing (OFDM), such as high spectral efficiency, robustness against multipath effects and flexible quality of service support (QoS), it is widely deployed in wireless communication systems. Using the multiple input multiple output (MIMO) techniques, spectral efficiency of OFDMA can be further enhanced by assuming that the channel across each transmit-receive antenna pair undergoes independent fading. However, OFDMA inherits many drawbacks of OFDM also. In a MIMOFDMA uplink with high mobility users, the transmitted signal undergoes both time and frequency selective (doubly selective) fading due to higher Doppler spread and multipath effects, respectively. The time variations of the channel impulse response within the OFDMA symbol duration will cause frequency dispersion that may destroy the orthogonality among the subcarriers. This results in multiple access interference (MAI) which may significantly degrade the overall system performance. The carrier frequency offset (CFO) caused by the local oscillator mismatches or instabilities also cause the loss of orthogonality among the subcarriers and resulting in MAI [1].

Carrier frequency offset (CFO), resulting from oscillators instabilities, is a common impairment in many communications systems. CFO estimation is therefore an essential component in the design of communications systems [3]. The performance of communication system with one bit per subcarrier CSI feedback is analyzed. A large class of CFO estimation schemes is the class of pilot-aided schemes, which is based on an a-priori known synchronization sequence, incorporated into the transmitted signal, and on modeling the CFO as an unknown deterministic parameter [3]. The work [17] designed a maximum likelihood (ML) scheme for the joint estimation of the CFO and of the channel transfer function (CTF) for unknown linear time-invariant (LTI) channels with additive white Gaussian noise (AWGN), without assuming a specific modulation scheme. Many suboptimal low-complexity approximations of the ML estimator (MLE) of [17] were proposed, especially for orthogonal frequency division multiplexing modulated signals and multiple antenna channels. Bit error rate (BER) is used for evaluation of the system performance. Assuming that the feedback channel is perfect, adaptive modulation selection (AMS) is used to exploit the CSI feedback and compared the results with non-adaptive modulation (fixed modulations) systems [8]-[10]. Most algorithms on CFO estimation in OFDM systems are based on the auto-correlation based method [6, 9], which uses cyclic prefix (CP) or pilots signals. However, this method is based on the assumption that during the time interval of two pilots, the channel is time-invariant. The assumption is violated for channel with large Doppler spread [4]. Adaptive technique can be applied to mitigate the deep fading effect if the channel state information (CSI) is available at the transmitter. To achieve the performance advantages of adaptive modulation, however, accurate receiver CSI is required at the transmitter. But in wireless communications, the channel is noisy and affected by CFO, the estimated CSI may be invalid. This is the fact behind the need for CFO correction in adaptive modulation.

2. ADAPTIVE MODULATION SELECTION

Adaptive modulation is a powerful technique for maximizing the data throughput of subcarriers allocated to a user. Adaptive modulation involves measuring the SNR of each subcarrier in the transmission, then selecting a modulation scheme that will maximize the spectral efficiency, while maintaining an acceptable BER [7]-[10].

The AMS scheme is based on the following idea. When a certain subcarrier is corrupted by fading channels, a constellation with smaller dimension and higher transmitted power can be assigned to this particular carrier, while constellation of large dimensions and less transmitted power can be assigned to the subcarriers whose channel gain is high. A low rate one bit per subcarrier feedback can be used to divide the subcarriers into two groups that use different constellations and transmitted powers. This adaptive modulation has well performed than conventional non-adaptive modulation techniques. The modulation scheme was chosen from the set of Binary Phase Shift Keying (BPSK),
Quadrature Phase Shift Keying (QPSK), 16-level Quadrature Amplitude Modulation (16-QAM), 64-level Quadrature Amplitude Modulation (64-QAM), as well as “No Transmission,” for which no signal was transmitted. Each scheme provides a tradeoff between spectral efficiency and the bit error rate.

