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Abstract:- Due to the requirements of high speed and low delays it is very difficult to design an efficient wireless communication system. Wireless communication system must have high throughput, low delays, low peak to average power ratio(PAPR), low complexity ratios, low probability and high power spectral density. Since past few decades different types of cellular networks were launched and went successful on the radio links such as WiMAX, that became very popular because of its high data rate (70Mbps) and support for providing wireless internet services over 50km distance. The UMTS Long Term Evolution (LTE) is an emerging technology in the evolution of 3G cellular services. LTE runs on an evolution of the existing UMTS infrastructure already used by over 80 percent of mobile subscribers globally. We have very limited resources in cellular technologies and it is important to utilize them with high efficiency. SC-OFDMA is one of the integral part of future mobile standards like LTE, LTE-A and ultra mobile broadband(UMB). In this research paper SC-FDMA technique for LTE system is explained. MATLAB/SIULINK was used to design the system and different adaptive modulation techniques were considered to compare the results. We use Additive White Gaussian Noise (AWGN) channel and introduce frequency selective (multipath) fading in the channel by using Rayleigh Fading model to evaluate the performance in presence of noise and fading.

Keywords: PAPR, LTE, LTE-A, 3G, UMB, SC-OFDMA, MATLAB, SIMULINK and AWGN.

1. INTRODUCTION OF LTE

The increasing necessity of higher data rates, reduced latencies and Internet Protocol Based Architectures of mobile networks has pushed the operators towards Long Term Evolution (LTE-3.9G). So, the Third Generation Partnership Project (3GPP) came up with a decision to develop a more sophisticated cellular communication standard known as the LTE (Release 8 & 9) [1]. This technology has set out for improvements in itself with regards to higher grades of quality in transmission of data such as Peer-to-Peer communication and quicker streaming of data (with increased bandwidth consumption). Even though high paced data packet accessing and the 3G networks are in practice with complete operation attributes, vendors and service providers already see themselves in competition to the fourth generation (4G) environment. The 4G is an unavoidable step in the progress and development of LTE. LTE, with its increased performance holds its importance as the one maintaining almost all the previous compatibilities.

SC-FDMA is a very useful technique used in the uplink of an LTE system because of its low PAPR and resistance to multipath degradations. Designing of any wireless system is quite challenging.

The author first prepared the modulation model to see BER plot for different modulation techniques. The second step that was achieved was Forward error Correction (FEC) model which is mostly used with Rayleigh fading channel and MIMO. Next OFDMA model was prepared and performance was observed and different results were considered. After SC-FDMA model was designed using Matlab/Simulink and different blocks required to make the model was selected. The spectrum was examined using FFT scope to make sure it was according to the required specifications. Different constellation results were also

considered for the performance measurement. Data rates and sample time was calculated for different modulations and arrange the blocks according to the model of SC-FDMA. Parameters of the different blocks were selected by calculating them accordingly. Different channels were introduced such as AWGN and Rayleigh fading channel to see the effects on parameters such as BER, probability of error, capacity, Power spectral density and Throughput. How different multipath signal propagation effects such as noise, fading and ISI affected these parameters were observed by adding AWGN channel and MIMO channel, and how they were combated. The type of fading introduced by adding Rayleigh fading channel was frequency selective fading. Different modulations were considered to see their effects on the parameters with both the models..

In the end first the results of constellation diagrams and spectrum for both OFDMA and SC-FDMA were observed and made conclusion accordingly then finally BER, probability of error, capacity and power density function and throughput were compared according to three different channels AWGN and MIMO with different modulations techniques for both OFDMA and SC-FDMA models and conclusions were made which are given in the last chapter results and conclusions.

Long Term Evolution (LTE) is the result of the standardization work done by 3GPP to achieve a high speed radio access in mobile communications. 3GPP is a collaboration of groups of telecom associations working on Global System for Mobile Communication (GSM) [1-10]. 3GPP published and introduced the various standards for LTE in Release 8 in 2008[2]. In 2010, the Release 9 was introduced to provide enhancements to LTE. In 2011, its Release 10 was brought as LTE-Advanced, to expand the limits and features of Release 8 and to meet the requirements of the *International Mobile Telecommunications Advanced* (IMT-Advanced) for the fourth generation (4G) of mobile technologies [1-10]. LTE radio transmission and reception specifications are documented in TS 36.101 for the user equipment (UE) and TS 36.104 for the eNB (Evolved Node B). As per these specifications, LTE is theoretically capable of supporting up to 1 Giga Bits per second (1 Gbps) for fixed user and up to 100 Mega Bits per second (100 Mbps) for high speed user. This is considerably high speed.

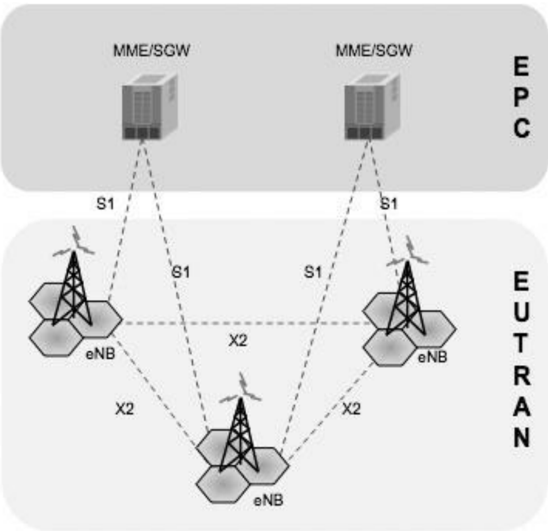


Figure 1: LTE Architecture

The specifications of LTE system and its comparison with the previous technologies are given below[3]

