IMPLEMENTATION OF SC-FDMA USING MATLAB

Submitted in partial fulfillment of the Degree of

Bachelor of Technology

In

Electronics and Communication Engineering

Under the supervision of

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to

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CERTIFICATE

This is to certify that project report entitled " Implementation of SC-FDMA using Matlab" submitted by Niti Chauhan, Srishti Singh and Neha Gupta in partial fulfillment for the award of degree of Bachelor of Technology in Electronics and Communication Engineering to Jaypee University of Information Technology, Waknaghat, Solan has been carried out under my supervision

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LIST OF ABBREVIATIONS

OFDM: Orthogonal Frequency Division Multiplexing

SC-FDMA: Single Carrier-Frequency Division Multiple Access

PA: Power Amplifier

FFT: Fast Fourier Transform

IFFT: Inverse Fast Fourier Transform

LTE: Long Term Evolution

ICI: Inter Carrier Interference

ISI: Inter Symbol Interference

BER: Bit Error Rate

PAPR: Peak To Average Power Ratio

AWGN :Additive white Gaussian noise

S/P: Serial To Parallel

P/S: Parellel To Serial

CP: Cyclic Prefix

ABSTRACT

The objective of this project is to demonstrate the concept and feasibility of an SCFDMA communication system. This objective is met by developing a MATLAB program to simulate a basic SC-FDMA communication system. In the initial stage of the project literature OFDM was studied and various important conclusions were drawn regarding the importance of multicarrier techniques and need of techniques which support higher data rates. Later a MATLAB code was generated to analyze the theoretical concepts. In the transmission AWGN (Additive White Gaussian Noise) communication channels were studied and the performance variation in terms of BER (Bit Error Rate) and PAPR (Peak to Average Power Ratio) was recorded. Performance of the system was studied by sending random data as input and taking the modulation method 16-QAM (Quadrature Amplitude Modulation).In the later stage of project SC-FDMA was studied, it's advantages over OFDM. The impact of few more new blocks different from OFDM which helps in reduction of the limitations like PAPR and BER. This could be clearly seen through the results produced from the MATLAB code of SC-FDMA's PAPR and BER.

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CHAPTER 1

INTRODUCTION TO OFDM

The fundamental principle of the OFDM system is to decompose the high rate data stream (bandwidth = W) into N lower rate data streams and then transmit them simultaneously over a large number of subcarrier.

As an analogy, FDM channel is like water flow out of a faucet, a whole bunch of water coming all in one stream; In contrast the OFDM signal is like a shower from which same amount of water will come as a lot of small streams. In a faucet all water comes in one big stream and cannot be sub-divided. OFDM shower is made up of a lot of little streams.

The advantage of one over the other is that if we put our thumb over the faucet hole, we can stop the water flow but we cannot do the same for the shower. So although both do the same thing, they respond differently to interference. Both methods carry the exact same amount of data. But in case of any interfere to some of these small streams, only some part of data in the OFDM method will suffer.

These small streams when seen as signals are called the sub-carriers in an OFDM system and they must be orthogonal for this idea to work. The independent sub-channels can be multiplexed by frequency division multiplexing (FDM), called multi-carrier transmission or it can be based on a code division multiplexing(CDM), in this case it is called multi-code transmission.

1.1 HISTORY OF OFDM

Multicarrier communication systems were first introduced in the 1960s, with the first OFDM patent being filed at Bell Labs in 1966. Initially only analogue design was proposed, using banks of sinusoidal signal generators and demodulators to process the signal for the multiple sub channels. In 1971, the Discrete Fourier Transform (DFT) was proposed, which made OFDM implementation cost-effective. Further complexity reductions were realized in 1980 by the application of the Wino grad Fourier Transform (WFT) or the Fast Fourier Transform (FFT).

OFDM then became the modulation of choice for many applications for both wired systems (such as Asymmetric Digital Subscriber Line (ADSL)) and wireless systems. Wireless applications of OFDM tended to focus on broadcast systems, such as Digital Video Broadcasting (DVB) and Digital Audio Broadcasting (DAB), and relatively low-power systems such as Wireless Local Area Networks (WLANs). Such applications benefit from the low complexity of the OFDM receiver, while not requiring a high-power transmitter in the consumer terminals. This avoids one of the main disadvantages of OFDM, namely that the transmitters in high-power applications tend to be more

expensive because of the high Peak to Average Power Ratio (PAPR). The first cellular mobile radio system based on OFDM was proposed in. Since then, the processing power of modern digital signal processors has increased remarkably, paving the way for OFDM, after much research and development, to find its way into the LTE downlink . Here, the key benefits of OFDM which come to the fore are not only the low-complexity receiver but also the ability of OFDM to be adapted in a straightforward manner to operate in different channel bandwidths according to spectrum availability.

