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# PERFORMANCE ANALYSIS OF MC-CDMA AND OFDM IN WIRELESS RAYLEIGH CHANNEL

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## *Abstract*

*Recent advances in wireless communications have made use of MC-CDMA and OFDM techniques to allow for high data rate transmission. Rapid time variations of the wireless communication channel have a effect on the performance of multicarrier modulation.*

*In this paper, we emphasis the Doppler spread and Computes its effect on the bit error rate (BER) for multicarrier code division multiple access (MC-CDMA) and orthogonal frequency division multiplexing (OFDM). Also, we evaluate the channel capacity to quantify the potential of MC-CDMA and OFDM. We evaluate the effect of Doppler spread with Doppler shift at various carrier frequencies. We also evaluate the capacity of LTI, OFDM, MC-CDMA and RAYLEIGH channels.*

***Keywordss:*** *Doppler effect, fading channels, intercarrier interference, multicarrier code division multiple access (MC-CDMA), multicarrier modulation, orthogonal frequency division multiplexing (OFDM), Raleigh fading***.**

## 1. Introduction

Wireless mobile communication systems of the 21st century have to ensure a wide range of multimedia services such as speech, image, and data transmission with different and variable bit rates up to 2 Mbit/s in hierarchical cell structures and in multi-operator scenarios. Research activities concerning the standardization of the third generation mobile radio systems are in progress world-wide. International investigations run under the generic term Future Public Land Mobile Telecommunications Systems (FPLMTS) or also International Mobile Telecommunications 2000 (IMT-2000), and in Europe they are referred to as Universal Mobile Telecommunications Systems (UMTS)

Furthermore, attention has to be focused on recent developments in wireless communications, such as in the field of multi-carrier (MC) communications, which can possibly improve the conventional multiple access schemes. In 1993, various concepts based on a combination of DS-CDMA and MC modulation were proposed.

## 2. Multi-Carrier CDMA

MC-CDMA is a modulation method that uses multi-carrier transmission of DS-CDMA type signals.

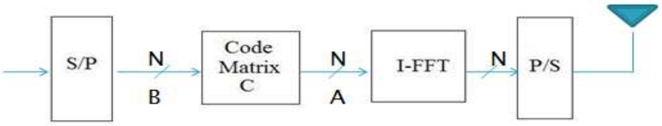

**Figure2.1 block diagram of MC-CDMA Transmitter**

Each bit is transmitted over *N* different sub carriers. Each sub carrier has its own phase offset, determined by the spreading code. The above transmitter can also be implemented as a Direct-Sequence CDMA transmitter i.e., one in which the user signal is multiplied by a fast code sequence.[7] However, the new code sequence is the Discrete Fourier Transform of a binary, say, Walsh hadamard code sequence, so it has complex values.[3]

A=CB A = [a0, a1………an-1] T

C - Code matrix

B =a [b0, b1……..bn-1]T

$WH_N$ - Walsh-Hadamard Matrix.

Case 1: When $C^{-1}=C^H$

Then $CC^N=I_N$

Case 2: When $C=I_N$

MC-CDMA reduces to OFDM

$$s(t) = \sum_{n=0}^{N-1} a_n \exp\{j\omega_c t + n\omega_s t\} \qquad \ldots\ldots\ldots\ldots\ldots (2.1a)$$

S (t)- Transmitted signal of multi carrier form

ωc -Carrier frequency

ωs - Sub carrier spacing

n - Sub carrier number

N - Number of sub carriers

$a_n$ -Modulation of the nth sub carrier carrying the user data

Figure 2.1 illustrates such a transmitter. Frames are created by a serial-to-parallel (S/P) conversion of an incoming stream of data, applying the code spreading, an I-FFT, and a parallel-to-serial (P/S) conversion with prefix insertion. The carrier frequency is $2\pi f_c = \omega_c$ . The received signal r(t) consists of the composition of all reflected waves, namely

$$r(t) = \sum_{n=0}^{N-1} \sum_{i=0}^{I_{\omega-1}} a_n D_i \, exp[j(\omega_c + n\omega_s + \omega_i) * (t - T_i)] + n(t) \tag{2.1b}$$

$a_n$ → Modulation of $n^{th}$ sub carrier carrying the user data.

$D_i$ → Amplitude.

$\omega_c$ → Carrier frequency.