Specification	Details
Peak downlink speed 64QAM (Mbps)	100 (SISO), 172 (2x2 MIMO), 326 (4x4 MIMO)
Peak uplink speed (Mbps)	50 (QPSK), 57 (16QAM), 86

	(64QAM)
Data type	All packet switched data (voice and data). No circuit switched.
Channel bandwidths	1.4, 3, 5, 10, 15 and 20 MHz
Duplex schemes	FDD and TDD
Latency	Idle to active less than 100 ms; and small packets ~10 ms
Spectral efficiency	Downlink: 3 to 4 x HSDPA Rel. 6 Uplink: 2 to 3 x HSUPA Rel. 6
Supported antenna configurations	Downlink: 4x2, 2x2, 1x2, 1x1 Uplink: 1x2, 1x1
Access schemes	OFDMA (downlink) & SC-FDMA (uplink)
Modulation types	QPSK, 16QAM, 64QAM (Uplink and downlink)
Coverage	Full performance up to 5 Km, Slight degradation (5 – 30) Km

LTE comparison with the other technologies is given below[4]

PARAMETERS	**WCDMA (UMTS)**	**HSPA HSDPA/ HSUPA**	**HSPA+**	**LTE**
Max downlink speed	384Kbps	14Mbps	28Mbps	100Mbps
Max uplink	128Kb	5.7Mb	11Mbp	50Mb

speed	ps	ps	s	ps
Latency round trip time	150ms	100ms	50ms (max)	~10ms
3GPP releases	Rel 99/4	Rel 5/6	Rel 7	Rel 8/10
Approx years of initial roll out	2003/04	2005/06 (HSDPA) 2007/08 (HSUPA)	2008/09	2009/10
Access technology	CDMA	CDMA	CDMA	OFDMA/ SC-FDMA

2. SC-FDMA MODEL

SC- FDMA transmission model also uses most of the blocks similar to the OFDMA but the main difference is DFT addition in transmitter. It is selected for the uplink of LTE because of its low peak to average power ratio (PAPR) .The transmission model of the SC-FDMA is shown in the fig. Below[5]

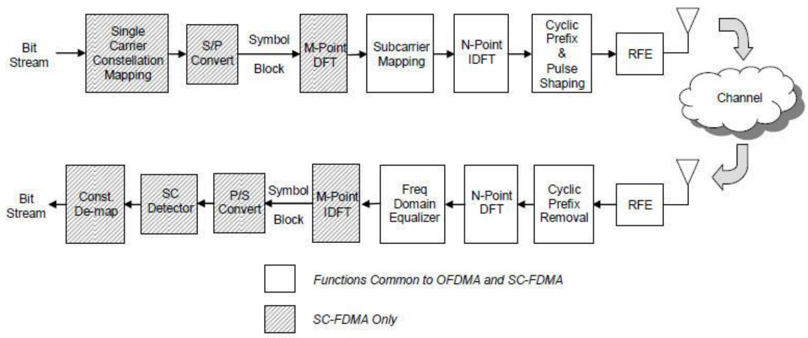


Figure 2: SC-FDMA MODEL

In SC-FDMA model an additional DFT block is present at the transmitter and an IDFT block at the receiver side. The input to the model is a stream of bits which is modulated according to QPSK, 16 QAM or 16 QAM depend upon the conditions of the channel. These symbols are first converted from serial to parallel by using the converter and then pass to the DFT block which present the frequency domain representation.[6]

Frequency domain transformation of the symbols is shown in the fig. given below

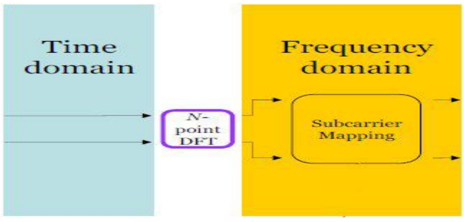


Figure 3: FFT operation

The output of the DFT block is forward to subcarrier mapping block. Different type of subcarrier mapping methods are used such as distributed and localizes which are explained later. The mapped subcarriers are forwarded to IFFT block which perform the reverse of process of DFT that is frequency to time domain representation. The function of the FFT block is shown in the fig given below

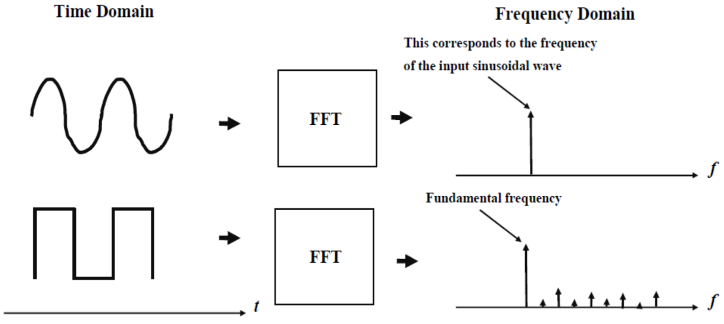


Figure 4: FFT Function[7]

The output of the IFFT block is forward to cyclic prefix block. The purpose of cyclic prefix is to reduce the multipath propagation signal effects such as ISI or IBI. Cyclic prefix is just the addition of zeros of last subsequent symbols of subcarrier mapping and present at the output of IFFT block and this CP should be greater than the channel delay spread to be efficient. In LTE, there are two types of cyclic prefix are used. Short and long CP. In short seven OFDMA symbols are present and in long six symbols are present. The CP is shown in the figure given below

