SYNCHRONIZATION TECHNIQUES FOR 3RD GENERATION PARTNERSHIP PROJECT-

LONG TERM EVOLUTION (3GPP-LTE)

A THESIS SUBMITTED IN PARTIAL FULFILMENT OF

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In

Electronics and Communication Engineering

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National Institute of Technology

Rourkela

CERTIFICATE

This is to certify that the thesis entitled "3rd generation partnership project- long term evolution (3GPP-LTE)" submitted by Prabin Kumar Panda (107EC027) and Pochineni Shalini (107EC028) in partial fulfilment for the requirements for the award of Bachelor of Technology Degree in Electronics and Communication Engineering at National Institute of Technology, Rourkela (Deemed University) is an authentic work carried out by them under my supervision and guidance.

To the best of my knowledge, the matter embodied in the thesis has not been submitted by any other University/Institute for the award of any Degree or Diploma.

Date:

Prof. Poonam Singh

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Communication Engineering

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ABSTRACT

To deal with the increasing demands on the mobile radio systems and data traffic, a successor of UMTS has been worked on, called Long Term Evolution (LTE). This will permit more powerful and better spectral efficiency of the transmission. Orthogonal Frequency Division Multiple Access (OFDMA) is used in the LTE downlink as a multiple access method. The uplink in the same is dependent on another method, Single carrier frequency division multiple access (SC-FDMA). The advantage of the method is that the signals exhibit lower peak to average power ratio (PAPR).

In this thesis, we focused on the comparison of the performance of SCFDMA and OFDMA under different conditions. We analysed how SCFDMA can be considered a better model. We implemented synchronisation techniques (timing and frequency), including the respective blocks in transmitter and receiver. Algorithms were done for the same and the simulation of all the above was done using MATLAB.

Keywords: UMTS, LTE, SCFDMA, OFDMA, PAPR, synchronisation, uplink, downlink, multiple access methods.

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LIST OF ABBREVIATIONS:

AWGN	Additive White Gaussian Noise
BER	Bit Error Rate
BPSK	Binary Phase Shift Keying
QPSK	Quadrature Phase Shift Keying
FFT	Fast Fourier Transform
DFT	Discrete Fourier Transform
OFDMA	Orthogonal Frequency Division Multiple Access
SC-FDMA	Single Carrie Frequency Division Multiple Access
PAPR	Peak to Average Power Ratio
SNR	Signal to Noise Ratio
CP	Cyclic Prefix
TDD	Time Division Duplex
FDD	Frequency Division Duplex
UTRAN	Universal Terrestrial Radio Access Network
LFDMA	Localised Frequency Division Multiple Access
IFDMA	Interleaved Frequency Division Multiple Access
CIR	Channel Impulse Response

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CHAPTER-1

INTRODUCTION

1.1 INTRODUCTION:

The ability of radios to provide continuous contact with the ships was first discovered by Guglielmo Marconi in 1897. Since then, the world has seen the communication methods improve by leaps and bounds, evolving year by year. The mobile communication industry has particularly boomed since the last decade and is expected to be that way through the next decade.

In the mobile communication systems, the most important quality is high bit rates in services like high quality audio, video, gaming, internet and others. At high bit data transmission, the channel impulse response tends to spread over many symbol periods. This may result in Inter symbol Interference (ISI). To mitigate the ISI present, OFDM stands as a very good option. The bandwidth in the OFDM signal is transmitted in parallel, after dividing into many narrow sub-channels. The channels are so narrow that the effect of delay spread is eliminated. But the OFDM method has some disadvantages as well. It has a high peak to average power ratio (PAPR). To avoid excessive inter modulation distortion; highly linear power amplifiers are required for signals with high PAPR. But this results in low power efficiency as the amplifiers need to work with a large backoff from their peak power to achieve such linearity. This can be overcome using SCFDMA technique which works at a lower PAPR. This helps in increasing the power efficiency. In 3GPP LTE, OFDMA has been proposed for downlink & SCFDMA for uplink transmission

1.2 **Digital Communication System**

A digital communication system comprises several functional units. Basically it is made of a transmitter and a receiver. The transmitter has a source encoder, which is used to represent the information in an efficient way. The output is usually in the form of bits, which are then fed into the channel encoder. In this stage, bits are added in a structured way which can facilitate the detection and correction of the errors. The modulator then transforms the signals to get a signal which is suitable for transmission. The signal is sent via the channel and at the receiver, the exact reverse function takes place. The signal is first demodulated , the result got is passed on to the decoder. The receiver analyses the demodulated signal and tries to look for errors. After this, the corrected bits are sent to the source decoder. The decoder is used to reconstruct the signal , to get the input signal or something very close to it (in the case of uncorrected errors).

The most important thing in the modulator and demodulator is the kind of schemes used to send and receive the signal. They should be power efficient and provide good results. The synchronisation also forms an important part in the receiver and transmitter. Each MIMO system needs synchronisation in both transmitter and receiver. Frequency synchronisation ensures that the orthogonality of the signal isn't lost. Timing synchronisation is essential as it makes sure that the sampling is done at the right time. This helps ensure that the samples are well synchronised and that the data errors are minimised. Thus, each part of the transmitter and receiver is important and has to be properly designed for error free and optimal transmission.