$\omega_s$ →Sub carrier spacing.

$\omega_i$ →Doppler frequency offset.

$T_i$ →Path delay.

n(t) →Additive White Gaussian Noise (AWGN).

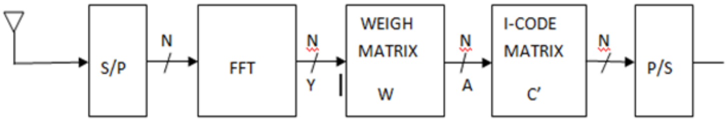

**Figure 2.2 Receiver Block Diagram**

In MC-CDMA, after recovery of the sub carriers, the signals at the output of the FFT have to be "unspread" by applying the inverse code matrix. We explicitly introduce the FFT, the inverse code matrix $C^{-1}$ , and a generic weigh matrix W. while the FFT and $C^{-1}$ are non adaptive and can be implemented efficiently using standard butterfly topologies.

## 3. OFDM Model

The OFDM system was modeled using Mat lab and is shown in Figure 3.1 A brief description of the model is provided below.[5]

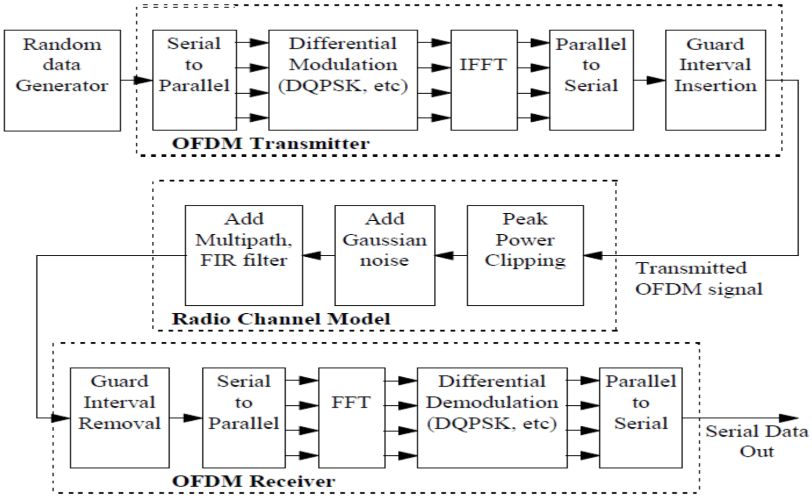

**Figure 3.1 Block diagram for OFDM**

The data to be transmitted on each carrier is then differential encoded with previous symbols, then mapped into a phase shift keying format. Since differential encoding requires an initial phase reference an extra symbol is added at the start for this purpose. The data on each symbol is then mapped to a phase angle based on the modulation method. For example QPSK the phase angles used are 0, 90, 180, and 270 degrees. The use of phase shift keying produces a constant amplitude signal and was chosen for its simplicity and to reduce problems with amplitude fluctuations due to fading. The guard period used was made up of two sections. Half of the guard period time is a zero amplitude transmission. The other half of the guard period is a cyclic extension of the symbol to be transmitted. This was to allow for symbol timing to be easily recovered by envelope detection. After the guard has been added, the symbols are then converted back to a serial time waveform. This is then the base band signal for the OFDM transmission.

## 4. Parameters of MC-CDMA and OFDM

### 4.1 Delay spread

Delay spread is a type of distortion that is caused when an identical signal arrives at different times at its destination. The signal usually arrives via multiple paths and with different angles of arrival. The time difference between the arrival moment of the first multipath component (typically the line-of-sight component) and the last one is called delay spread.[6]

### 4.2Doppler Spread

Doppler Spread $B_D$ is a measure of the spectral broadening caused by the time rate of change of the mobile radio channel and is defined as the range of frequencies over which the received Doppler spectrum is essentially non-zero. When a pure sinusoidal tone of frequency $f_c$ is transmitted, the received signal spectrum, called the Doppler spectrum, will have components in the range $f_c - f_d$ to $f_c + f_d$ ,where $f_d$ is the Doppler shift. The amount of spectral broadening depends on $f_d$ which is a function of the relative velocity of the mobile, and the angle θ between the direction of motion of the mobile and direction of arrival of the scattered waves. If the base band signal bandwidth is much greater than $B_D$ the effects of Doppler spread are negligible at the receiver. This is a slow fading channel. [4]