3. SUBCARRIER MAPPING

Subcarrier mapping is an important feature used in uplink model and it plays very important role in transmitter. it maps the symbols coming from output of DFT block on the subcarriers available in the whole bandwidth available. There are two types of method used for subcarrier mapping. 1. Localized subcarrier mapping 2. Distributed subcarrier mapping.[8]

In case of localized subcarrier mapping zero padding take place above and below the actual information. While in case of distributed subcarrier mapping zero padding and information take place parallel over the whole bandwidth. For SC-FDMA localized subcarrier mapping is mostly used. However IFDMA is also very efficient which does not make use of DFT and IDFT blocks and mapped the symbols over the bandwidth. The two types of subcarrier mapping is shown in the fig. given below

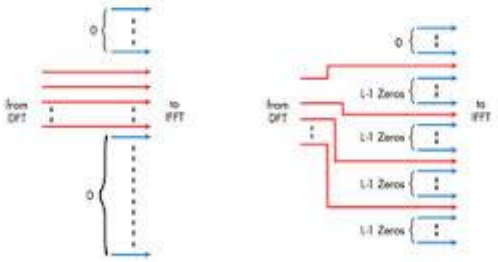


Figure 5: Subcarrier mappings

4. FRAME STRUCTURE

Type 1: This frame can be used for both time division duplex mode as well as Frequency division duple mode. It consist of 20 slots with the duration of each slot 0.5 msec. 2 slots together form a sub frame also known as transmit time interval (TTI) which means the whole frame consist 10 sub frame so the duration of whole frame is 10 msec. this frame is mainly used for the frequency division duplex so half of the sub frames are used for the downlink and half for the uplink. The frame structure is shown in the fig given below[9]

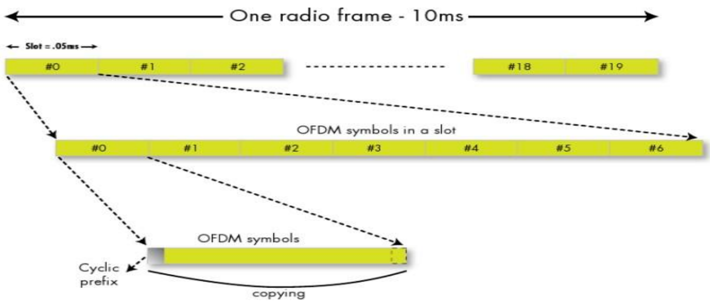


Figure 6: Frame type 1

Type 2: This frame is mainly used for the Time division duplex. In this case the whole frame is divided into two half frame with both the half frames have 5 sub frames each and duration of each frame is 1 msec. the frame structure is shown in the fig given below

In this frame case special sub frames are used which consist of three main fields. (D_WPTS) downlink pilot slot, (U_PPTS) uplink pilot slot and G_P guard period. The duration of each slot may vary but the total duration of the sub frame remain the same.

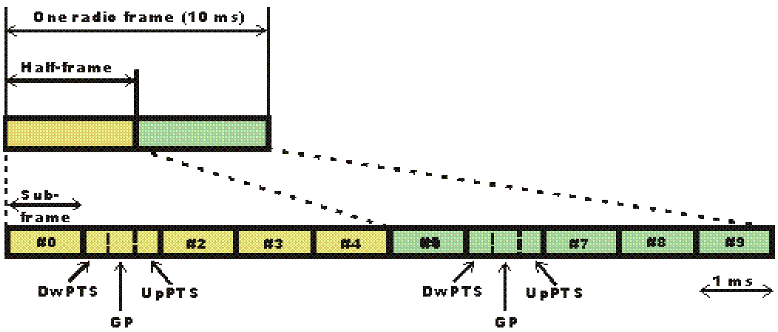


Figure 7: Type 2

5. PARAMETERS

BER vs SNR:-

For the BER vs SNR comparison AWGN channel was introduced and by changing the SNR value in the channel BER value was selected. Different values of SNR had different values of BER. Then by using a function for drawing graph in matlab the graph was drawn and then according to it different comparisons were made according to different modulations. Values are shown in appendix.

Probability of error:-

For probability of error calculations different modulations have different formulas. So by selecting formula according to modulation format the calculations were made. For different SNR, probability of error was also different. So again graphs were drawn and comparisons were made. Calculations are shown in appendix

Throughput:-

For throughput, formula was calculated and by selecting different values according to the formula throughput was calculated. It also have different formulas for different modulation format. With different SNR values were drawn and compared. The calculation is shown in appendix.

Capacity:-

For capacity again the values were calculated according to the formula, graph was drawn and comparison was made in the light of the graph.

Power spectral density:-

For power spectral density the FFT scope was used to see the spectrum. And after getting the spectrum from the model comparison was made according to the spectrum how the power varies for both the models. It is also important because it gives power comparison for power consumption method.

6. PARAMETERS FOR SIMULATION

The parameters used for the simulation are given in the table below

PARAMETERS	**ASSUMPTIONS**
Number of subcarriers (FFT length)	2048
Subcarrier spacing	15 KHz
CP length	144
Sampling frequency	30.72 MHz
Symbol duration	66.6 μsec
Modulations	QPSK, 16 QAM and 64 QAM
System Bandwidth	20 MHz
Occupied bandwidth	18 MHz
Channels	AWGN and Rayleigh fading channel
Data block size	128
Fading	Frequency selective