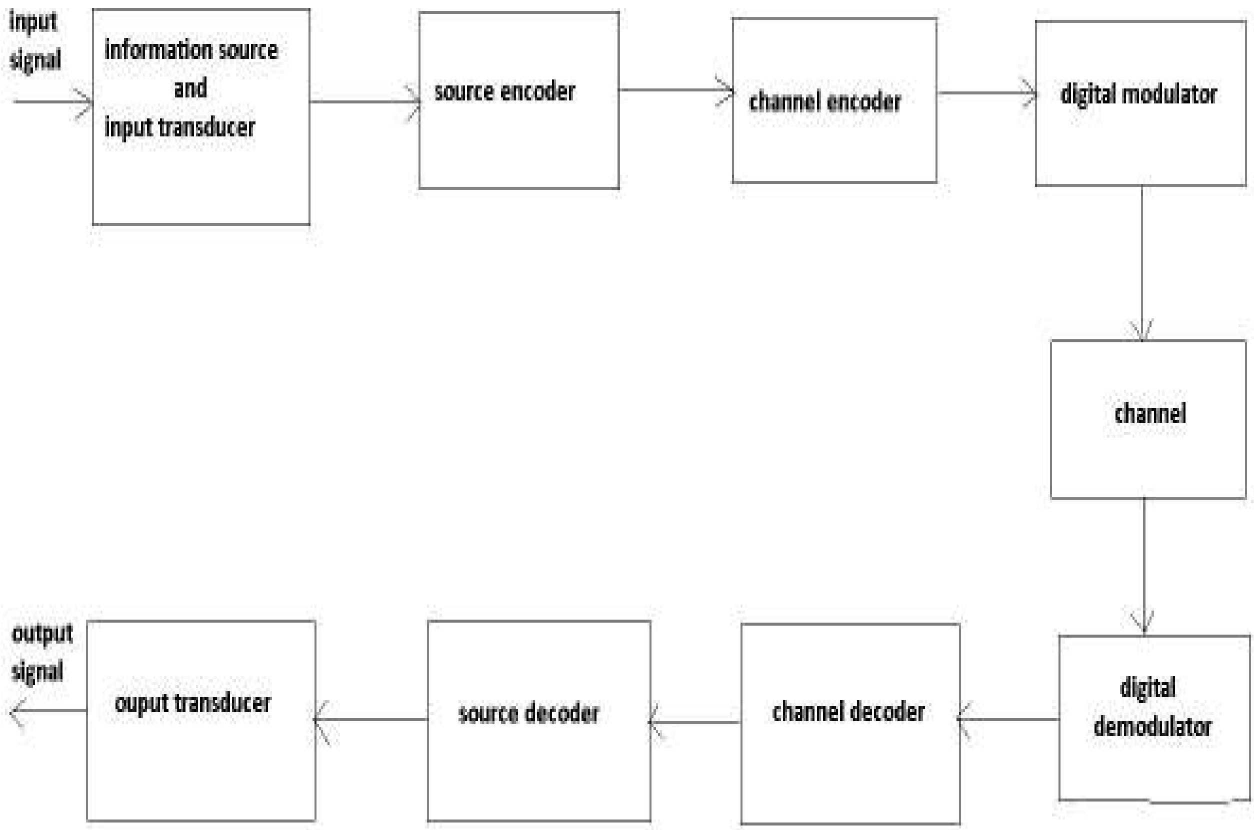


FIG 1: BASIC ELEMENTS OF DIGITAL COMMUNICATION SYSTEM

CHAPTER 2

ORTHOGONAL FREQUENCY DIVISION MULTIPLEXING

2.1 INTRODUCTION

The principles of orthogonal frequency division multiplexing (OFDM) have been discussed for quite some time. But they have been implemented the in the real time applications in recent years. New developments in technology have brought new benefits of using OFDM in radio, television and most importantly in wireless networking systems. In recent years, OFDM has become instrumental and the most used in applications like broadband wireless, home networking, wireless LAN and others.

2.2 BASICS

OFDM stands for "Orthogonal Frequency Division Multiplexing ". In OFDM, the signal which is a high-rate data stream is split into lower rate streams. These generated lower rate streams are then transmitted simultaneously, over a number of carriers, i.e., in parallel. OFDM sends multiple signals on orthogonal carrier frequencies unlike the conventional modulation schemes that send only one signal at a time. This results in better usage of bandwidth. It can also be manipulated to facilitate more robust communication during interference and noise. The major advantage of OFDM is ability to deal with all this without using complex equalization filters. The low symbol rate facilitates the use of guard interval, which helps reduce the inter symbol interference (ISI).

2.3 ORTHOGONALITY:

In OFDM, the subcarriers are chosen such that they are orthogonal. This helps in eliminating the cross talk between sub carriers.

The orthogonality requires the sub carrier spacing to be Δf=k/T, where *T* is the useful symbol duration and *k* is a positive integer. In OFDM, having good frequency synchronisation is very essential as it may otherwise lead to inter carrier interference (ICI)

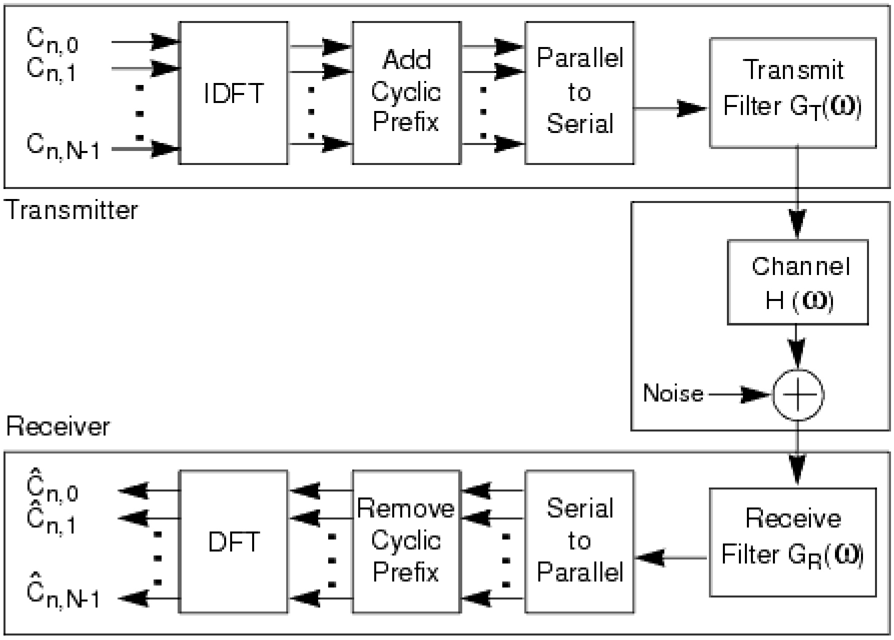


FIG 2:BASIC OFDM COMMUNICATION SYSTEM

2.4 MATHEMATICS INVOLVED:

The subcarriers in the OFDM signal are modulated using methods like quadrature amplitude modulation or other shift keying methods.

If N sub-carriers are used, and each sub-carrier is modulated using M alternative symbols, the OFDM symbol alphabet consists of M^N combined symbols.

The low pass equivalent OFDM signal is expressed as:

$$\nu(t) = \sum_{k=0}^{N-1} X_k e^{j2\pi kt/T}, \quad 0 \le t < T,$$

where $\{X_k\}$ are the data symbols, N is the number of sub-carriers, and T is the OFDM symbol time. The sub-carrier spacing of $\frac{1}{T}$ makes them orthogonal over each symbol period; this property is expressed as:

$$\frac{1}{T}\int_0^T \left(e^{j2\pi k_1 t/T}\right)^* \left(e^{j2\pi k_2 t/T}\right) dt$$
$$=\frac{1}{T}\int_0^T e^{j2\pi(k_2-k_1)t/T} dt = \delta_{k_1 k_2}$$

where $(\cdot)^*$ denotes the complex conjugate operator .

To avoid intersymbol interference in multipath fading channels, a guard interval of length T_{g} is inserted prior to the OFDM block. During this interval, a *cyclic prefix* is transmitted such that the signal in the interval $-T_{\mathrm{g}} \leq t < 0$ equals the signal in the interval $(T-T_{\mathrm{g}}) \leq t < T$. The OFDM signal with cyclic prefix is thus:

$$\nu(t) = \sum_{k=0}^{N-1} X_k e^{j2\pi kt/T}, \quad -T_{\mathrm{g}} \leq t < T$$

The low-pass signal above can be either real or complex-valued. Real-valued low-pass equivalent signals are typically transmitted at baseband—wireline applications such as DSL use this approach. For wireless applications, the low-pass signal is typically complex-valued; in which case, the transmitted signal is up-converted to a carrier frequency f_c. In general, the transmitted signal can be represented as:

$$s(t) = \Re\left\{\nu(t)e^{j2\pi f_c t}\right\}$$
$$= \sum_{k=0}^{N-1} |X_k| \cos\left(2\pi[f_c + k/T]t + \arg[X_k]\right)$$

OFDM selects a group of subcarriers which are overlapped in the frequency domain but are orthogonal in time domain. Thus even though they are overlapped, they tend to be orthogonal. This property is used at the receiver to separate the signal. The fourier transform is the frequency domain representation of a signal. This representation can be compared to the describing of a chord of music in terms of the notes played.

2.5 CHOICE OF PARAMETERS

The choice of the parameters in the OFDM transmitter blocks helps make a tradeoff between the the requirements. The bandwidth , bit rate and delay spread are the most important factors observed. To minimise the signal to noise ratio loss caused by the guard time, the symbol duration must be made larger than the guard time. But there is an upper limit for this as , a larger symbol duration will result in increased larger complexity of implementation (as there are more subcarriers with a smaller subcarrier spacing) . This will result in an increased peak to average power ratio (PAPR) which will affect the power efficiency of the system. A practical design has to be chosen taking all these points into consideration.

