Performance Analysis of SC-OFDM in term of ICI and Multiple User Access for Uplink

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Abstract— **Orthogonal Frequency Division Multiplexing (OFDM) is prominent standard for 4G and next generation wireless communication systems. OFDM is one of the most popular key broadband technologies for LTE and next generation. OFDM divides the wideband among the set of orthogonal overlapping subcarriers hence the presence of the carrier frequency offset (CFO) can introduce severe distortion in an OFDM system. As it results the loss of orthogonalityamong the subcarriers so this creates the interference among the subcarrier this called Intercarrier interference (ICI). System performance can be improved by Discrete Fourier transform (DFT) pre Coded OFDM (Single Carrier OFDM),the benefit of using DFT pre coded OFDM under conditions with ICI present are clearly evident by comparing to traditional OFDM under similar conditions. SC-OFDM has zero ICI and the low Peak to average power ratio (PAPR).The following analysis of OFDM and SC-OFDM systems with ICI present is provided to show how ICI affects overall performance. Currently, the demand for mobile data is increasing rapidly as more people switch to smartphones and a new standard had been introduced to address the issue. Single Carrier Frequency Division Multi-Access (SC-FDMA) was defined as the uplink modulation for LTE.**

Index—**Orthogonal Frequency Division Multiplexing (OFDM,)Carrier Frequency Offset (CFO), Intercarrier interference(ICI), DFT pre Coded OFDM,Single Carrier OFDM (SC-OFDM), SC-OFDMA (SC-FDMA).**

I. INTRODUCTION

Orthogonal frequency division multiplexing (OFDM) is a transmission technique that can achieve high data rate of more than 100Mbps.This makes it reliable and has improved bandwidth efficiency with respect to conventional Frequency Division Multiplexing (FDM), Time Division Multiplexing (TDM) and Code Division Multiple Access (CDMA). OFDM is seen as the future technology for communication in wireless local area systems as it is used for 802.11a and Wi-Fi standard. Furthermore, it is the key broadband technologies;services forresidential consumers typically to provide faster downstream speeds than upstream speeds.

OFDM exhibits much better bandwidth efficiency than classical techniques of Wireless communication provided that the orthogonalitybetween the carriers is preserved.

The distortion effect of OFDM is Inter Symbol Interference (ISI),Inter Carrier Interference (ICI) is loss of synchronization caused by frequency offset between oscillators at the transmitter and the receiver. This causes the carriers to lose orthogonality, so they cannot be completely separated at the receiver. As a consequence, ICI lowers the signal-to-noise ratio (SNR) and increases the error probability. The spectral efficiency OFDM is high and it is well suited for multipath propagation environment. The subcarriers used for the data modulation are linearly independent. If the orthogonality of the subcarriers is lost due to the Doppler spread in mobile environment or by means of energy spill over the neighbouring subcarriers, it results inICI. Compared to the standard window functions the time domain window function effectively suppresses ICI in OFDM systems.[1],[2]

For orthogonal frequency-division multiplexing (OFDM) systems, the frequency offsets in mobile radio channels distort the orthogonality between subcarriers resulting in ICI. An efficient ICI cancellation method termed ICI self-cancellation scheme synchronizes in time and frequency domain. In OFDM because of CFO all the subcarrier in each symbol will have the same phase rotation. Further timing offset leads to linear increase in phase rotation. The above scheme works in two very simple steps. At the transmitter side, one data symbol is modulated onto a group of adjacent subcarriers with a group of weighted coefficients. The weighted coefficients are designed so that the ICI caused by the channel frequency errors can be minimized. At the receiver side, by linearly combining the received signals on these subcarriers with proposed coefficients, the residual ICI contained in the received signals can be reduced. The carrier-to-interference power ratio (CIR) can be increased by 15 and 30 dB when the group size is two or three, respectively, for a channel with a constant frequency offset.[2].[4].

In this paper the effect of ICI is analyzed on an DFT Pre Coded OFDM System. The DFT pre Coded Orthogonal Frequency Division Multiplexing has been considered as better technique for next generation wireless communication systems. Compared to traditional OFDM, DFT pre coded OFDM has demonstrated excellent bit error rate (BER) performance, as well as low peak to average power ratio (PAPR).Though the DFT pre coded OFDM has similar property as the OFDM, the main difference in DFT pre coded OFDM is that each data symbol is DFT transformed before mapping to subcarriers hence each data symbol is carried on a separate subcarrier and hence the technique is also called the Single Carrier OFDM (SC-OFDM). Existing techniques for OFDM can be directly adopted in SC-OFDM to improve performance;however, this improved performance comes at cost of decreased throughput. In this paper the effect of ICI is analyzed on both OFDM and SC-OFDM systems.[3],[5],[8] The basic principles of single-carrier orthogonal frequency division multiple access with iterative multiuser detection, called grouped frequency division multiple access. GFDMA allows multiple users to share a common set of subcarriers and separates the signals of users by employing distinct interleavers and frequency domain multiuser detection.