### 4.3 Effect on BER for OFDM

Various definitions of BERs are relevant to a system designer: the instantaneous BER $B_0$ of an individual sub carrier with a given amplitude, and the local-mean BER $B_1$, thus averaged over all channels. We compute $B_0$ as the BER for a given $\beta_{n,n}$, but otherwise averaged over all channels, i.e., averaged over $\beta_{m,n}(m \neq n)$. So, $B_0$ can be interpreted as the expected value of the BER if only the sub carrier amplitude is known (or estimated) from measurements, but without any knowledge about the Instantaneous value of the ICI.[7] A typical OFDM receiver would forward such side information to the error correction decoder We consider a quasi-stationary radio link in which channel variations cause ICI, but the power $P_0 = \beta_{n,n} \beta^*_{n,n}/2$ for each sub-carrier is reasonably constant during an OFDM frame.[1] Formally these two assumptions conflict, but for small Doppler shifts they may be reasonably accurate. For OFDM, the instantaneous signal-to-noise-plus ICI ratio $\gamma$ equals. $B_0$ is the BER for an individual sub carrier. This can be calculated as ,

$$B_0 = \operatorname{erfc}\left(\sqrt{\gamma}\right) \ldots\ldots\ldots\ldots\ldots\ldots(4.3a)$$

Where $\gamma$ is signal to noise+ ICI ratio.

$$\gamma = \frac{\beta_{nn}\beta^*_{nn}T_s}{\sum_{\Delta\neq 0} P_\Delta T_s + N_0}$$

After averaging , the local mean BER for BPSK modulating becomes ,

$$B_1 = \frac{1}{2} - \frac{1}{2}\sqrt{\frac{\gamma}{\frac{\pi^2 f_\Delta^2}{6 f_s^2}\gamma + 1}} \ldots\ldots\ldots\ldots\ldots\ldots(4.3b)$$

In the denominator, the summing is over all integer $\Delta$ within the range of active sub carriers, thus including $\Delta=0$. Here we have implicitly assumed that the signal amplitude $\beta_{m,m}$ and the ICI $\beta_{n,n}$ are statistically independent. Although the results in the previous section suggest that this is reasonable for our model, we acknowledge that for other channel models this may not necessarily be an accurate assumption.

### 4.4 Effect of BER for MC-CDMA

This section addresses the local-mean BER . For MC-CDMA (but not for OFDM), the BER for one specific user signal converges to the local-mean BER if the number of sub carriers is sufficiently large and the transmit bandwidth largely exceeds the coherence bandwidth. The decision variable for user bit zero, after combining all sub carrier signals, consists of

$$x = x_0 + x_{MUI} + x_{ICI} + x_n$$

where
$x_0$ wanted signal;
$x_{MUI}$ multi-user interference (due to imperfect restoration of the sub carrier amplitudes),
$x_{ICI}$ inter carrier interference (due to crosstalk between and ), $x_{noise}$ noise.

MUI for the EN/N0 per MC-CDMA symbol is calculated as below

$$\sum 10\log 10\frac{(1-\mathrm{d})^2}{\frac{\mathrm{c}}{\mathrm{p}}(1-\mathrm{d})^2\mathrm{k}} \quad \ldots\ldots\ldots\ldots\ldots(4.4a)$$

Noise for the EN/N0 per MC-CDMA symbol is calculated as below

$$\sum 10log10\frac{(1-d)^2}{\{(d\left[1+\frac{c}{p}\right]-\frac{c}{p})/c\}} \quad \ldots\ldots\ldots\ldots\ldots\ldots(4.4b)$$

MUI plus Noise for the EN/N0 per MC-CDMA symbol is calculated as below

In this we consider different channels $x_{MUI,}$ $x_{ICI,}$ and $x_{noise}$ so the local mean BER for BPSK becomes

$$B_{1=}\frac{1}{2}erfc\sqrt{E_N/N_0} \quad \ldots\ldots\ldots\ldots\ldots\ldots(4.4c)$$

$$\frac{E_N}{N_0}=\frac{M_{11}^2T_S^2}{\sigma_{ICI}^2+\sigma_{MUI}^2+\sigma_{noise}^2}$$

Here, M11→$P_0/N_{0.}$

We can introduce the Figure of merit as,

$$\frac{E_N}{N_0}=\zeta P_0T_S/N_0$$

Here ζ represents the Figure of merit.