CHAPTER 3

SINGLE-CARRIER FREQUENCY DIVISION MULTIPLE ACCESS

3.1 INTRODUCTION

The main problem with the OFDM technique is that it the waveform exhibits quite pronounced envelope fluctuations. This results in a high PAPR value. When a signal has high PAPR value, it requires highly linear power amplifiers so as to avoid excessive inter modulation distortion. The amplifiers have to work with a large backoff from the peak power to achieve the same. This results in a low power efficient system. The other disadvantage of the technique is that in cellular uplink transmission, there is an inevitable frequency offset. This destroys the orthogonality, thus resulting in multiple access interference. To overcome these disadvantages, a new scheme called single carrier frequency division multiple access (SCFDMA). In this method, the subcarriers are transmitted sequentially and not in parallel. In this process, the envelope fluctuations reduce. Thereby, SCFDMA waveforms have inherently lower PAPR than OFDMA signals.

3.2 BASICS

It is a frequency division multiple access scheme. A single communication source is to be shared by multiple users, which is the same technique used in other multiple access schemes. SCFDMA can also be viewed as a linearly precoded OFDMA scheme. In SCFDMA , there is a DFT processing before the usual OFDMA processing. Guard intervals help in eliminating the time spreading among blocks. The SCFDMA assigns different sets of non overlapping fourier coefficients to different users. This is done by the DFT at the transmitter. The main difference in SCFDMA is that it leads to single carrier transmit signal while OFDMA deals with multiple carrier scheme. This helps n reducing PAPR. The reason being that in OFDMA the multiple subcarriers are directly modulated by the transmit symbols, in SCFDMA the DFT block first pre-processes the transmit symbols.

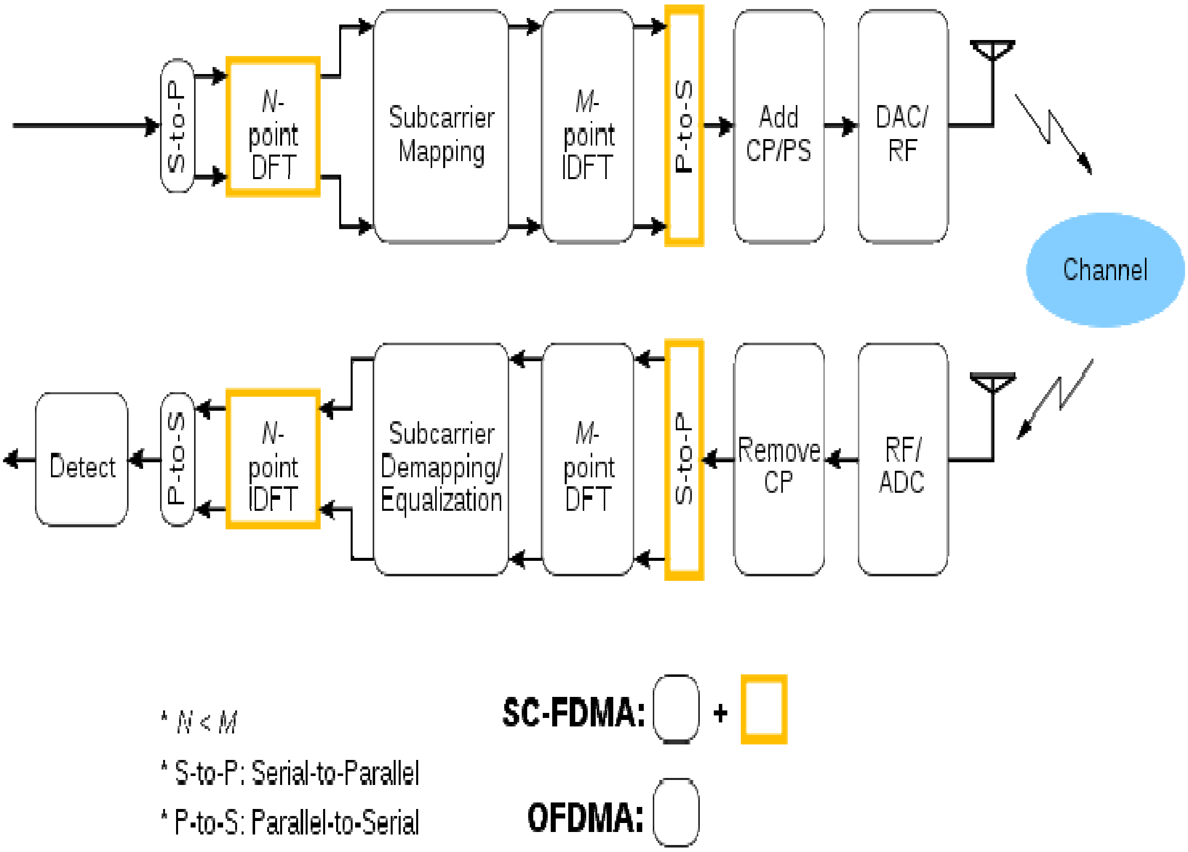


FIG 3:BLOCK DIAGRAM OF OFDMA AND SCFDMA

3.3 System Configuration of Single Carrier FDMA

Binary input signal is converted to a sequence of modulated subcarriers by the transmitter of the SCFDMA system. A baseband modulator transforms the data to a series of complex numbers using one of the modulation schemes like BPSK, QPSK, 16-QAM and 64-QAM. The modulation symbols are then grouped into blocks containing N symbols. An N point DFT is performed to have a frequency domain representation of the input data. The data is then mapped onto orthogonal subcarriers. If N symbols are transmitted per block, then without co-channel , Q simultaneous transmissions can be carried out by the system. An M point inverse DFT transforms the subcarrier amplitudes to time domain. Each output then modulates a single frequency carrier. The modulated symbols are then sent serially. Before transmission, a cyclic prefix is added to the data. This helps in preventing the inter block interference which might occur due to multipath propagation.

In general, CP used is obtained by taking the last part of the block and adding this at the beginning. If the length of the prefix is greater than the maximum delay spread of the channel, then inter block interference won't take place. Making the end and beginning of the prefix same will help facilitate transforming the linear convolution problem into a circular convolution one. SC-FDMA is sometimes referred to as DFT spread OFDMA. PAPR is defined as the ratio of peak power to average power of the transmitted signal.

CHAPTER 4

SYCHRONISATION IN AN OFDMA SYSTEM

4.1 INTRODUCTION:

Even though the concept behind OFDMA is pretty simple, the design stands as a challenging task. One of the most important problems is its synchronisation and this plays a big role in the design of the physical layer. OFDMA provides increased robustness against multipath distortions as it is easy to perform equalisation in the frequency domain. It also provides extra flexibility as it allows independent selection of parameters over each subcarrier. In OFDMA systems, the subcarriers are divided into exclusive subcarriers which are assigned to different users for simultaneous transmission. Multiple access interference can be avoided due to the orthogonality in the subcarriers. But for the best use of OFDMA, timing and frequency synchronisation pose a big challenge. OFDMA is extremely sensitive to frequency offsets and timing errors. Timing errors result in inter block interference and frequency offsets spoil the orthogonality and result in interference, making the method less robust. So, both these issues need to be addressed to make sure that the system works just fine.