Table 3: Parameters for simulation

7. SIMULATION MODEL

SC-FDMA WITH AWGN CHANNEL

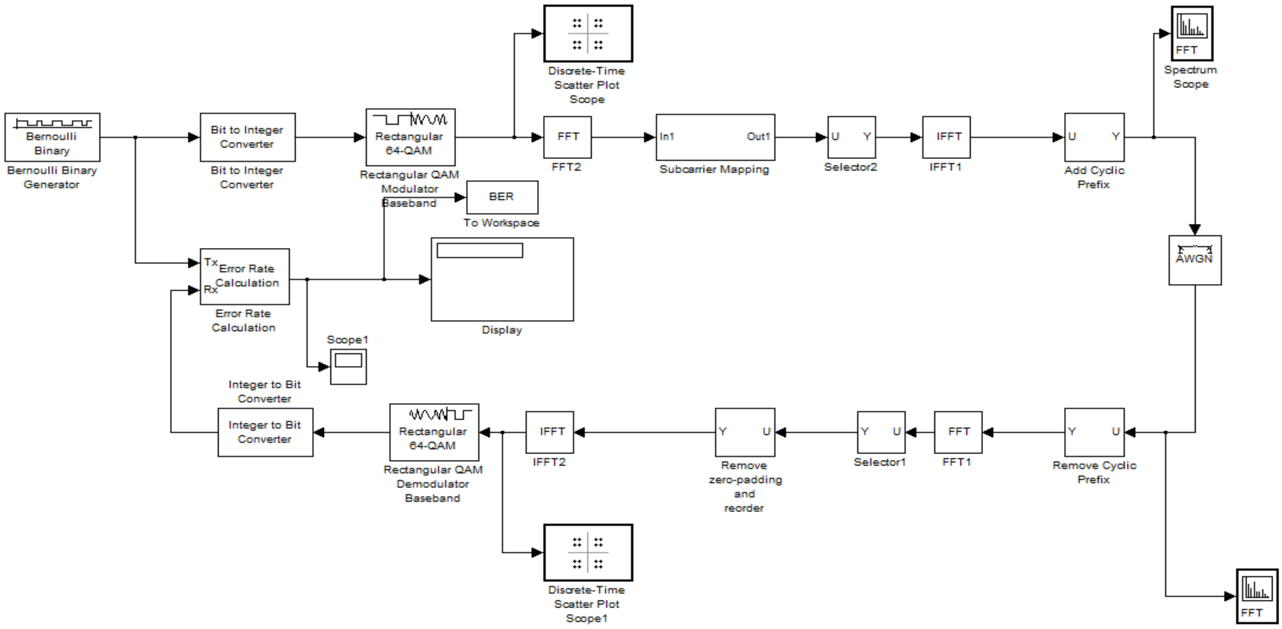


FIG: MODEL WITH AWGN

SC-FDMA WITH RAYLEIGH FADING CHANNEL

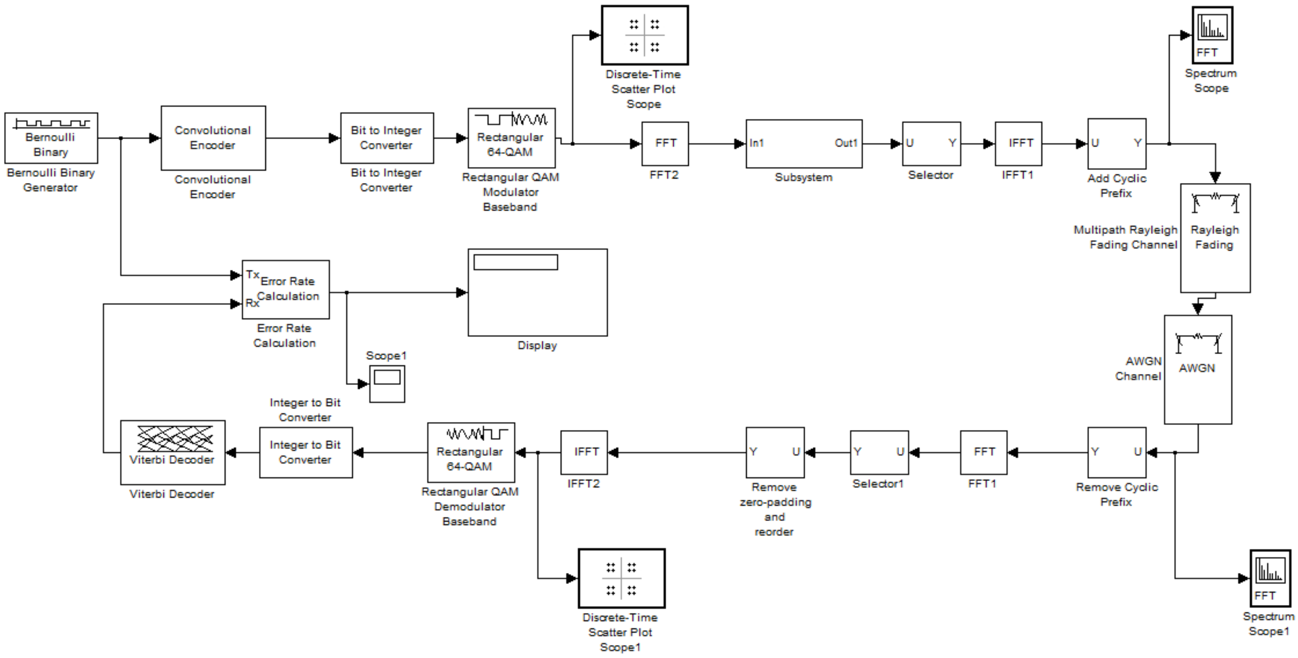
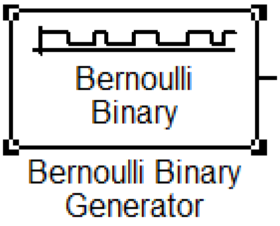


FIG: MODEL WITH FADING CHANNEL

8. MODEL DISCRIPTION

- Bernoulli Binary Generator



This block generates the random binary data using the Bernoulli distribution with parameter (p). The distribution is zero probability with p (any real number between 0 and 1) and probability is one with (1-p). The mean value for the distribution is (1-p) and the variance is p(1-p). The output signal may be frame based or sample based row or column vector or 1-D array. This generator is accessible from the Communication Systems Toolbox in MATLAB Library.