### 4.5 Channel capacity

The capacity for dimension for MC-CDMA can be estimated as

$$\frac{1}{2}log_2(1+\frac{\zeta P_0T_S}{N_0})$$

…………(4.5a)

The capacity for dimension for OFDM can be estimated as,

$$C_{OFDM}=\frac{1}{ln2}exp\left(\frac{N_0}{2P_0T_S}\right)E_1(\frac{N_0}{2P_0T_S}) \quad \ldots\ldots\ldots\ldots(4.5b)$$

### 4.6 Raleigh distribution

Raleigh distribution is a continuous probability distribution. It can arise when a two-dimensional vector (e.g. wind velocity, which consists of a speed value and a direction) has elements that are normally distributed, are uncorrelated, and have equal variance.[5] The vector's magnitude (e.g. wind speed) will then have a Raleigh distribution. The Raleigh probability density function is

$$f(x|\sigma)=\frac{x\exp\left(\frac{-x^2}{2\sigma^2}\right)}{\sigma^2} \quad \ldots\ldots.(4.6a)$$

For $x\in[0,\infty)$.

## 5. SIMULATION RESULTS

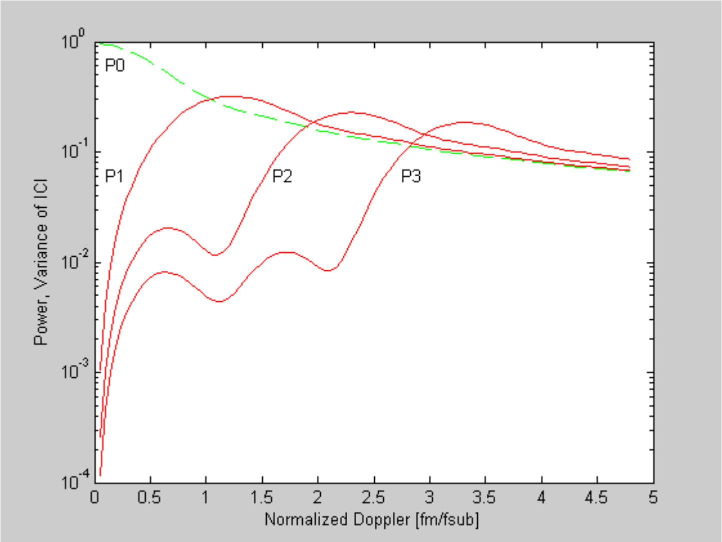

**Figure 5.1 plots the received power Po and the ICI powers P1,P2 andP3 versus the normalized Doppler spread λ for PT=1.**

Here the Figure is plotted between the normalised doppler vs power ,variance of ICI. In this normaised is nothing but ratio of modulating frequency to the sub-carrier frequency.Here the sub-carrier frequency is kept constant and modulating frequency is varied.

Here the Figure is plotted for $p_0$,$p_1$,$p_2$,$p_3$ . Where $p_0$ represents actual power intially obtain at the output.$p_1$,$p_2$,$p_3$ represents the reflected powers obtained at the output after some delays. From this Figure we can observe the effect of reflected power to the actual power at different doppler shifts.