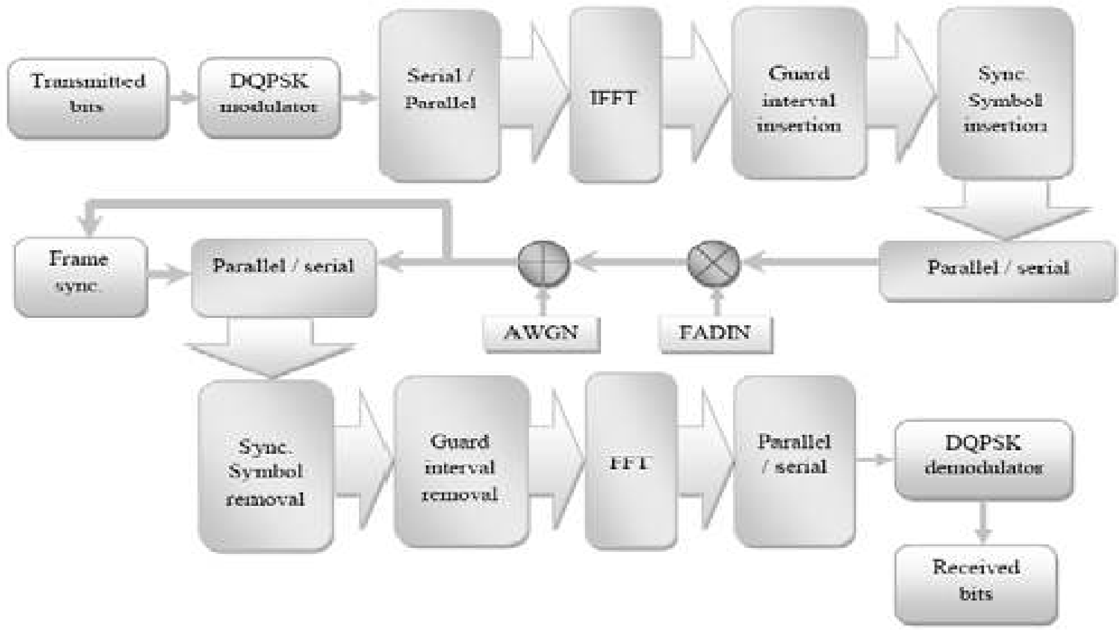


FIG 4:Simplified OFDM system model with synchronization

4.2 SENSITIVITY TO TIMING AND FREQUENCY ERRORS:

We need to see how the uncompensated errors will affect the performance of the system. Considering the downlink transmission,

4.2.1 TIMING OFFSET:

The samples of only one single block must be included by the DFT window so as to avoid the inter block interference. As a repercussion of multipath dispersion, each received block extends over the first L-1 samples of the next block. In a well designed system, the length of cyclic prefix must be greater than the length of the CIR. Then a certain length of the guard interval is not affected by the block. Error occurs when the timing error is more resulting in a cyclic shift of the output. The DFT output looks like

$$R_i(n)=e^{j2\pi n\Delta\theta/N} H(n)d_i(n) + W_i(n),$$

Where $\Delta\theta$ is the timing error. If the timing error is more then, in addition to IBI, it results in ICI as well. In this case, the output will be,

$$R_i(n)=e^{j2\pi n\Delta\theta/N}\alpha(\Delta\theta)H(n)d_i(n) + I_i(n,\Delta\theta) + W_i(n),$$

Where $\alpha(\Delta\theta)$ is the attenuation factor and $I_i(n,\Delta\theta)$ accounts for IBI and ICI.

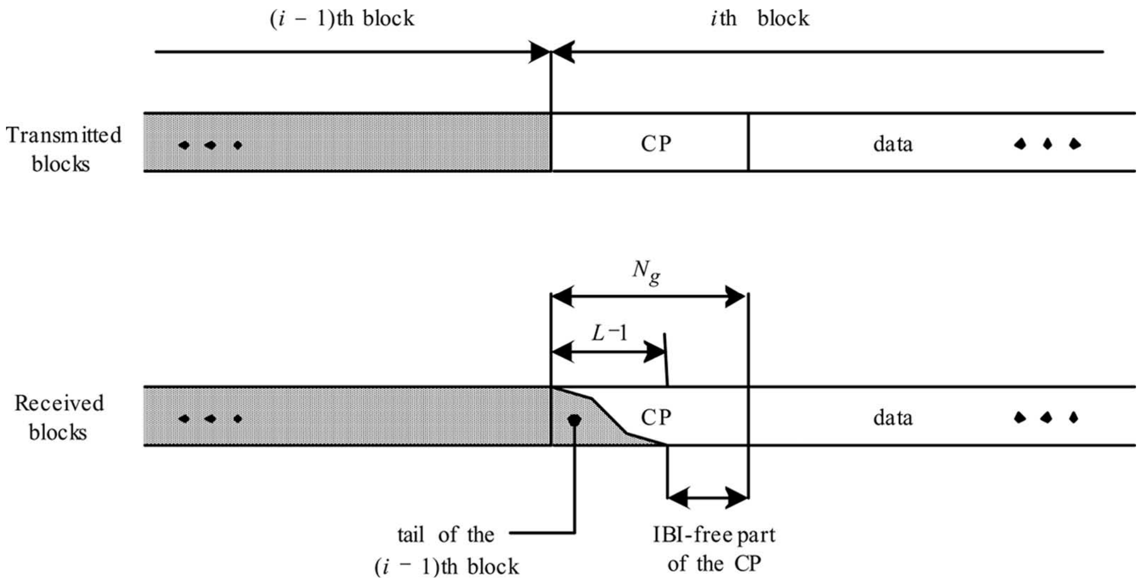


FIG 5: OVERLAPPING DUE TO MULTIPATH DISPERSION

4.2.2 FREQUENCY OFFSET:

Orthogonality of the subcarriers is lost due to frequency offset. This is because the offset shifts the signal in the frequency domain. Assuming the ideal timing synchronisation, the DFT output of the ith block , let frequency error be ε, we get

$$R_i(n)=e^{j\mu} \sum_{p=0}^{N-1} H(p)d(p)f(\varepsilon + p - n) + W(n)$$

where $\mu=2\pi i\varepsilon N_T/N$ and f(x) is defined as

$$f(x)=[\sin(\pi x)/N \sin(\pi x/N)]\ e^{j\pi x(N-1)/N}$$

If the frequency error is an intergral multiple of the subcarrier spacing, ε is interger valued and the above equation becomes

$$R_i(n)=e^{j\mu}H(|n-\varepsilon|_N)d_i(|n-\varepsilon|_N)+ W_i(n)$$

The above equation indicates that there will only be a shift in the modulated subcarriers if we have an integer frequency offset. Orthogonality is thereby preserved. When ε is not integer valued, subcarriers no longer remain orthogonal and the equation becomes,

$$R_i(n)=e^{j\mu}H(n)d_i(n)f_N(\varepsilon) + I_i(n,\varepsilon) +W_i(n),$$

Where $I_i(n,\varepsilon)$ is a zero mean ICI term.

In OFDMA downlink, frequency and timing acquisition is performed by each terminal by exploiting the pilot symbol sent by the other station. First the coarse estimates are carried out and then fine tracking is done to remove the existing error and get the desired output.