- QPSK/QAM modulator and demodulator

Baseband modulations used for LTE system are QPSK (Quadrature Phase Shift Keying) [19], 16 QAM and 64 QAM (Quadrature Amplitude Modulation) with n=2, n=4 and n=6 bits per symbol for each of the schemes. In QPSK, there are four phase decision points. When transition occurs from one state to another state, it is possible to pass through the origin and this denotes minimum magnitude. On transition from UE to the BS, OQPSK is used to prevent transition through the origin. QAM is a mixture of the phase and amplitude modulation because of the variations present in the system for both phase and amplitude. Quantized QAM was used for the purpose of carrying high data rates across the system. Constellation points are arranged in a square pattern having equal horizontal and vertical spacing according to the gray coding method (based on the hamming distance between each adjacent constellation point).

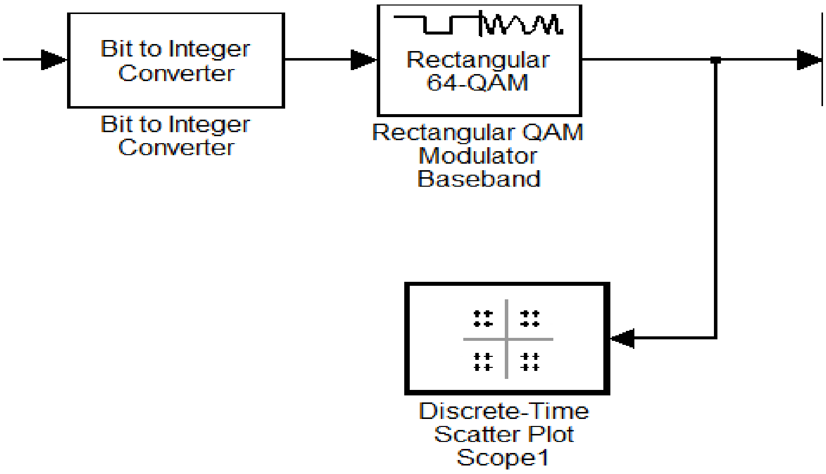


Figure: Baseband modulaor

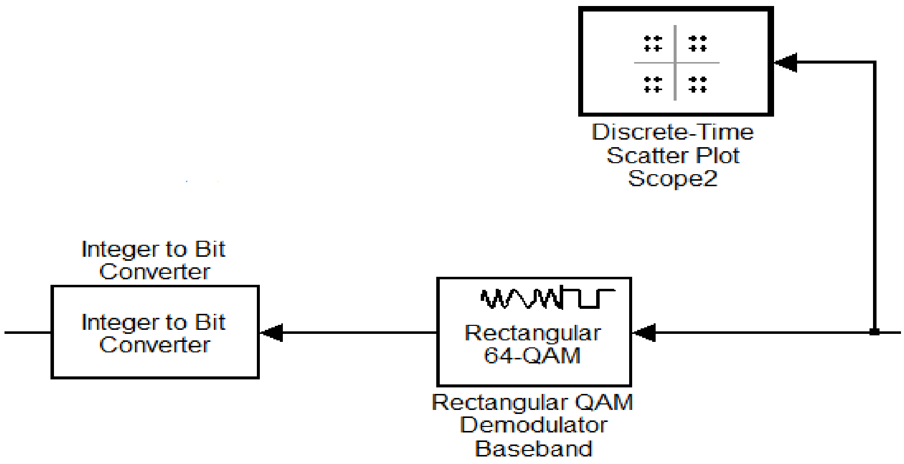


Figure: Baseband Demodulator

- OFDM Transmitter

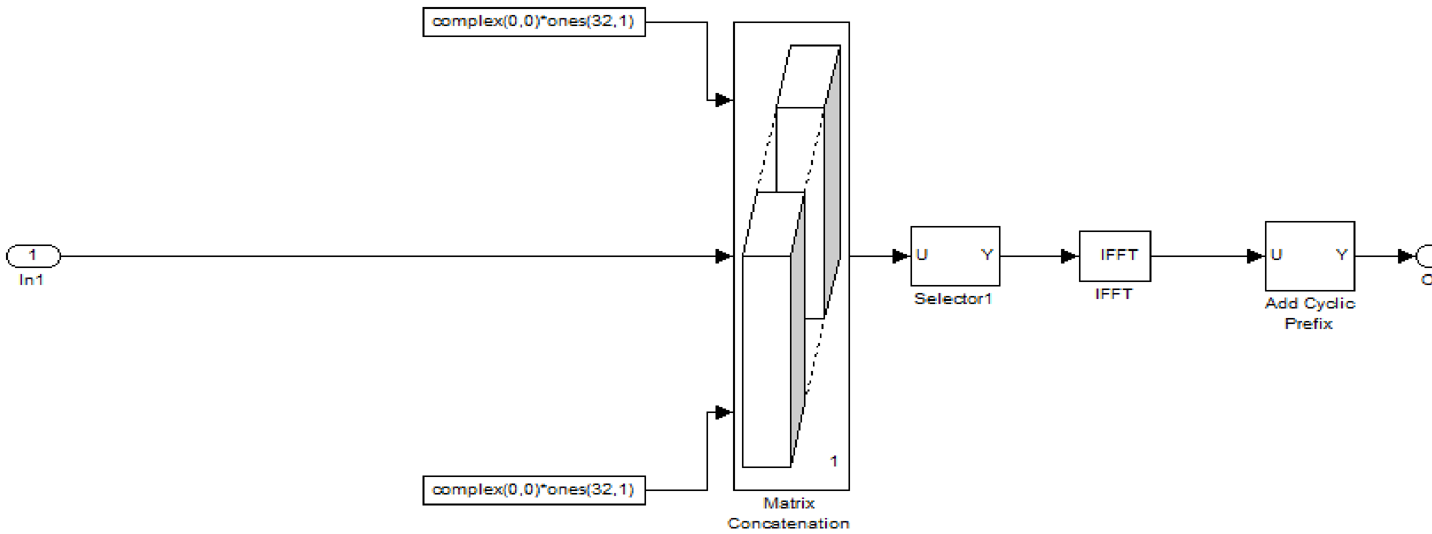


Figure: OFDM transmitter

After being modulated in the QPSK/QAM modulator, the symbols are fed to the OFDM transmitter for mapping them onto subcarriers according to the FFT size. If the FFT size is not met with the number of subcarriers then zero padding (addition of guard subcarriers) is done to fulfill this requirement. The FFT size is set according to the bandwidth of the system. The subcarriers are then passed to IFFT block to convert the frequency domain symbols to time domain symbols and then CP is added to these symbols to prevent from interference over the channel. Zero padding is performed by the addition of complex (0, 0) for a particular number of guard subcarriers to accommodate in to the FFT size. For example, if the bandwidth of the system is 20 MHz, then the FFT size should be 2048 and thus the input to the OFDM transmitter must add up with guard subcarriers. The OFDM transmitter subsystem is shown below that was used for simulation.

- OFDM Receiver