**Effect of BER for MC-CDMA**

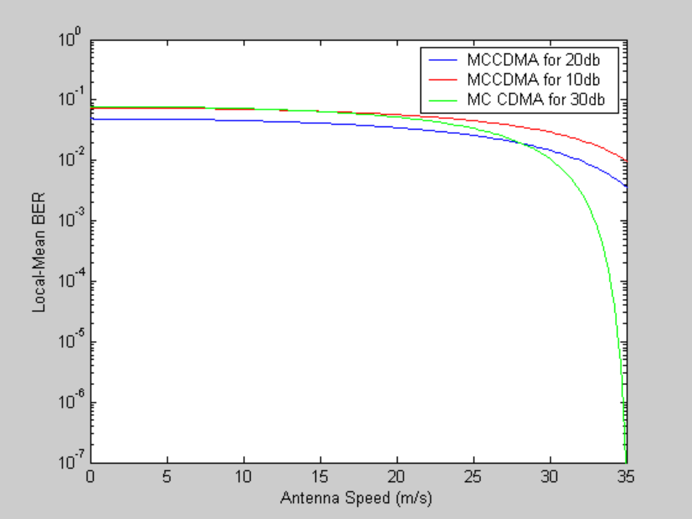

**Figure 5.2(a) shows the plot between local mean BER vs Antenna speed up to 35m/sec for MC-CDMA**

### Effect of BER for OFDM

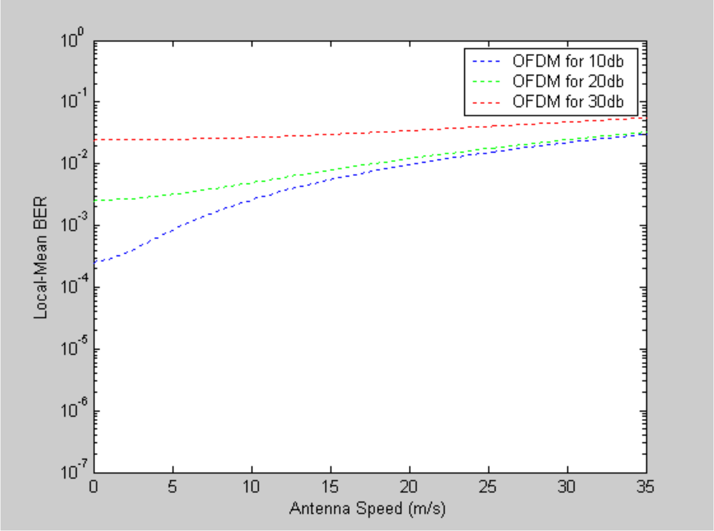

**Figure 5.2(b)** shows the plot between local mean BER vs Antenna speed upto 35m/sec for OFDM

### Comparision of BER for MC-CDMA and OFDM

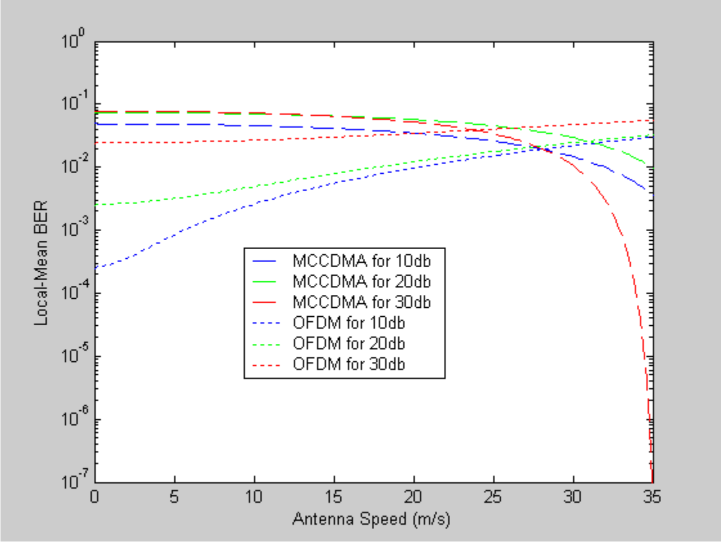

**Figure 5.2(c) shows the plot between local mean BER vs Antenna speed upto 35m/sec for OFDM and MC-CDMA**

Here the Figure is plotted between antenna speed vs local mean BER for BPSK. In this graph we are mainly comparing the BER for MC-CDMA and OFDM. Here the graph is plotted for the BER's of MC-CDMA and OFDM for various range of db's such as 10,20,30 ….db's.

At stationary position BER for MC-CDMA is more when compared to OFDM. As the user is in motion the BER for MC-CDMA gradually decreases, where as in OFDM BER Increases because MC-CDMA is a coded technique. So it takes less interference for MC-CDMA. Local mean varies because of the terrain and the effect of other obstacles. Observation of local mean indicates that it can be characterized statistically.