Although through timing synchronisation achieves synchronisation in time domain but the data in frequency domain are yet to be synchronised after timing synchronisation.The idea is to use repetitive blocks like in timing synchronisation & from it estimate the frequency offset as the repetitive blocks will remain same except for the phase change introduced due to the channel.The phase shift can be said to be half of the subcarrier spacing as fractional part plus integral multiple part of subcarrier spacing,i.e,

$$\varepsilon = \nu + 2\eta$$

where ε=frequency error, ν=fractional frequency error which varies from (-1,1] and η=integral frequency error which is an integer.

S&C method is one of the basic frequency synchronisation methods. It uses two blocks: First one is the same as timing synchronisation one. Second one uses differentially encoded pseudo-noise sequence with PN1 (even subcarrier) and PN2 (odd subcarrier).

Mathematically the received signal can be as follow:

$r(k) = s'(k) + w(k), \theta <= k <= \theta + N/2 - 1$

$r(k+N/2) = s'(k)\, e^{j\pi\nu} + w(k+N/2), \theta <= k <= \theta + N/2 - 1$

Clearly as can be seen there is an introduction of an multiplicative term $e^{j\pi\nu}$ in lower N/2 half identical first block of S & C. Hence the fractional frequency offset can be estimated as follow:

$\nu' = (1/\pi)\, \arg\{\sum_{k=0}^{\theta+\frac{N}{2}-1} r\left(k+\frac{N}{2}\right) r'(k)\}$

CHAPTER 5

SIMULATIONS AND RESULTS

SIMULATION OF SC-FDMA:

ALGORITHM:

Transmitter:

1. Random 64 data points are created & BPSK modulated.
2. Converted into parallel of block size of 8.
3. Do FFT on each block.
4. Subcarrier mapping is automatically done with the chosen data point value & block size.
5. Perform IFFT.
6. Add CP.
7. Convert Parallel-to-Serial.

Channel:

8. Created a Gaussian channel.
9. Added Gaussian noise.

Receiver:

10. Convert data back to parallel form.
11. Remove CP
12. Perform FFT.
13. Perform IFFT.
14. Convert to series stream.
15. Demodulate the data.

ALGORITHM FOR M-ary BER USING SC-FDMA:

Transmitter:

1. Random 2^14 data point are created & M-ary modulated.
2. Converted into parallel of block size of 8.
3. Do FFT on each block.
4. Subcarrier mapping is automatically done with the chosen data point value & block size.
5. Perform IFFT.
6. Add CP.
7. Convert Parallel-to-Serial.

Channel:

8. Created a Gaussian channel.
9. Added White Gaussian noise .

Receiver:

10. Convert data back to parallel form.
11. Remove CP.
12. Perform FFT and then perform IFFT.
13. Convert to series stream.
14. Demodulate the data.

15. Compare demodulated output data stream with the input data .

16. Calculate practical bit error.

17. Repeat from step 11 onwards for different set of values of SNR the above process.

18. Compute above steps for different values of M(=2,4,16).

19. Plot the BER graph for different values of M.

Algorithm for S & C timing synchronization :

Transmitter:

1. Function to do padding if the serial data can't be segmented into an integer number of blocks.
2. Create blocks of data points from the serial stream and perform IDFT on each block.
3. Create an S and C block which has two identical halves.
4. Insert S and C block in between every block.
5. Operate column wise and add cyclic prefix to the existing blocks of data.

Convert into an OFDM signal and transmit the resultant signal through a Gaussian noise channel.

Receiver:

1.Convert the data block to parallel form to perform FFT.

2.Remove CP and perform FFT.

3.Determine the start of the block by using a sliding window which searches for maximum autocorrelation between two half of the window and hence the original OFDM signal.

4.Demodulate the data.

Algorithm for S & C frequency synchronization(fractional part only):

Transmitter:

1. Function to do padding if the serial data can't be segmented into an integer number of blocks.
2. Create blocks of data points from the serial stream and perform IDFT on each block.
3. Create an S and C block which has two identical halves.
4. Insert S and C block in between every block.
5. Operate column wise and add cyclic prefix to the existing blocks of data.
6. Convert into an OFDM signal and transmit the resultant signal through a Gaussian noise channel with introduction of frequency offset of a given specified value.

Receiver:

7. Convert the data block to parallel form to perform FFT.
8. Remove CP and perform FFT.
9. Then the reference block is extracted & from it frequency offset is estimated.
10. Then reference blocks are removed & the original FFT received signals are computed such that frequency synchronization is obtained using the estimated frequency offset from previous step.
11. Demodulate the data.

OBSERVATIONS:

Transmitted and received data using SC-FDMA:

Fig 6: Without noise: (pink:-transmitted data, blue:-received data):

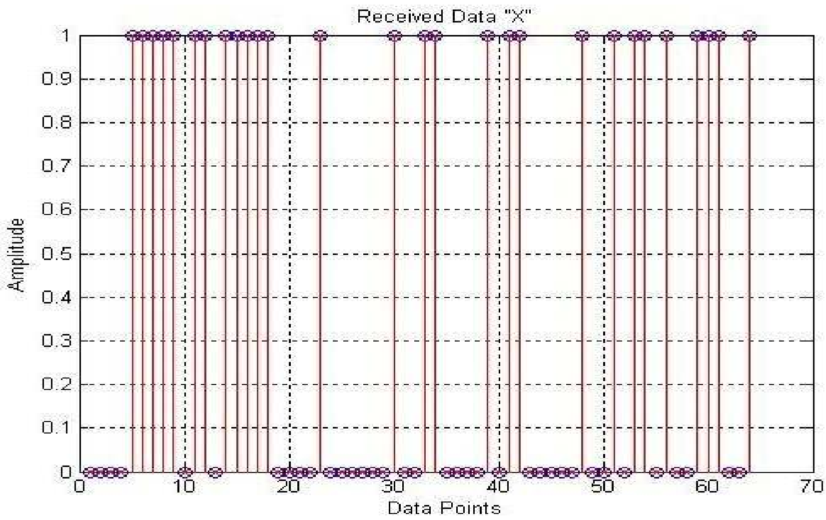
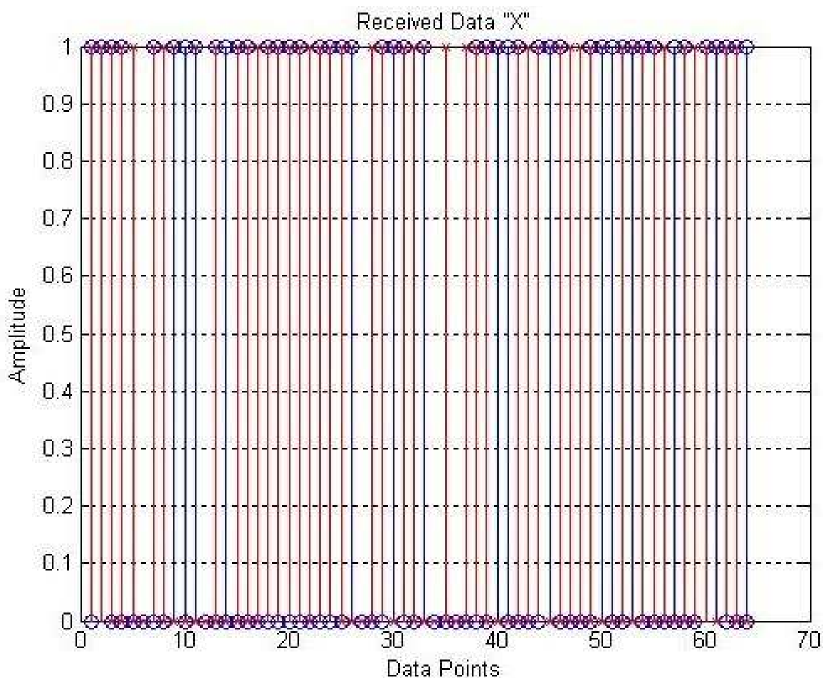
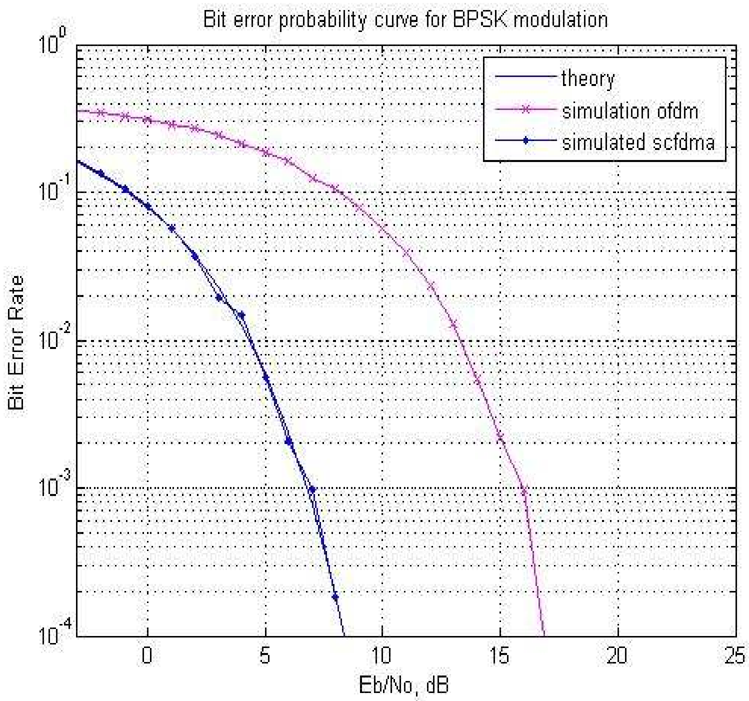