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Some attractive features of SC-OFDMA are explained, including low-cost iterative multiuser detection, multiuser and frequency and flexibility in resource allocation, in ITU — Radio communication Standardization Sector (ITU-R) Working Party 5D. Solutions should properly weigh flexibility and efficiency in order to realistically cope with the data rate targets of 1 Gb/s in local areas and 100 Mb/s in wide areas. Such targets can be reached by a combination of very wide spectrum allocation (i.e., on the order of 100 MHz) having with high peak spectral efficiency by using multiple antennas, we have analyzed 100 MHz bandwidth configurations for the uplink of local area IMT-A. Within this framework, the performance of SC-FDMA, as strong access scheme candidates for the uplink.[9],[10].

II. SYSTEM MODEL

The rapid growth in the need for large information transfer in every branch of life requires improvement in high data rate transmission. This can be accomplished by using Orthogonal Frequency Division Multiplexing (OFDM). OFDM is a multicarrier transmission technique used for wireless communication in which a high-rate data sequence is split into multiple low rate blocks,then each one is modulated onto separate sub carriers. The IEEE 802.11a standard incorporates OFDM due its robustness under multipath fading conditions.[3].[10].

In OFDM, a frequency-selective channel is divided into narrower flat fading channels, although the frequency responses of the channels overlap with each other. The key idea of OFDM is that a single user would make use of all orthogonal subcarrier in divided frequency bands. Therefore, the data rate can be increased significantly. Since the bandwidth is divided into several narrow subchannels, each subchannel requires a longer symbol period. In this manner the OFDM system can overcome the Intersymbol interference (ISI) problem. As a consequence, the OFDM system can result in lower bit error rates while handling higher data rates than conventional communication systems. A basic OFDM implementation scheme is shown in Figure 1. Data at each sub-carrier (x_K) are input into the inverse discrete Fourier transform (IDFT) to be converted to time-domain data (x_k) and after parallel-to-serial conversion (P/S), a cyclic prefix is added to prevent intersymbol interference (ISI). At the receiver, the cyclic prefix is re-moved, because it contains no information symbols. After the serial-to-parallel (S/P) con-version, the received data in the time domain are converted to the frequency domain using the DFT algorithm. The cyclic prefix (CP) is the most common guard interval (GI). The GI is introduced initially to eliminate the inter block interference (IBI). Since one block of input data symbols are associated with a single transmitted waveform in an OFDM system, most people refer IBI as ISI. The cyclic prefix (CP) is a good substitute of the zero-padding GI. In the CP scheme, the GI is a copy of the partial waveform. Based on the fact that the Fourier bases are periodic functions, the orthogonality of subcarriers can be preserved consequently,[1],[4]

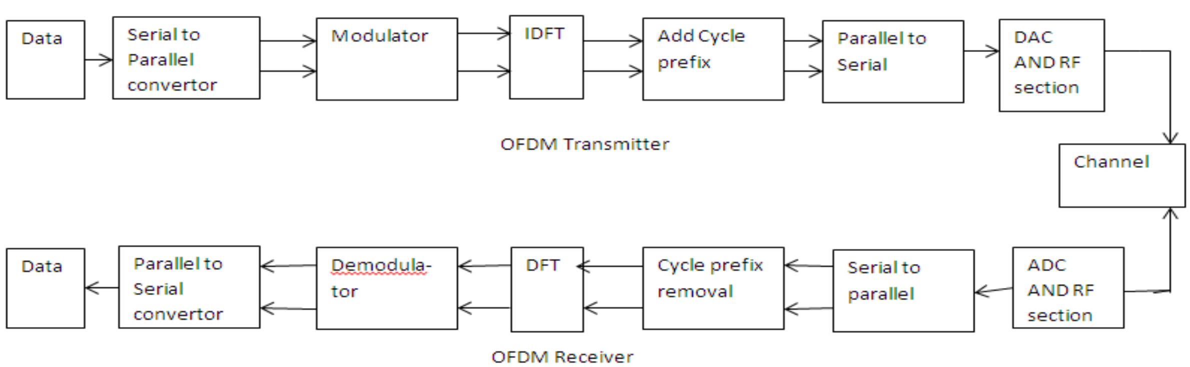

Fig.1. OFDM Transceiver

In OFDM the data are transmitted in blocks of length N. The n-th data block {x_k[0]….x_k[N-1]} is transformed into the signal block {x_k [0]….x_k[N-1]} by the IFFT as given by