The spectral efficiency can be maximized by choosing the highest modulation scheme that will give an acceptable Bit Error Rate (BER). In systems that use a fixed modulation scheme the subcarrier modulation must be designed to provide an acceptable BER under the worst channel conditions. This results in most systems using BPSK or QPSK. However these modulation schemes give a poor spectral efficiency (1-2 b/s/Hz) and results in an excess link margin most of the time. Using adaptive modulation, the remote stations can use a much higher modulation scheme when the radio channel is good. Thus as a remote station approaches the base station, the modulation can be increased from 1 b/s/Hz (BPSK) up to 4-8 b/s/Hz (16-QAM – 256-QAM), significantly increasing the spectral efficiency of the overall system. Using adaptive modulation can effectively control the BER of the transmission, as subcarriers that have a poor SNR can be allocated a low modulation scheme such as BPSK or none at all, rather than causing large amounts of errors with a fixed modulation scheme. This significantly reduces the need for Forward Error Correction.

In order to keep the system complexity low, the modulation scheme is not varied on a subcarrier-by-subcarrier basis, but instead the total OFDM bandwidth of total subcarriers is split into blocks of adjacent subcarriers, referred to as subbands, and the same modulation scheme is employed for all subcarriers of the same subband. This substantially simplifies the task of modem mode signaling.

Frequency errors in the transmission due to synchronization errors and Doppler shift result in a loss of orthogonality between the subcarriers. A frequency offset of only 1-2% of the subcarrier spacing results in the effective SNR being limited to 20 dB.

3. OFDM SYSTEM MODEL WITH CARRIER FREQUENCY OFFSET ESTIMATION AND CORRECTION

OFDM partitions the incoming data stream into N low rate parallel sub streams, as is shown in the baseband equivalent model of fig.1, which modulate a set of subcarriers using Inverse Discrete Fourier Transform (IDFT) so as to obtain the time domain signals. A cyclic prefix is then added to the time domain signal to eliminate inter symbol interference (ISI) caused by channel multipath fading and enables simple channel equalization at the receiver. The inverse fast Fourier transform (IFFT) is performed on the transmit symbol sequence (1):

\[
X_m(n) = \begin{cases} 
\frac{1}{N} \sum_{k=0}^{N-1} X_m(k) e^{j2\pi(n-k)N}, & \text{for } 0 \leq n \leq N + N_g - 1 \\
0, & \text{otherwise}
\end{cases}
\]

where \(N\) and \(N_g\) are the number of data samples and cyclic prefix samples, respectively.

The OFDM symbol \(x_m(n)\) is passed through a channel \(h_m(n)\) and is affected by Additive white Gaussian noise \(W(n)\). When the oscillator of the receiver is perfectly matched to the carrier of the received signal, a carrier frequency offset and a phase offset will not appear. Then the received signal can be represented as follows:

\[
y_m[n] = h_m[n] \ast x_m[n] + W(n)
\]

where \(\ast\) is the convolution operator.

The insertion of guard intervals renders the received carriers orthogonal on the \(N\) point symbol interval. However the demodulation process, which is implemented with a DFT, is affected by carrier frequency offset. The CFO will appear when the oscillator of the receiver is not perfectly matched to the carrier of the received signal. After removing the cyclic prefix and taking the \(N\) point DFT at the receiver, \((k + r)^{th}\) subcarrier signal of the \(m^{th}\) symbol can be expressed as [2]

\[
Y_m(k + r) = X_m(k) H_m(k) C_m(0) + \sum_{l=0}^{N-1} X_m(k - l) H_m(k - l) C_m(l) + Z_m(k + r)
\]

Where

\[
C_m(l) = \frac{\sin \pi e}{N \sin(\pi(l + r + e)/N)} e^{j\pi(l-r-1)/N} e^{-j\pi(l-r)/N}
\]

\[
C_m(0) = \frac{\sin \pi e}{N \sin(\pi e/N)}
\]

From equation (3), it can be seen that the received signal is attenuated by the factor which is normalized frequency offset which is defined as \(\epsilon = fN/T\). In equation (3) the second term is the ICI caused by the frequency offset. Third term \(Z_m(k+r)\) denotes the AWGN noise with zero mean and variance \(\sigma^2\).