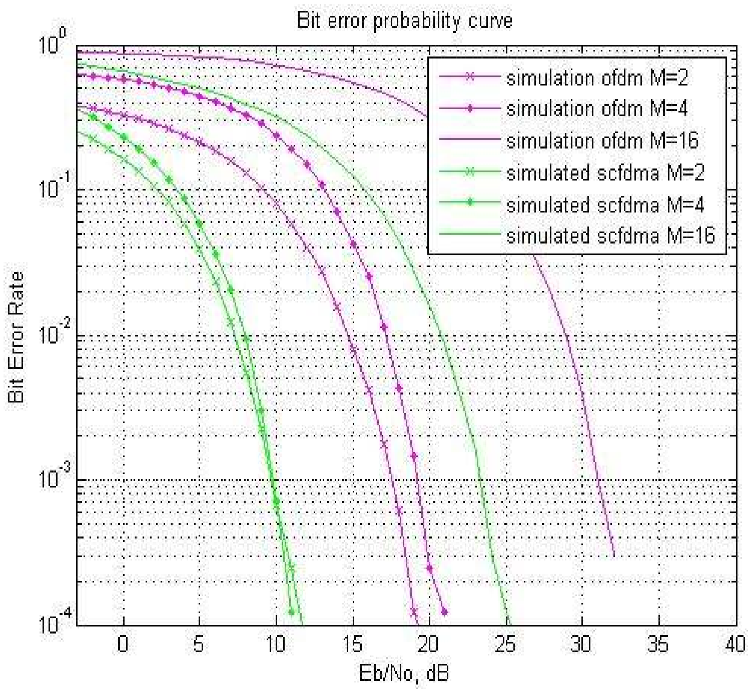
Fig 7: With noise: (pink:-transmitted data, blue:-received data):



<u>Fig 8:Probability error curve:</u>



<u>Fig 9:For different M values:</u>



Timing & frequency synchronization:

For S & C block:

Fig 10:Bit error probability curve:

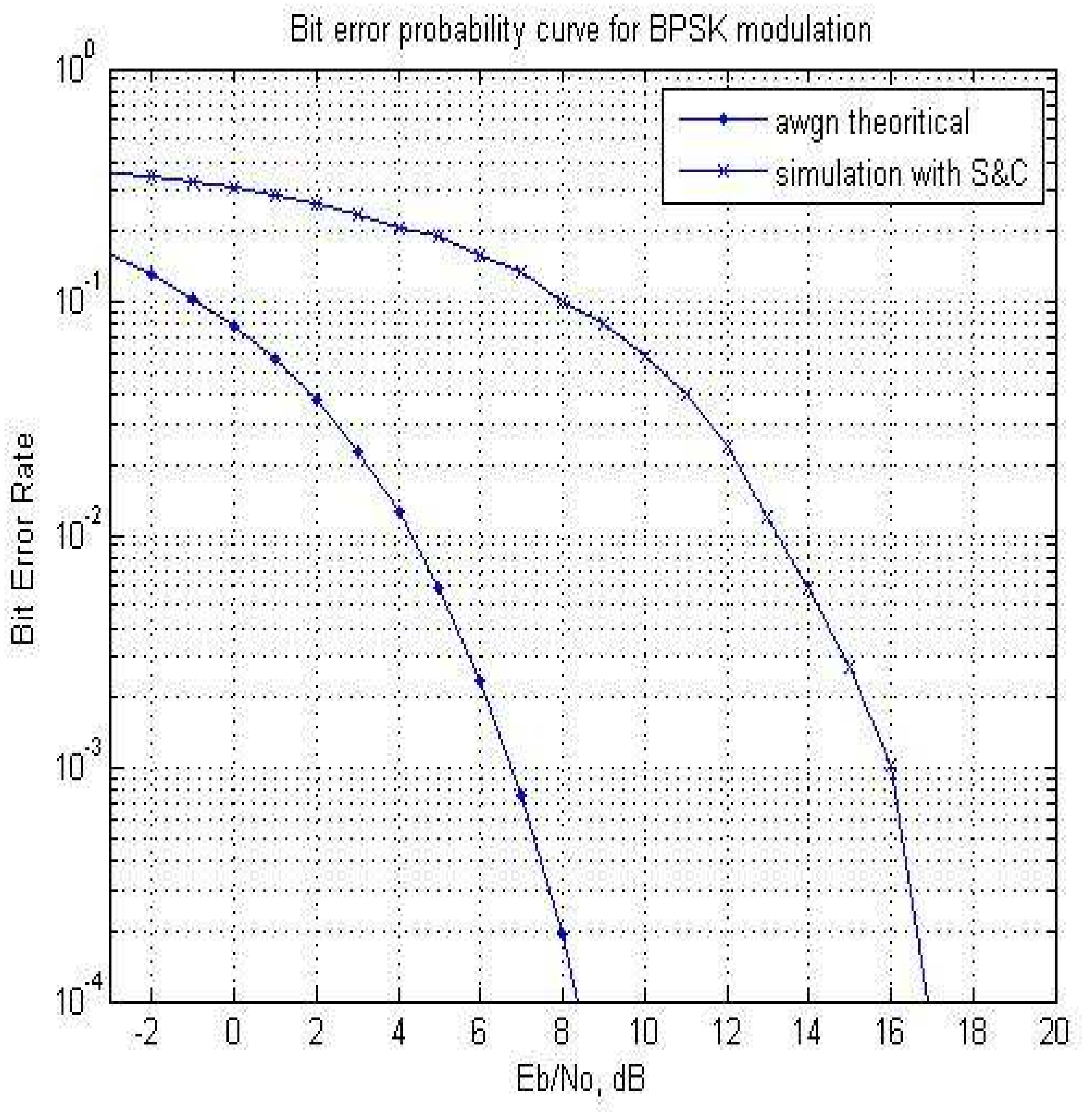


Fig 11:Block pivot error versus SNR curve:

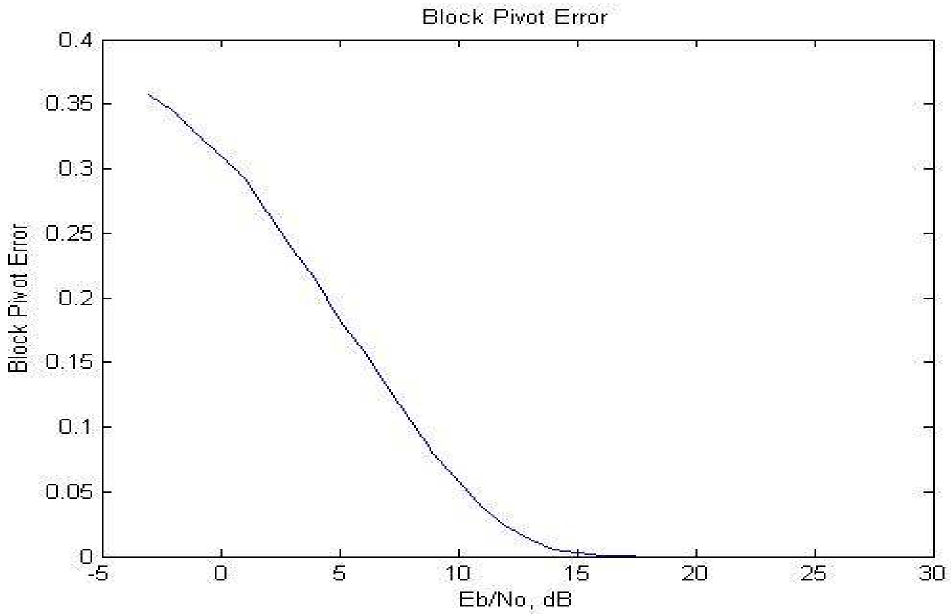


Fig 12:Timing metric:

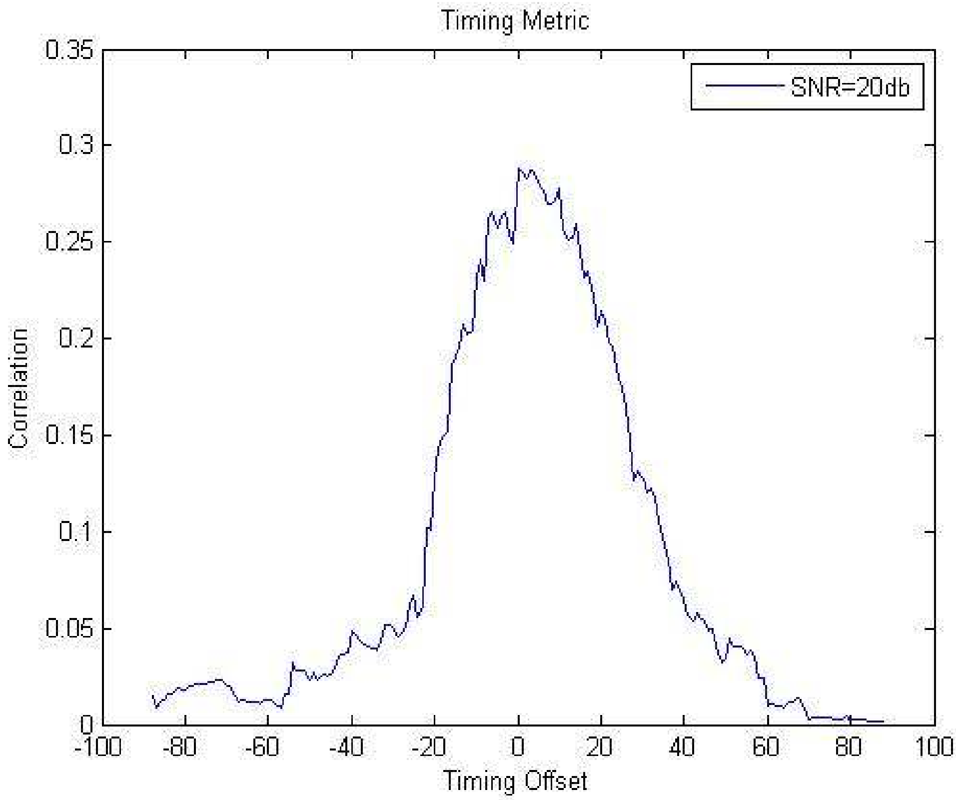
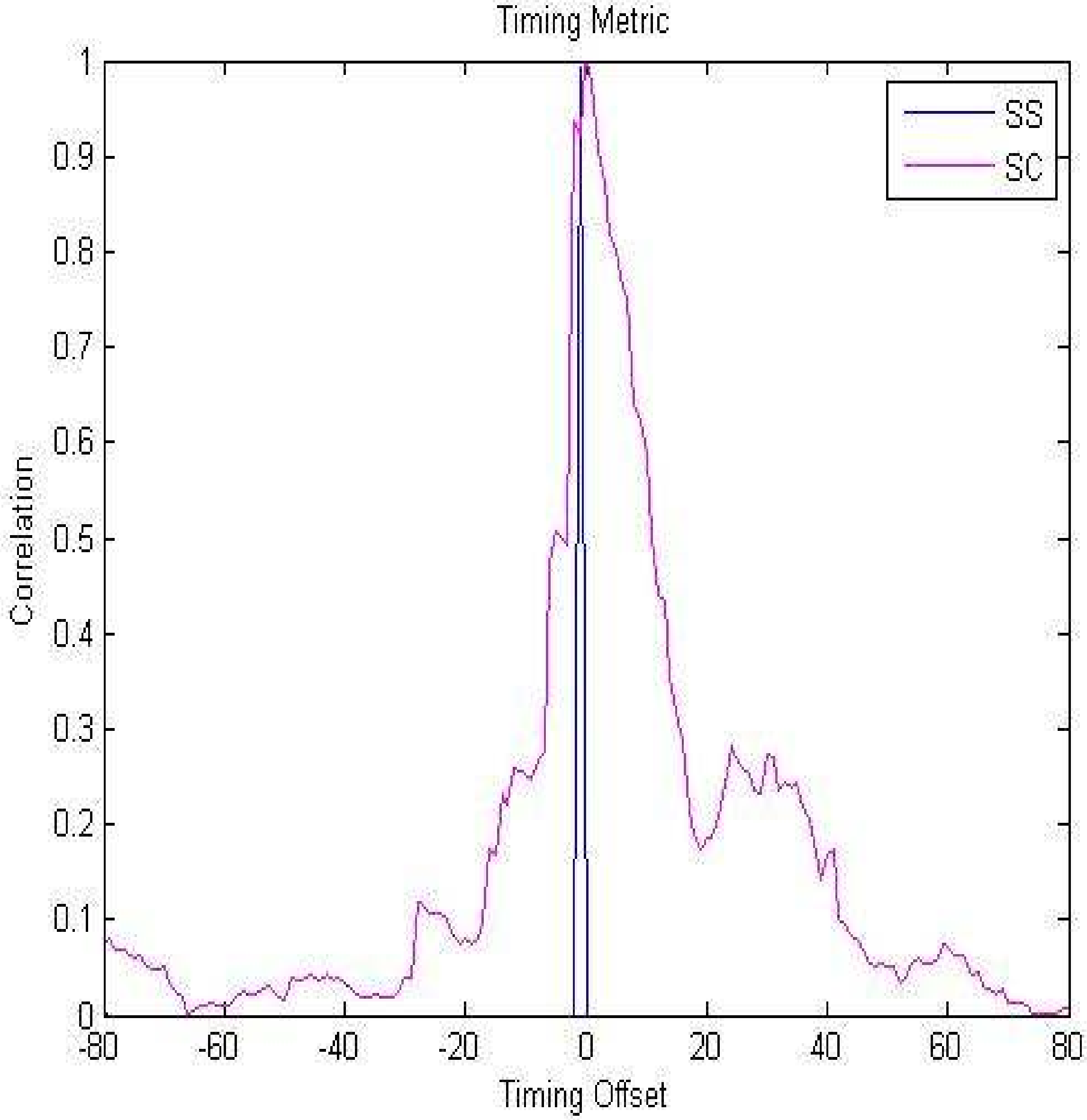