$$S(t) = \sum_{k=0}^{N-1} x_k \, e^{j2\pi k\Delta ft} e^{j2\pi fot} p(t) \qquad (1)$$

Where $x_k$is thek^{th} data symbol; Δf - spacing between subcarriers, p(t) is rectangular pulse shape with time limit spanning one OFDM, To symbol, 0≤T, ensure orthogonality among subcarrier. AndΔf = 1/T = 1/NT_b, Where T_b data symbol period .

At the receiver, the received signal is down-converted to form a base-band signal. The low-pass filters are used to separate subcarrier waveforms. Orthogonality of sub-carriers will

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ensure that only the targeted subcarrier waveform will be preserved in each sub-band. Ideally, the following transmission channel propagation and cyclic prefix removal, the signal that the receiver corresponds to

$$r(t)=\sum_{K=0}^{N-1} \propto_k x_k e^{j2\pi(k+\varepsilon)\Delta f(t+\Delta t)} e^{j2\pi f_0(t+\Delta t)} p(t+\Delta t)+n \quad (2)$$

where n(t) is Additive White Gaussian Noise (AWGN), α is the complex fading gain on the k^{th} subcarrier,Δtrepresents the time delay and f0 is the CFO, The normalized carrier frequency offset (NCFO) is denoted as $\varepsilon = f_0/\Delta f$

The OFDM demodulator detects each symbol by decomposing *r(t)*onto *N* orthogonal subcarriers (via application of an FFT), where perfect timing estimation is assumed. If the NCFO is zero, the received signal on the k^{th}subcarrier simply equals to $yk= x_k\alpha_k+n_k$.[3]. However, when the NCFO is non-zero, the received signal on the k^{th}subcarrier corresponds to

$$y_k=x_k\propto_k s(0)+\sum_{l=0,l\neq k}^{N-1} x_l \propto_l S(l-k)+ n(k) \quad (3)$$

Where the first term is desired signal component and second term is ICI component

$$y_k^{ICI} = \sum_{l=0,l\neq k}^{N-1} x_l \propto_l s(l-k) \quad (4)$$

And S(l-k) is ICI Coefficient from ith sub carrier to k^{th} subcarrier

$$S(l\text{-}k) = \frac{\sin[\pi(\varepsilon+l\text{-}k)]}{N\sin\left[\frac{\pi}{N}(\varepsilon+l\text{-}k)\right]}.\exp\left[j\pi\left(1\text{-}\frac{1}{N}\right)(\varepsilon+l\text{-}k)\right] \quad (5)$$

Now denoting $\_x = \{x_0, x_1, . . . , x_{N-1}\}$ is

the transmitted symbol vector, $\_y = \{y_0, y_1, . . . , y_{N-1}\}$ is the received signal vector, $\_n = \{n_0, n_1, . . . , n_{N-1}\}$ is the noise vector and there is fading environment so

H=diag{ α_0 α_1 α_2............. α_{N-1}} where α is the fadinggain.Further

$$y=xHS+n \quad (6)$$

S is the ICI coefficient matrix defined as the N X N matrix.

$$S = \begin{bmatrix} S(0) & S(-1) & \cdots & S(1-N) \\ S(1) & S(0) & \cdots & S(2-N) \\ \vdots & \vdots & \ddots & \vdots \\ S(N-1) & S(N-2) & \cdots & S(0) \end{bmatrix} \quad (7)$$