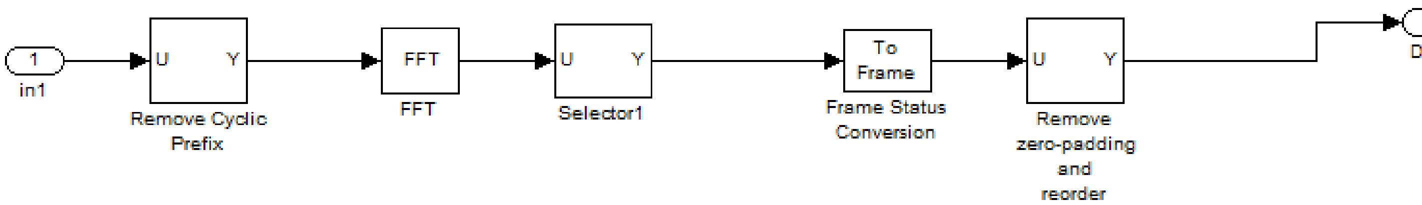


Figure: OFDM receiver

At the OFDM receiver, the cyclic prefix is eradicated from the time domain signal and then transformed to frequency domain signal after processing through the FFT module. A selector is just used to cap the specific range of the spectrum of the system. The zero padding is further removed from the subcarriers and desired number of symbols is then recovered from which the data is acquired. The process is shown in the following diagram.

- AWGN Channel

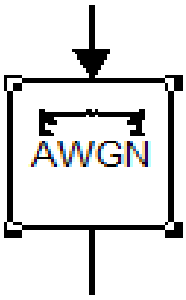


Figure: AWGN Channel

This process adds white Guassian noise to the signal on the multipath channel. Noise power in the AWGN channel is described by the SNR (Signal to Noise Ratio) or the EbNo (Ratio of Energy of Bit to Noise Power Density). The block will add a real or complex Guassian noise to produce a real or a complex output signal, respectively. The sample time is inherited from the input signal. The AWGN channel block accepts a scalar, vector or a matrix input (with a single or double value) and outputs port data type from the signals driving that block.

- RAYLEIGH Fading Channel

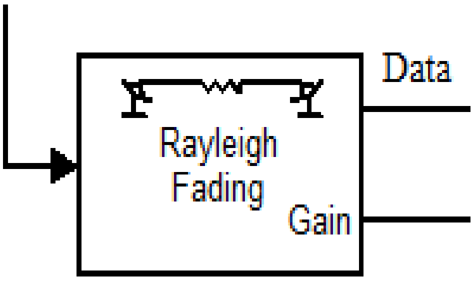


Figure: Rayleigh Fading Channel

This block implements a baseband simulation for a Rayleigh fading multipath propagation channel. This block can be used to design the mobile communication system. It accepts a scalar/vector signal with a sample time greater than zero. Doppler shifts are created in the signal's spectrum due to the relative motion of the transceiver. Different Doppler frequency can be assigned to each different path in the multipath channel. Each signal in a multipath channel faces reflections at multiple points and then travel towards the receiver through different paths with different time delays. For a Rayleigh fading channel the signals are so distributed with noise that they need more SNR for reconstruction. The Rayleigh fading block multiplies the input signals by the samples from the Rayleigh distribution complex random process. The block is accessible from the Communication System Toolbox in the MATLAB/Simulink Library.