Fig 13:Comparison between S&S and S&C:



S and C frequency synchronisation:

Fig 14: Bit error rate for different frequency offset:

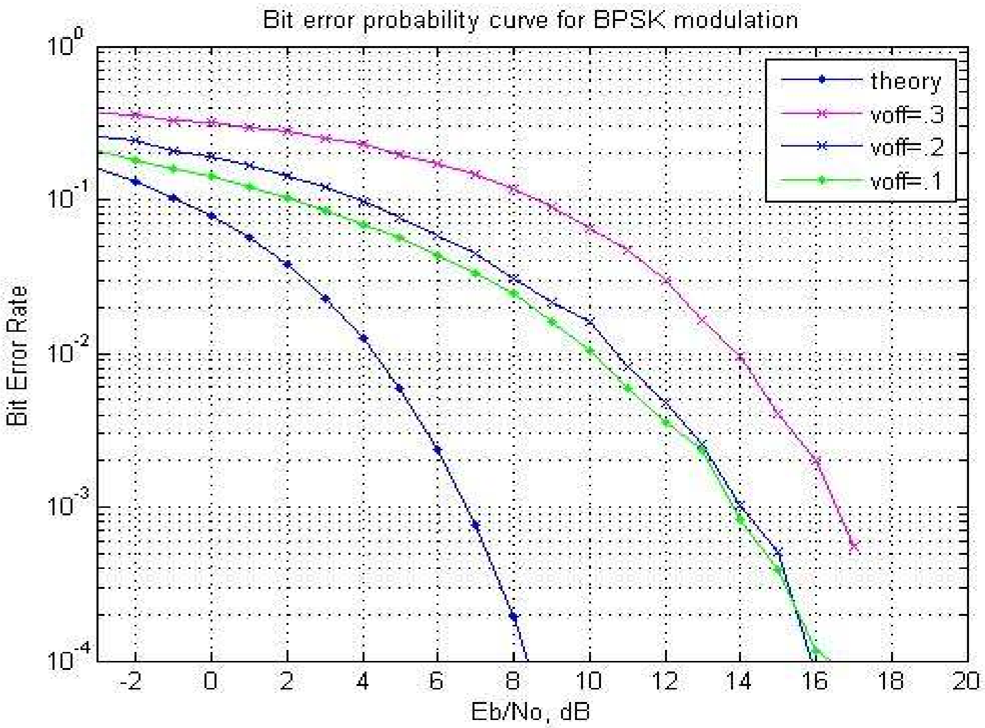
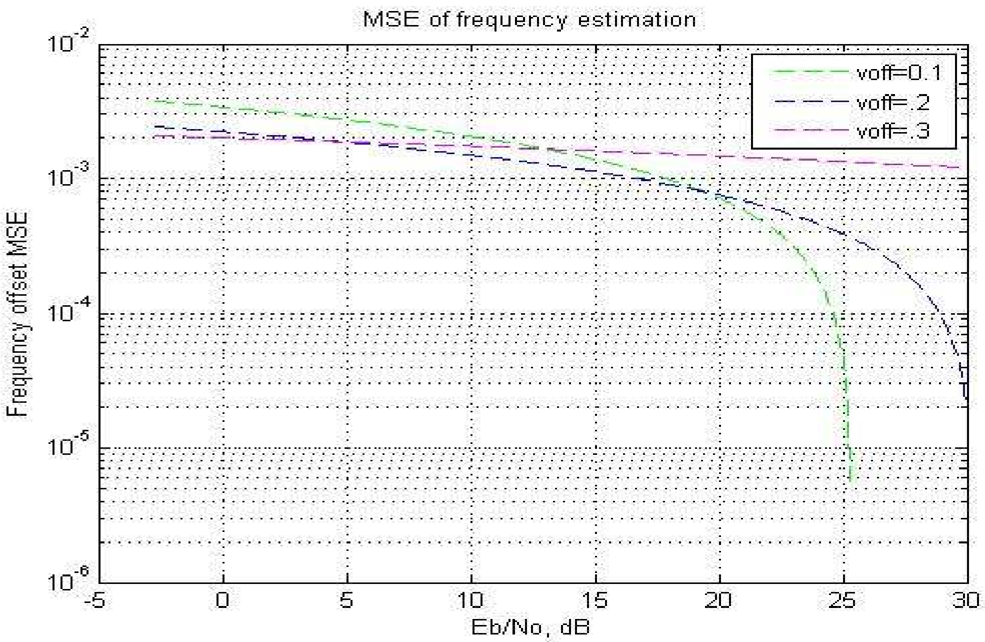


Fig 15: MSE variation with SNR:



INFERENCE:

Our study shows the following observations:

- In the ideal case of zero CFOs and TOs (i.e., perfect synchronization), the BER performance of SC-FDMA is better than that of OFDMA due to the inherent frequency diversity that is possible in SC-FDMA. Because of the presence of inter-symbol interference in SC-FDMA, the performance of SC-FDMA can be further expected to be improved by trying to arrest it.
- As the value of M increases, the BER performance tends to deteriorate as shown in the plot. But there also SC-FDMA outperforms OFDMA.
- BER graph using timing synchronization block & with zero timing offset are almost identical. So S&C method achieves timing synchronization.
- The block pivot error is found to be decreasing with increase in SNR value.
- The timing metric of the S&C algorithm exhibits a large plateau that may greatly reduce the estimation accuracy. This leads to search for sharper timing metric algorithms.
- SS blocks with four repetitive block patterns obtain sharper timing metric trajectories as compared to SC timing metric. Thus reference blocks with even more than four repetitive segments can be designed to further increase the sharpness of the timing trajectory & hence improves estimation accuracy.
- The bit error rate is higher for higher values of frequency offsets using S and C algorithm.
- The mean square error is found to decrease with increase in SNR. Also for higher values of frequency offset, the MSE is found to be higher.

FUTURE WORK

- The timing synchronisation of the OFDM system has been studied. The fractional part was implemented .
- The integral part estimation of the frequency acquisition is to be implemented for OFDM system.
- The timing and frequency synchronisation which have been implemented for an OFDM system should also be extended to a SC-FDMA system.
- Better methods of implementation of the synchronisation methods can be found out as synchronisation (both time and frequency) at the receiver is very important for designing an efficient communication system.

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