One of the ways of canceling the effect of ICI in OFDM systems is statistically estimating the frequency offset and canceling this offset at the receiver. In this technique, an OFDM symbol stream of \(N\) symbols is replicated. These symbols are then modulated using a \(2N\)-point inverse discrete Fourier transform (IDFT). At the receiver, to get the sequence \(Y_k\) the first set of \(N\) symbols are demodulated using an \(N\)-point discrete Fourier transform (DFT), and the second set is demodulated with another \(N\)-point DFT to yield the sequence \(Y_{2k}\). The frequency offset is the phase difference between \(Y_{1k}\) and \(Y_{2k}\), that is, \(Y_{2k} - Y_{1k} e^{j2\pi\epsilon}\). The maximum likelihood estimate of the normalized frequency offset is given by:

\[
\hat{\epsilon} = (1/2\pi) \tan^{-1}(\sum_{k=0}^{N-1} \text{Im}[Y_{2k} Y_{1k}^*]/(\sum_{k=0}^{N-1} \text{Re}[Y_{2k} Y_{1k}^*]))
\]
This maximum likelihood estimate is a conditionally unbiased estimate of the frequency offset and will be computed using the received data [2].

Once the frequency offset is known, the ICI distortion in the data symbols can be reduced by multiplying received symbols with a complex conjugate of the frequency shift.

Figure 1: Block diagram of Proposed System Model for CFO correction by Adaptive Modulation

4. SPECTRAL EFFICIENCY OF ADAPTIVE OFDM

The spectral efficiency is defined as the average data rate per unit bandwidth. When we send $k() = \log_2 [M()]$ (bits/symbol), the instantaneous data rate is $k() / T_s$ (bps), where $T_s$ is the symbol period. Assuming Nyquist data pulse $B = 1/T_s$, for the discrete rate adaptation the spectral efficiency is given by [9]

$$\frac{R}{B} = \sum_{\gamma_i} k_i \int p(\gamma) d\gamma \quad (b / s / Hz)$$

For the Discrete Rate case, the rate region boundaries define the range of $k$ values over which different constellations are transmitted. More clearly, the different constellation sizes correspond to a set of discrete rates $k_i$ which are allocated respectively to each fading region $[\gamma_i, \gamma_{i+1}]$. When the instantaneous SNR falls within a given fading region, the associated signal constellation is transmitted.

Assume M-QAM is employed for each sub channel, and $[n, k]$ bits/symbol are sent for the $k$th tone in the $n$th block. We investigate the spectral efficiency under a constrained average BER requirement. According to [9], given the channel frequency response $H(n, k)$, the instantaneous BER for the $k$th tone in the $n$th block can be approximated by

$$P_e(n,k) = 0.2 \exp \left( - \frac{1.6 E_s}{N_0} \left| H(n,k) \right|^2 \right)$$

Where $E_s$ is the symbol energy at the transmitter, and $N_0 / 2$ is the variance of the real/imaginary part of the Gaussian noise $W[n,k]$.

4.1 Non Adaptive Modulation

Consider first the case of non adaptive modulation, where $[n, k] = 0$ is a constant for all $n$ and $k$. Since $H[n, k]$ is a complex Gaussian random variable and all $H[n, k]$ have identical distributions, the overall average BER become

$$P_e = E_{H[n,k]} \{ P_e[n,k] \} = \frac{1.6}{0.2} \frac{E_s}{N_0}$$

Assume $P$ target is the target average BER. Then by inverting, the maximum number of bits that can be transmitted given the average BER constraint is
The spectral efficiency (number of bits per second per Hz) is equal to $\beta$, under the assumption that the symbol interval is the reciprocal of the subchannel and bandwidth.

### 4.2 Ideal adaptive OFDM

For adaptive OFDM, different modulation schemes are used for different subchannels. In this section we assume that perfect knowledge of the receiver information channel is available at the transmitter. To achieve the acceptable target BER ($P_{\text{target}}$), the number of bits transmitted in each subchannel can be derived from (6) as

$$\beta[n,k] = \log_2 \left[ \frac{E}{1.6^n |H[n,k]|^2} + 1 \right]$$

Therefore, the average spectral efficiency $R$ is

$$R = \mathbb{E}[H[n,k]] \{ \beta[n,k] \}$$

The average spectral efficiency of adaptive OFDM for target BER of $10^{-3}$ is obtained through a Monte Carlo simulation is shown in Fig 3. Inter carrier interference and the overhead due to the Guard interval is not considered. The result indicate that a significant improvement in spectral efficiency or bit rate than the non adaptive modulation techniques.