**Capacity of MC-CDMA**

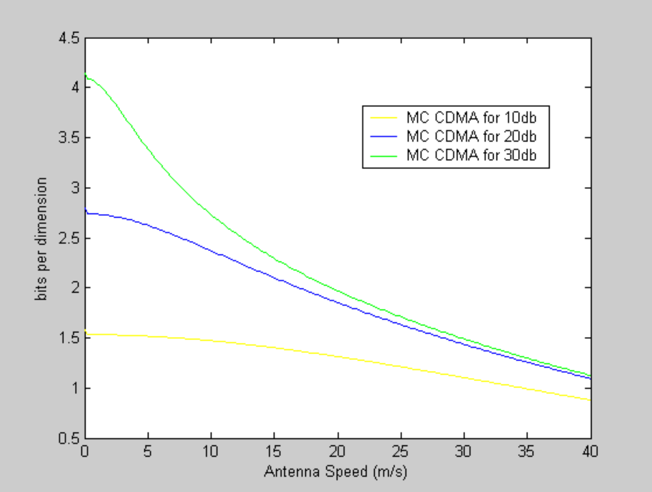

**Figure 5.3(a) shows the plot between Bits per dimension vs Antenna speed upto 40m/sec for MC-CDMA**

**Capacity of OFDM**

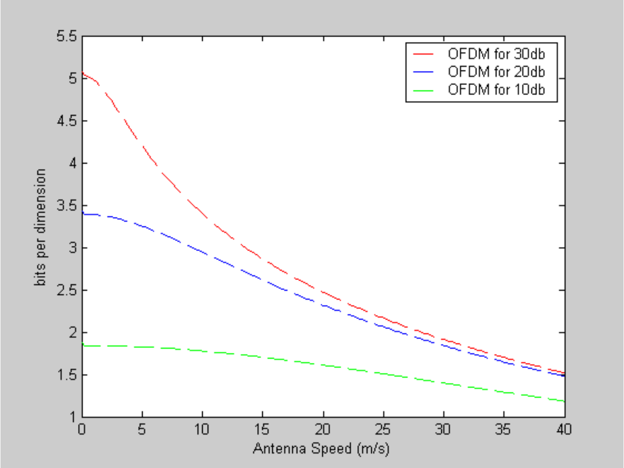

**Figure 5.3(b) shows the plot between Bits per dimension vs Antenna speed upto 40m/sec for OFDM**

## Comparisons of capacity for MC-CDMA and OFDM

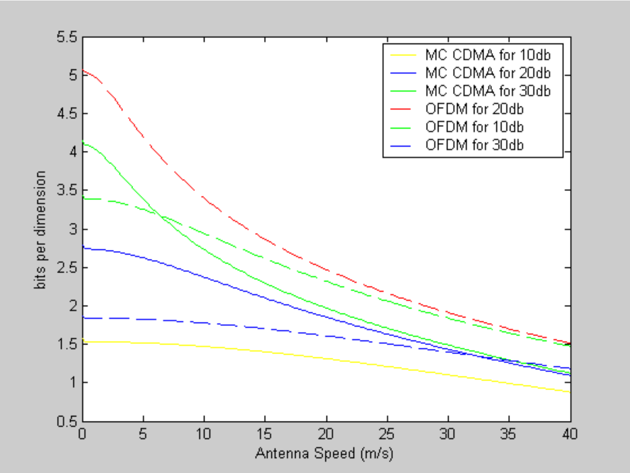

**Figure 5.3(c) shows the plot between Bits per dimension Antenna speed upto 40m/sec for OFDM and MC-CDMA**

Here the Figure is plotted for antenna speed vs bits per dimensions. In this we are mainly comparing the capacity for the MC-CDMA and OFDM. Here the graph is plotted for the capacity for MC-CDMA and OFDM at different db's such as 10,20,30….db's. At higher antenna speeds the capacity is almost similar for both MC-CDMA and OFDM. At lower speeds the capacity for MC-CDMA is less compared to OFDM because in MC-CDMA spreading takes place. So the bit duration for MC-CDMA is more compared to OFDM. For MC-CDMA due to high data rates its take more time to transmit. So capacity for MC-CDMA is less compared to MC-CDMA.