9. Results obtained

- Spectrum or responce

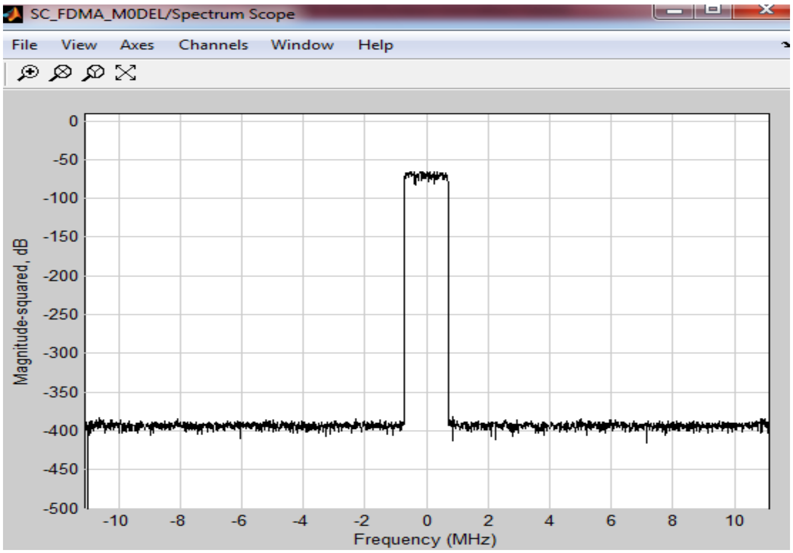


Figure: spectrum

The spectrum or responce of the model shows that the actual data rate in 1 to 2 Mbps while all other information in the spectrum is zero padding or non information carriers.

- Constellation Diagram

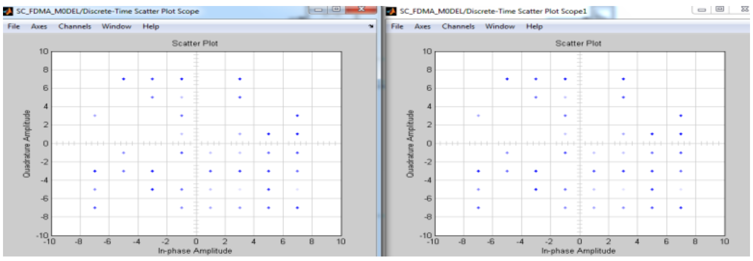


Figure: conctellation map

From the constellation diagram it can be seen that the symbols are widely spreaded from each other this is due to AWGN channel which added gaussian noise effect.

- BER VS SNR

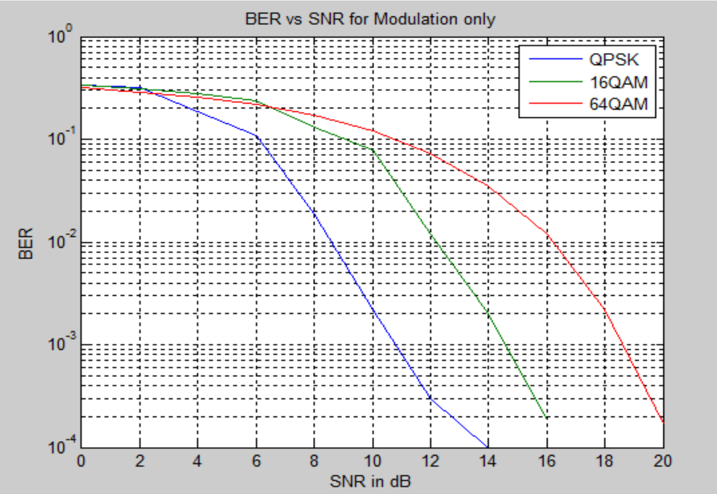


Figure: BER Vs SNR

From the above graph following information can be obtained for a BER of 10^{-3}

Modulation Type	Bits per symbol	SNR(dB)
QPSK/4QAM	2	10.5
16QAM	4	14.5
64QAM	6	19

From the above table it can be seen that BER is same for QPSK and 4QAM but BER inreases as the modulation type increases thats why 64QAM has higher value of 19 and its more efficient.

- Probability of error

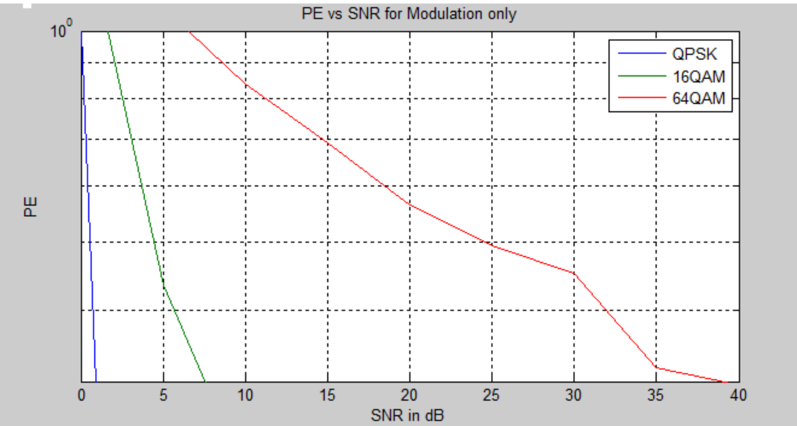


Figure: Probability of error

From the above graph probability of error 10^{-4} for different modulation techniques is

Modulation type	Bits per Symbol	SNR
QPSK/4QAM	2	1
16QAM	4	7
64QAM	6	40

From the above table it can be seen that PE is lower for QPSK/4QAM and higher for 64QAM.