### 4.3 Adaptive Modulation with CFO Correction

The spectral efficiency of the proposed adaptive modulation with CFO has been derived theoretically and it is expressed as follows.

$$\beta[n,k] = \log_2 \left[ \frac{E}{1.6\gamma E[n,k] |H[n,k]|^2} + 1 \right]$$

Therefore, the average spectral efficiency $R$ is;

$$R = \mathbb{E}[H[n,k]] \{ \beta[n,k] \}$$

The average SNR in the presence of CFO for AWGN channel is

$$\gamma(\epsilon) = \frac{C_m(0)^2 \gamma}{(1-C_m(0)^2)\gamma + 1}$$

$$C_m(0) = \frac{\sin(\pi \epsilon)}{N \sin(\pi \epsilon / N)}$$

where $\gamma$ is the average SNR in the absence of CFO for AWGN channel. Thus by introducing the CFO correction in adaptive modulation, the attenuation of SNR is reduced and hence the spectral efficiency is improved.

### 5. PROPOSED ALGORITHM

The CFO will directly affect the received average SNR. This attenuation is more noticeable when SNR is large. Due to this the adaptive modulation without CFO correction will not maximize the spectral efficiency. The proposed method corrects the CFO before the estimation of CSI that is threshold is measured after the CFO correction. Thus, by introducing the CFO correction in adaptive modulation, the attenuation of SNR is compensated and hence the spectral efficiency is improved.

For implementation of the proposed algorithm following steps have been adopted;

**Step 1:** Estimate the threshold SNR (i.e. region boundaries) for the given target BER using the following equations:

$$Y_m(k+r) = X_m(k)H_m(k)C_m(0) + \sum_{i=1, i \neq 0}^{N-1} X_m(k-1)H_m(k-1)C_m(i) + Z_m(k+r)$$
Where:

\[ \sum_{i=1}^{N-1} X_m(k-1) H_m(k-1) C_m(l) + Z_m(k + r) \] is error function.

\[ C_m(l) = \frac{\sin\pi\varepsilon}{N \sin(\pi(l + \varepsilon)/N)} e^{j\pi(l+1)} e^{-j\pi(l-r)/N} \]

Where:

\[ C_m(0) = \frac{\sin\pi\varepsilon}{N \sin(\pi\varepsilon/N)} \]

**Step 2:** Estimate the CFO (\(\varepsilon\)) using ML estimate technique.

\[ \varepsilon = \frac{1}{2\pi} \tan^{-1} \left[ \frac{\sum_{k=-K}^{K} \text{Im}[Y_{2k} Y_{1k}^*]}{\sum_{k=-K}^{K} \text{Re}[Y_{2k} Y_{1k}^*]} \right] \]

At the receiver, to get the sequence \(Y_{1k}\) the first set of N symbols are demodulated using an N-point FFT, and the second set is demodulated with another N-point FFT to yield the sequence \(Y_{2k}\). The frequency offset is the phase difference between \(Y_{1k}\) and \(Y_{2k}\) that is,

\[ Y_{2k} = Y_{1k} e^{j\varepsilon} \]

**Step 3:** Determine the average SNR \(\gamma(\varepsilon)\) i.e. threshold SNR in the presence of CFO for AWGN channel expressed as:

\[ \gamma(\varepsilon) = \frac{C_m(0)^2 \gamma}{(1 - C_m(0)^2) \gamma + 1} \]

**Step 4:** Finally determine the average SNR of the received signal using:

\[ \gamma = \frac{C_m(0)^2 - (1 - C_m(0)^2) \gamma(\varepsilon)}{C_m(0)^2} \]

**Step 5:** Compare this received average SNR with threshold SNR and select the constellation size M.

If \(\gamma < \gamma_1\) then no transmission

If \(\gamma_1 \leq \gamma < \gamma_2\) then \(M = 2\) (BPSK or 2QAM)

If \(\gamma_2 \leq \gamma < \gamma_3\) then \(M = 4\) (QPSK or 4QAM)

If \(\gamma_3 \leq \gamma < \gamma_4\) then \(M = 16\) (16QAM) and so on.

**Step 6:** Perform the adaptive modulation with respect to the size M.

**Step 7:** Plot the graph between BER for different values of SNR for different modulation i.e. distinguish values of M.