**Table 5.1 Mobile speed, Doppler shift, and Doppler frequency**

| SPEED of the Mobile in m/s | Km/hr | Doppler Shift at 9 GHz | Doppler Spread | Doppler Shift at 4 GHz |
|---|---|---|---|---|
| 2 | 7.2 | 60 | -376.8 to 376.8 | 26.6 |
| 4 | 14.4 | 120 | -753.6 to 753.6 | 53.32 |
| 6 | 21.6 | 180 | -1130.4to 130.4 | 79.99 |
| 8 | 28.8 | 240 | -1507.2to 507.2 | 106.66 |
| 10 | 36 | 300 | -1884 to 1884 | 133.33 |
| 14 | 50.4 | 420 | -2637 to 2637 | 186.662 |
| 18 | 64.8 | 540 | -3391 to 3391 | 239.994 |
| 26 | 93.6 | 780 | -4898 to 4898 | 346.658 |
| 30 | 108 | 900 | -5682 to5682 | 399.99 |
| 34 | 122.4 | 1020 | -6905 to 6905 | 453.322 |
| 38 | 136.8 | 1140 | -7159 to 7159 | 506.654 |
| 40 | 144 | 1200 | -7536 to 7536 | 533.32 |

The effect of Doppler at 9 GHz carrier frequency is shown in Figure 5.3. The frame duration is 0.896 microseconds, with an FFT size of 8192 is considered here. This corresponds to a subcarrier spacing of $f_s$ =1.17 kHz and a data rate of 9.14 M symbols/s. Figure 5.3 depicts the capacity in bits per dimension for OFDM and MC-CDMA versus antenna speeds v for Eb/N0 of 10, 20 and 30 dB. Mobile speeds and Doppler shifts are shown in table 5.1. It depicts that Doppler shift increases with mobile speed.

Figure 5.3 plot is drawn between Capacity in bits per dimension for OFDM and MC-CDMA versus antenna speeds. It depicts that with the increase of antenna speed, the channel capacity is better for OFDM than MC-CDMA. MC-CDMA systems cannot achieve the full channel capacity whereas for Coded-OFDM, high channel capacity can be achieved. For large SNR, it has apparently less capacity than for a fixed channel by 0.42 bit per dimension with the 30dB SNR. Lower mobile speeds and large SNR Doppler shift could not affect the channel capacity in both the multicarrier systems. As the Carrier frequency increases the Doppler shift increases, correspondingly its Doppler spread becomes severe.If the Doppler spread increases then interference takes place.To overcome this interference we have to implement adaptive equalization to eliminate the effect of Doppler spectrum.