- Power spectral density

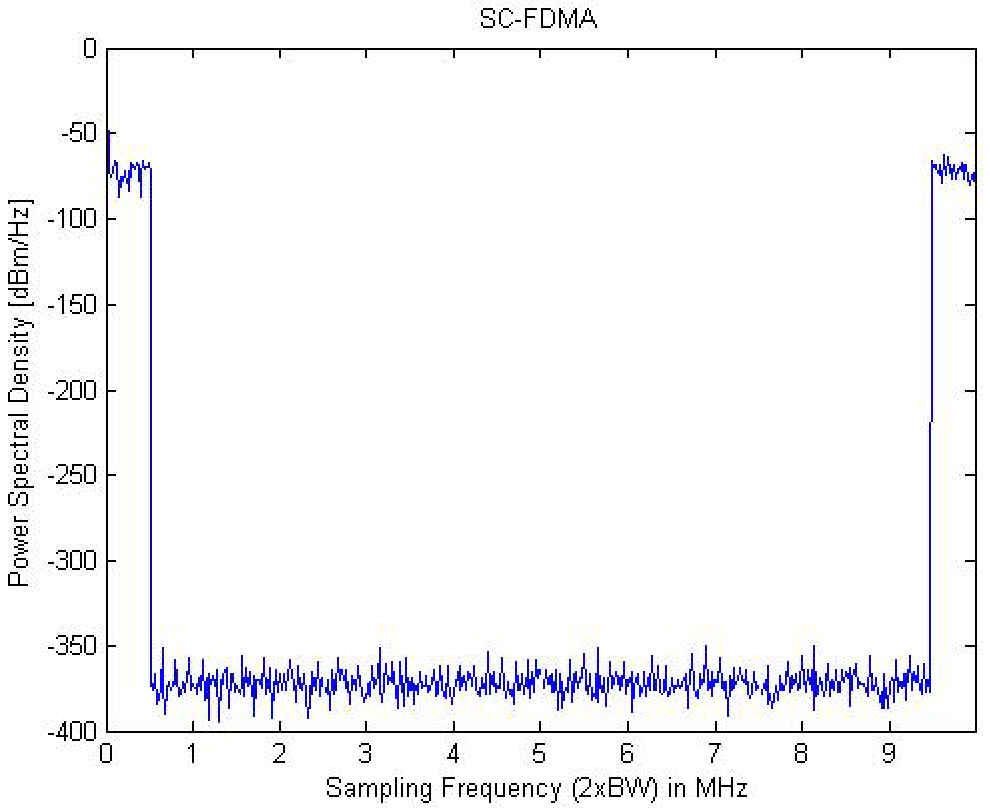
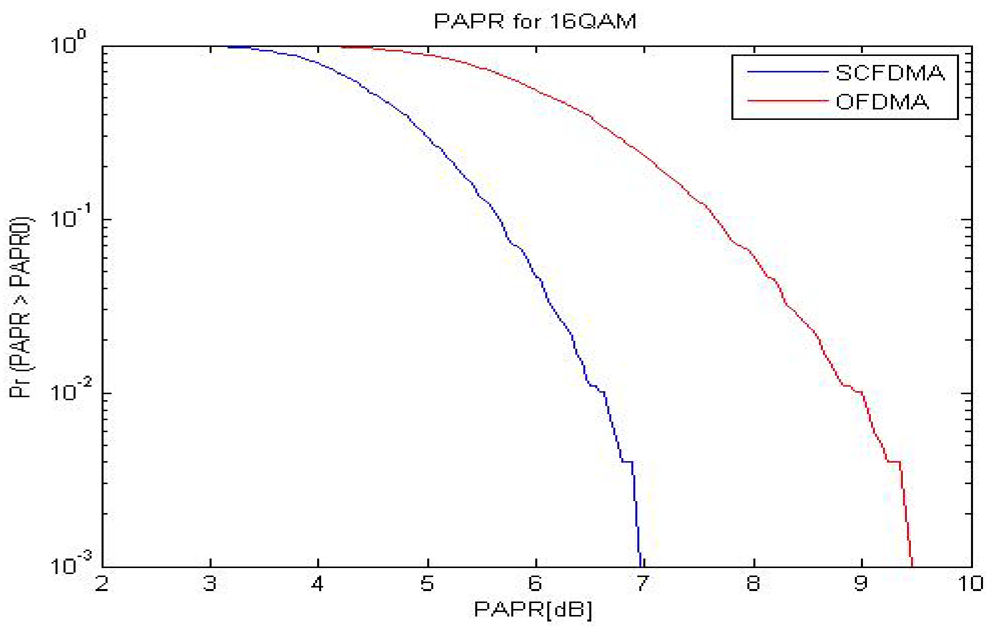


Figure: power spectral density

From the power spectral density map itcan be seen that average power of all symbols is -375. It is an important measure because power consumption is important for devices or UE.

- Peak to Average power ratio



From peak to average power ratio map it can be seen that PAPR for SC-FDMA is low as compared to OFDMA. Which is one of the most important reason why is is deployed in LTE uplik.

10. Conclusion

The conclusion of the thesis is that BER is an important factor for every communication model. The performance of the model is mainly depend on this factor so its important to know this for SC-FDMA and OFDMA model. The first conclusion of the thesis was that the BER for SC-FDMA model require less SNR for all three modulation types as compared to OFDMA model. Along with this conclusion the author also concluded how to determine data rates of the models for different modulation formats. From the calculations determined in the thesis it was concluded that lower modulations improves the system performance requiring less SNR and higher order modulations improves the bandwidth efficiency of the system. Probability of error is also important. If this value is known it is easy to know at what value of SNR error free transmission is possible. In this thesis it was also concluded how to determine this value for different modulations for both the models. From calculations it was concluded that this value is important for adaptive modulation point of view.

Power is an important issue for the practical models and power saving for the user end is an important issue for the uplink. From calculations of power spectral density it was concluded that average power for the SC-FDMA is high AS compared to the OFDMA that's why SC-FDMA has less PAPR and more useful technique for uplink as compared to OFDMA.

Finally the author conclude that throughput of the system improves with greater SNR for all the modulation types. From calculations it was concluded that for throughput SNR requirement increases with the modulation order.

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