2.1 ICI COEFFICIENT ANALYSIS

To offer an initial understanding how the ICI coefficient impacts system performance, first focus on AWGN channel to determine the ICI power. This can be done using the Carrier to- Interference Power Ratio (CIR), [3] it can be defined as

$$CIR = \frac{\text{Desired signal power}}{\text{ICI power}} \quad (8)$$

However, when there is no ICI present, e.g., $\varepsilon \rightarrow 0$, the ICI power can be estimated using the Interference-to-Carrier Power Ratio (ICR), defined as:

$$ICR = \frac{\text{ICI power}}{\text{Desired signal power}} \quad (9)$$

III. DFT PRE CODED OFDM (SC-OFDM)

In OFDM systems, digital modulation and demodulations can be comprehended with the IFFT and FFT. OFDM services N separate subcarrier to transmit data instead of one main carrier. Input data is grouped into a block of N bits, where N = $N_s \times M_n$ and M_n is the number of bits used to represent a symbol for each subcarrier. So that maintain orthogonality between the subcarriers, they are required to be spaced apart by an integer multiple of the subcarrier symbol rate R_s. The subcarrier symbol rate is linked to overall coded bit rate R_c of the entire system by $R_s = R_c$ /N.[3],[5]. The output signal of an OFDM can be written as:

$$X(t) = \sum_{n=0}^{N-1_s} X_k e^{2\pi j(n-\frac{N_s}{2})\frac{t}{T_b}} \quad (10)$$

Where X_k are the complex representations of the subcarrier symbols and Tb is the symbol period.

Whereas DFT pre coded OFDM (SC-OFDM) and other similar technologies associate the benefits of multi-carrier transmission with single carrier transmission using a cyclic prefix and frequency domain processing. Conceptual illustrations of the DFT pre coded OFDM (SC-OFDM) transmitter and receiver are shown in Fig. (3). This technique, multi-carrier transmission with single carrier transmission (SC-FDMA LTE) having the advantages like fast data rate, easy implementation and efficient delivery Compared to a conventional OFDM system. The SC-OFDM system allocates each parallel data set to all sub-carriers using different phase-rotated spectral spreading on each symbol. The spreading code set resembles to the normalized DFT matrix with the k^{th}data symbol being spread to the i^{th}subcarrier employing spreading code consisting of *N* total data symbols.[3],[6].

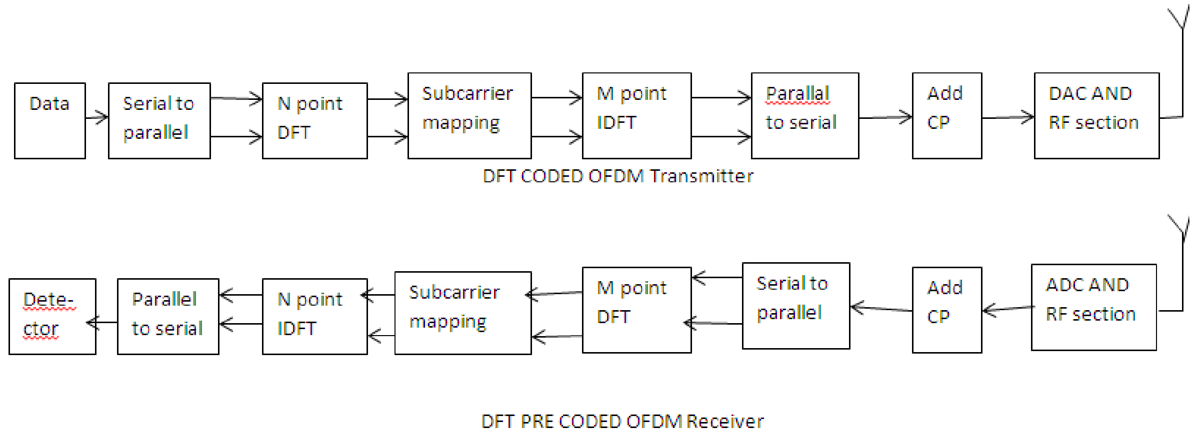

Fig.2. System model of DFT Pre-Coded OFDM

The block diagram of Fig. (2) shows a basic SC-OFDM transmitter / receiver arrangement. Note that many of the functional blocks are common to both SC-OFDMA and OFDMA, thus there is a significant degree of functional commonality among the uplink and downlink signal. The functional blocks in the system are

1. Constellation mapping: Changes received bit stream to single carrier symbols (BPSK, QPSK, or 16QAM depending on channel conditions)
2. M-point DFT: Converts time domain SC symbol block into M discrete tones, the DFT is additional block that makes significant difference between the OFDM and SC-OFDM.
3. Subcarrier mapping: Maps DFT output tones to specified subcarriers for transmission. SC-OFDMA systems either use contiguous tones (localized) or uniformly spaced tones (distributed). The current working assumption in LTE is that localized subcarrier mapping will be used. The trades between localized and distributed subcarrier mapping are discussed further below.
4. N-point IDFT: Converts mapped subcarriers back into time domain for transmission
5. Cyclic prefix and pulse shaping: Cyclic prefix is pre-pended to the composite SC-FDMA symbol to provide multipath immunity in the same manner as described for OFDM. As in the case of OFDM, pulse shaping is employed to prevent spectral regrowth [5].