**Step 8:** Plot the graph between BER for different values of SNR for distinguish values of CFO.

### 6. SIMULATION RESULTS

For simulation of this proposed CFO estimation algorithm using adaptive modulation technique, the implementation has been performed using MATLAB 2012. The simulation has been done with following specification mentioned in table 1.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bandwidth for each user</td>
<td>20 MHz</td>
</tr>
<tr>
<td>Number of subcarriers</td>
<td>64,128,256,512</td>
</tr>
<tr>
<td>Cyclic Prefix Length</td>
<td>16</td>
</tr>
<tr>
<td>Number of pilots</td>
<td>4</td>
</tr>
<tr>
<td>Subcarrier frequency spacing</td>
<td>0.3125 MHz</td>
</tr>
<tr>
<td>FFT/FFT period</td>
<td>3.2 (\mu)s</td>
</tr>
<tr>
<td>Guard interval duration</td>
<td>0.8 (\mu)s</td>
</tr>
<tr>
<td>Modulation method</td>
<td>BPSK, QPSK, 16QAM, 64QAM</td>
</tr>
</tbody>
</table>

Table 1: The Simulation Parameters

#### 6.1 SNR Performance vs BER Sensitivity under AWGN with Proposed Technique

![Figure 2: BER sensitivity vs SNR under AWGN with proposed adaptive modulation technique](image-url)
Figure 2 shows the comparison of SNR vs BER for different modulation techniques. It shows that the BER rate mainly depends on the constellation size $M$. BPSK provides good BER performance, but its spectral efficiency is low for lower SBR, which is very low compared to other modulation schemes. At the same time 64-QAM will able to provide better spectral efficiency that is high, but it fails to maintain good BER performance and thus low QoS. Hence to achieve maximum spectral efficiency with achieving target BER, adaptive modulation technique is used.

The range of average SNR for the various modulation schemes have been derived from step 1 of the proposed algorithm or the threshold SNR (i.e. region boundaries) have been measured using Figure 2. These boundary values are tabulated in Table 2.

<table>
<thead>
<tr>
<th>Target BER</th>
<th>M=2 (BPSK)</th>
<th>M=4 (QPSK)</th>
<th>M=8 (16-QAM)</th>
<th>M=16 (64-QAM)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$10^{-2}$</td>
<td>4 dB</td>
<td>7 dB</td>
<td>20-21 dB</td>
<td>27 dB</td>
</tr>
<tr>
<td>$10^{-3}$</td>
<td>6-7 dB</td>
<td>10 dB</td>
<td>25 dB</td>
<td>30 dB</td>
</tr>
<tr>
<td>$10^{-4}$</td>
<td>8-9 dB</td>
<td>13-14 dB</td>
<td>28 dB</td>
<td>32 dB</td>
</tr>
<tr>
<td>$10^{-5}$</td>
<td>9 dB</td>
<td>17-18 dB</td>
<td>30 dB</td>
<td>35 dB</td>
</tr>
<tr>
<td>$10^{-6}$</td>
<td>10 dB</td>
<td>18-19 dB</td>
<td>32 dB</td>
<td>37 dB</td>
</tr>
</tbody>
</table>

Table 2: BER vs SNR for Proposed Techniques of Figure 2

6.2 SNR Performance vs BER Sensitivity under AWGN with BPSK Modulation Technique for Different Values of CFO by Proposed Algorithm

Figure 3: BER sensitivity vs CFO under AWGN with BPSK technique by proposed algorithm

Figure 3 shows that SNR degradation is more when CFO is higher. Also the result shows that SNR degradation is more for the higher values of actual SNRs than for the lower values of actual SNRs. These SNR degradations for different CFO are tabulated in Table 3.

<table>
<thead>
<tr>
<th>Target BER</th>
<th>Bit to Noise Ratio (dB) for Different Values of CFO</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CFO=0</td>
</tr>
<tr>
<td>$10^{-2}$</td>
<td>4 dB</td>
</tr>
<tr>
<td>$10^{-3}$</td>
<td>6-7 dB</td>
</tr>
<tr>
<td>$10^{-4}$</td>
<td>8-9 dB</td>
</tr>
<tr>
<td>$10^{-5}$</td>
<td>9 dB</td>
</tr>
<tr>
<td>$10^{-6}$</td>
<td>10 dB</td>
</tr>
</tbody>
</table>

Table 3: SNR degradations for different CFO for BPSK of Figure 3

It can be observed from table 3 that for CFO=0.05 SNR is 7 dB for target BER of 10-3. For this values the average spectral efficiency of 6 bps/Hz, which is better as well good BER performance.
6.3 Spectral Efficiency vs SNR for BPSK

Figure 4 shows the relation between Spectral Efficiency vs Signal to Noise Ratio for BPSK. This shows the capacity of Adaptive modulation with CFO = 0.05 has a better spectral efficiency. The proposed adaptive modulation with CFO correction technique gives better performance. This means that the adaptive modulation with CFO=0.05 achieves average spectral efficiency of 6 bps/Hz, which is better as well good BER performance.