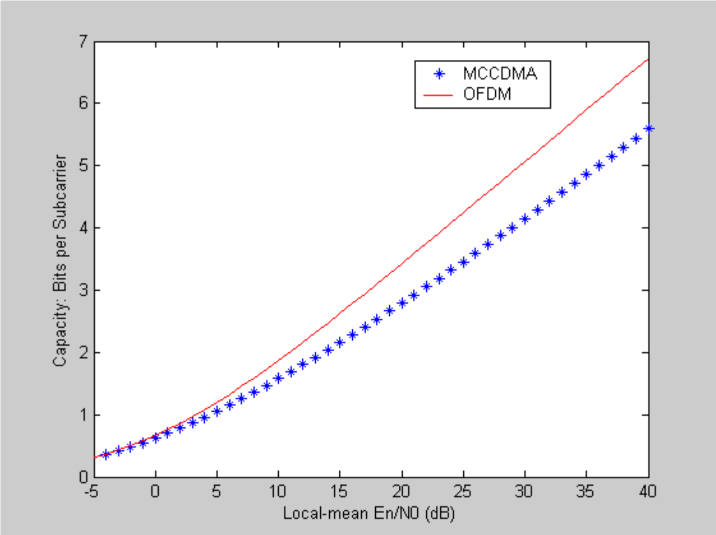

**Figure5.3(a) Comparison of capacities for MC-CDMA and OFDM**

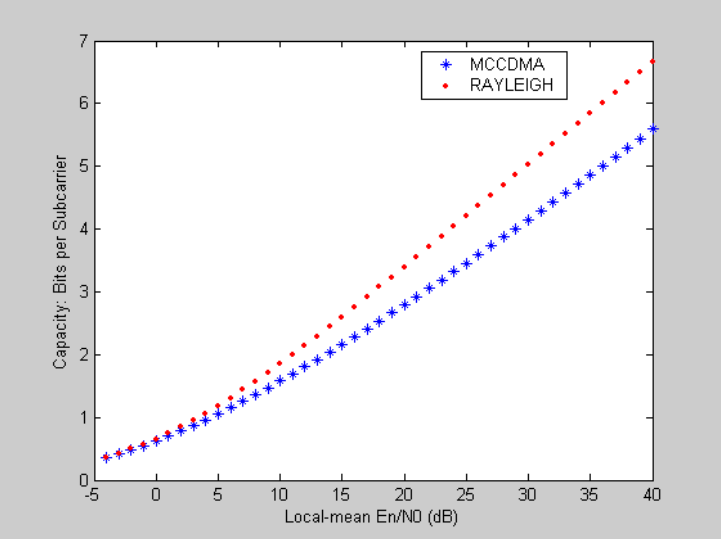

**Figure 5.3(b) Comparison of capacities for MC-CDMA and Rayleigh**

**Comparison of capacity for OFDM, MC-CDMA,LTI AND RAYLEIGH**

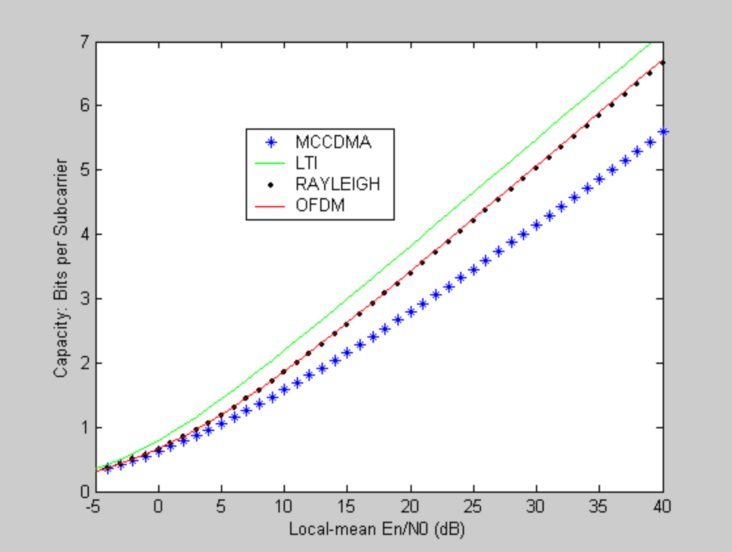

**Figure 5.4 shows the plot between capacity bits per sub carrier vs local mean En/N0 upto 40db for OFDM, MC-CDMA, LTI AND RAYLEIGH**

Here the Figure is plotted between the local mean En/N0 vs capacity bits per sub-carrier. here the graph is plotted for capacities of LTI ,MC-CDMA and RAYLEIGH. Here we are comparing capacities for LTI, MC-CDMA and RAYLEIGH. The orthogonality is destroyed when the channel is time variant.

The capacity is linearly increases with signal to noise when it is expressed in db's. for LTI it takes less time to transmit compared to the MC-CDMA and RAYLEIGH. Since the LTI is noise free channel.

The Rayleigh channel is having deep fades at every half of the wave length. so it takes comparatively more time to transmit than the LTI

For MC-CDMA due to spreading the bit duration is more so it takes more time to transmit. so the capacity for MC-CDMA is comparatively less than the LTI and the RAYLEIGH channel.

## 6. Conclusion

We have presented a framework that allows a theoretical estimation of the BER of MC-CDMA with a linear receiver. We compared the performance of MC-CDMA and OFDM using parameters like BER and Channel capacity by simulating in MATLAB. A rapid decrease of the BER is seen when antenna speeds increase, but less dramatic than reported for OFDM

If the number of subcarriers is very large (infinity), we found that MC-CDMA does not have an advantage over OFDM in terms of the theoretical channel capacity. We concluded that for a system with many subcarriers and a channel with sufficiently large delay spread, MC-CDMA symbols see a nonfading channel. OFDM can achieve capacity only through ideal error correction decoding. Loss of performance of linear MC-CDMA relative to OFDM is mainly due to the absence of a method to exploit correlated noise in the decision variables of the various user symbols. The performance penalty depends on the local mean SNR of the received signal. However, it becomes small for moderate SNR, say below 10 or 15 dB.

In this paper, we compared MC-CDMA with OFDM. Results indicated that for typical conditions, MC-CDMA has advantages over OFDM. The merits of MC-CDMA should be sought also in its ease of implementation as it is not substantially more complicated than uncoded OFDM. Its error correction coding can be simpler than for C-OFDM.

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