The transmitted SC-OFDM symbol corresponds to

$$S(t) = \frac{1}{\sqrt{N}} \sum_{i=0}^{N-1} \sum_{k=0}^{N-1} x_k \, e^{-j\frac{2\pi}{N}ik} e^{j2\pi i\Delta f t} e^{j2\pi f_e t} p(t) \qquad (11)$$

Where x_k, k_{th} data symbol,Δf - spacing between subcarriers, p(t is rectangular pulse shape with time limit spanning one OFDM To symbol, 0≤T, ensure orthogonality among subcarriers and $\Delta f = 1/T = 1/NT_b$, where T_b data symbol period and Δf is the frequency spacing between the subcarriers The received DFT pre coded OFDM signal r(t) for the transmitted signal is given by

$$r(t) = \frac{1}{\sqrt{N}} \sum_{i=0}^{N-1} \propto_i \sum_{k=0}^{N-1} x_k \, e^{-j\frac{2\pi}{N}ik} . d. p(t+\Delta t) + n(t) \qquad (12)$$

where, d= $e^{j2\pi(i+\varepsilon)\Delta f(t+\Delta t)} e^{j2\pi f_e(t+\Delta t)}$

At the SC-OFDM receiver, the SC-OFDM demodulator detects the k^{th}data symbol by:

1. Decomposing the received signal *r*(*t*) into *N* orthogonal subcarriers (via application of an FFT, and perfect timing estimation is assumed),
2. Applying the k^{th}symbol's spreading code,
3. Combining the *N* results with an suitable combining scheme,
4. Decision of each symbol will be made based on the result from the "Combiner" at the detector end.
5.Subcarrier Mapping:It converts the M point to N point and it is the key operation in DFT pre coded OFDM. It can be mapped in either Localized or Distributed Mode.[3],[9].
6. SC-OFDMA Modulation: SC OFDMA (SC-FDMA) is a new multiple access technique that utilizes single carriermodulation, DFT spread orthogonal frequency multiplexing, and frequency domain equalization. It has a similar structure and performance as OFDM. SC-FDMA is currently adopted as the uplink multiple access scheme for 3GPP LTE. Transmitter and receiver structure for SC-FDMA and OFDM are given in Figures 4 and 5. It is evident from the figures that SC-FDMA transceiver has similar structure as a typical OFDM system except the addition of a new DFT block before subcarrier mapping. Hence, SC-OFDMA can be considered as an OFDM system with a DFT mapper.

IV. SIMULATION RESULTS

For fractional and integerCFO(ε) variation, the dominant energy response of S meets to S(0) when ε = 0. However, as ε varies fractionally from 0.1 to 0.4, the energy in S spreads across all subcarriers. The ICI coefficient is periodic with period *N, i.e.,* $S_{N+\varepsilon} = S_\varepsilon$ .Since CFO dependent ICI can reduce the System performance due to Coefficient energy leakage and leading shifts as illustrate in fig 3 and fig.4.

.ICR versus ε for OFDM and SC-OFDM systems, evident that ICR of DFT pre coded OFDM (SC-OFDM) is zero for all ε values, meaning the desired signal component used for data estimation is unaffected by ICI. Given the CIR of SC-OFDM is much lower than that of the OFDM system, the benefit of using SC-OFDM under conditions with ICI present are clearly obvious by comparing to traditional OFDM under similar conditions. The following analysis of OFDM and SC-OFDM systems with ICI present is provided to show how ICI affects overall performance and helps explain why the SC-OFDM system having better performance in term of ICI, experiences almost zero ICR fig.5.