![Figure 4: Spectral Efficiency vs Signal to Noise Ratio for BPSK CFO=0.05](image)

### Table 4: Spectral Efficiency vs Signal to Noise Ratio for BPSK CFO=0.05

<table>
<thead>
<tr>
<th>Spectral Efficiency (R/W) (Bit/Sec/Hz)</th>
<th>Signal to Noise Ratio (E_b/N_0) (dB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(10^{12})</td>
<td>2</td>
</tr>
<tr>
<td>(10^{13})</td>
<td>3</td>
</tr>
<tr>
<td>(10^{14})</td>
<td>4</td>
</tr>
<tr>
<td>(10^{15})</td>
<td>5</td>
</tr>
<tr>
<td>(10^{16})</td>
<td>6</td>
</tr>
<tr>
<td>(10^{17})</td>
<td>7</td>
</tr>
<tr>
<td>(10^{18})</td>
<td>8</td>
</tr>
<tr>
<td>(10^{19})</td>
<td>9</td>
</tr>
<tr>
<td>(10^{20})</td>
<td>10</td>
</tr>
</tbody>
</table>

6.4 SNR Degradation of Frequency Offset

Figure 5 shows the calculated degradation of the SNR due to the frequency offset. For smaller CFO values, the degradation is less than as compared to higher CFO values. Also, as the supplied SNR is more the degradation in SNR is less.

![Figure 5: SNR degradation of frequency offset for different values of E_b/N_0](image)
Table 5: SNR degradation with CFO for different values of $E_b/N_0$ for Figure 5

6.5 Simulation Results Comparison

In [3] the performance of four algorithms are shown for CFO estimation under no CFO case for QPSK modulation, it is compared with our proposed algorithm, given in table 6. This shows 6-7 dB improvement at the target BER of 10^{-2}. Also we can clearly see that 12-13 dB improvement with [3] at the target BER of 10^{-3}.

Table 6: Simulation Results Comparison under NO CFO case

In Ref. [1] the performance of two algorithms named joint estimation algorithm [1] & Perfect Sync. & Chan. has been compared for CFO estimation with CFO=0.05, it is compared with our proposed algorithm, given in table 6. This shows 15 dB improvement at the target BER of $10^{-2}$. Also we can clearly see that an 15 dB improvement with [5] for CFO=0.05 at the target BER of $10^{-3}$.

Figure 6: Simulation Results Comparison under no CFO case (Table 6)
Table 7: Simulation Results Comparison for CFO=0.05

<table>
<thead>
<tr>
<th>Target BER</th>
<th>CFO=0.05</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>This Work</td>
</tr>
<tr>
<td>$10^2$</td>
<td>4.5 dB</td>
</tr>
<tr>
<td>$10^3$</td>
<td>7 dB</td>
</tr>
<tr>
<td>$10^4$</td>
<td>9 dB</td>
</tr>
<tr>
<td>$10^5$</td>
<td>10 dB</td>
</tr>
<tr>
<td>$10^6$</td>
<td>11.12 dB</td>
</tr>
</tbody>
</table>

Figure 7: Simulation Results Comparison for CFO=0.05 (Table 7)

7. CONCLUSION

In this paper we have implemented CFO correction under the influence of the CFO on OFDM transmission over AWGN channels. OFDM is very much sensitive to carrier frequency offset, which attenuates the desired signal and causes inter carrier interference, thus reducing the SNR. In this paper we have analyzed the Adaptive modulation with CFO and compared the average spectral efficiency with non-adaptive modulation methods. Proposed adaptive modulation algorithm with CFO=0.05 achieves average spectral efficiency of that the proposed adaptive modulation algorithm gives optimum average spectral efficiency up to 5-6 bps/Hz for the target BER of $10^{-3}$ & up to 8-9 bps/Hz for the target BER of $10^{-6}$. The proposed modulation technique is tested by MATLAB computer simulations and the simulation results exhibits better performance than the conventional adaptive modulation techniques.

8. REFERENCES