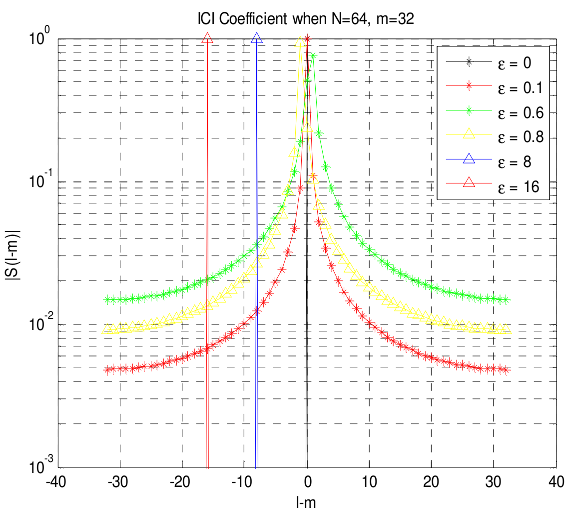

Fig. 3. Normalized ICI coefficient magnitudewith respect to subcarriers

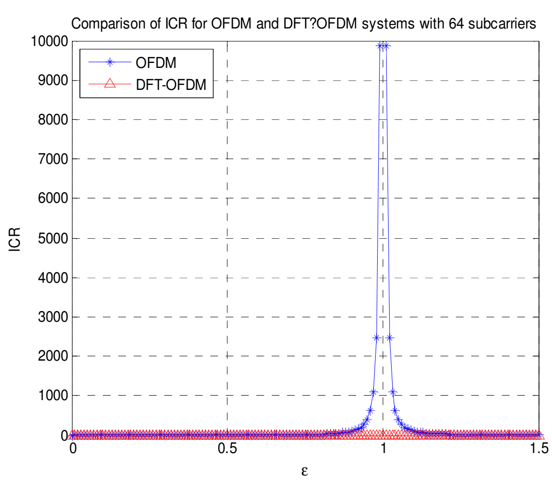

Fig.4. Comparison between OFDM and DFT pre coded OFDM (SC-OFDM) with respect to ICR

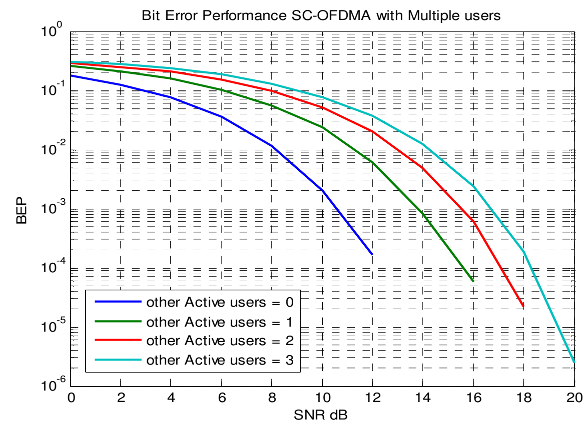

Fig.5. Simulation output SNR verses BER performance for SC-OFDMA with multiple users

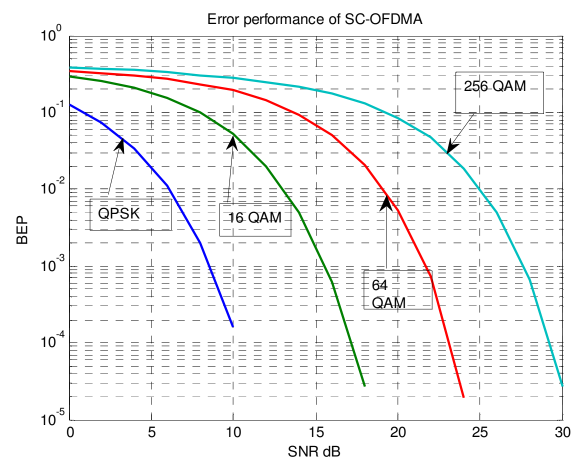

Fig.6. Simulation output SNR verses BER performance for SC-OFDMA with single user for various modulation type

V. Conclusion

The large value of CFO degrades the System performance, the increasing value of CFO the energy spreads across the all subcarrier and the ICI Coefficient is periodic with period N. The benefit of using SC-OFDM under conditions with ICI present are clearly evident by comparing to traditional OFDM under similar conditions. The following analysis of OFDM and SC-OFDM systems with ICI present is provided to show how ICI affects overall performance and helps explain why the SCOFDM system experiences zero ICR. The basic principles of SC-FDMA, always one user to share a common set of subcarriers. The interference caused by the other users is cancelled with users pecific interleavers and frequency-domain multiuser detection. Simulation results show that SC-OFDMA having loewer BER Performance for less no. of users as we increase the no. of users BER is going to increase because the interference increases as the no. of users increase. The Comparison Performance of SC-OFDM with respect to SNR and BER for various modulation type is showing that the the lower modulation type has low BER as we proceed for application like DVB so we required higher modulation type as ($M=2^n$) so system complexity and BER is going to increase.

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