1.2 ORTHOGONALITY

The key to OFDM is maintaining orthogonality of the carriers. If the integral of the product of two signals is zero over a time period, then these two signals are said to be orthogonal to each other. Two sinusoids with frequencies that are integer multiples of a common frequency can satisfy this criterion. Therefore orthogonality is defined by :

$$\int_0^T \cos(2\pi nft) \cos(2\pi mft)\, dt = 0 \ (m \neq n) \tag{1.1}$$

Where n and m are two unequal integers; f is the fundamental frequency; T is the period over which the integration is taken. For OFDM, T is one symbol period and f set to 1/T for optimal effectiveness.

1.2.1 Importance of Orthogonality

The main concept in OFDM is orthogonality of the sub-carriers. The "orthogonal" part of the OFDM name indicates that there is a precise mathematical relationship between the frequencies of the carriers in the system. It is possible to arrange the carriers in an OFDM Signal so that the sidebands of the individual carriers overlap and the signals can still be received without adjacent carrier interference. In order to do this the carriers must be mathematically orthogonal.

The Carriers are linearly independent (i.e. orthogonal) if the carrier spacing is a multiple of 1/Ts. Where, Ts is the symbol duration. The orthogonality among the carriers can be maintained if the OFDM signal is defined by using Fourier transform procedures. The OFDM system transmits a large number of narrowband carriers, which are closely spaced.

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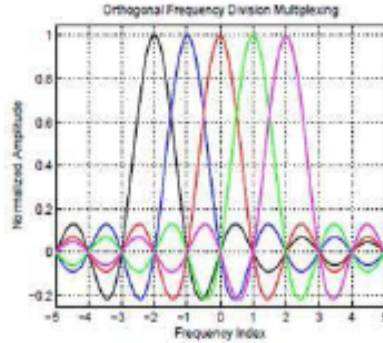
Figure 1.1: Orthogonality in frequency domain

As can be observed from the above representation Orthogonality in OFDM system ensures that all the subcarriers other than the intended one go through 0 at the sampling instant.

Orthogonality calls for both frequency and time synchronization. Frequency offset and jitter cause inter-carrier interference (ICI) in the system because the contribution from other subcarriers at such sampling instant is not 0. Let's take a sine wave of frequency m and multiply it by a sinusoid (sine or a cosine) of a frequency n, where both m and n are integers. The integral or the area under this product is given by:

$$f(t) = \sin(n\omega t) * \sin(m\omega t) \tag{1.2}$$
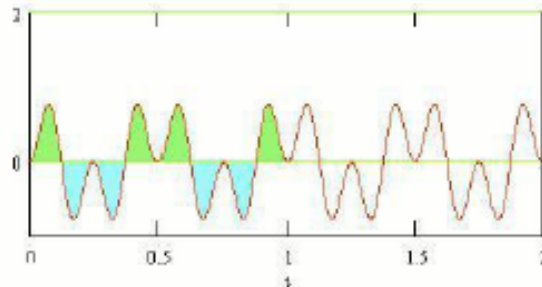
Figure 1.2: The area under a sine wave multiplied by its own harmonic is always zero

By the simple trignometric relationship, this is equal to a sum of two sinusoids of frequencies (m+n) and (m-n)

$$f(t) = \frac{1}{2}\cos(m - n) - \frac{1}{2}\cos(m + n) \tag{1.3}$$

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These two components are each a sinusoid, so the integral is equal to zero over one period.

$$f(t) = \int_0^{2\pi} \tfrac{1}{2}\cos(m-n) - \int_0^{2\pi} \tfrac{1}{2}\cos(m+n) \qquad (1.4)$$

We conclude that when we multiply a sinusoid of frequency n by a sinusoid of frequency m/n, the area under the product is zero. In general for all integers n and m, sin mx, cosmx, cosnx, sin nx are all orthogonal to each other. These frequencies are called harmonics.

Definition of carrier:

The maximum number of carriers used by OFDM is limited by the size of the IFFT. This is determined as follows:

$$N_{carriers} \leq \frac{IFFT\ size}{2} - 2 \quad \text{real valued time signal} \qquad (1.5)$$

$$N_{carriers} \leq IFFT\ size - 1\ \text{complex valued time signal} \qquad (1.6)$$

In order to generate a real-valued time signal, OFDM (frequency) carriers must be defined in complex conjugate pairs, which are symmetric about the Nyquist frequency (fmax). This puts the number of potential carriers equal to the IFFT size/2. The Nyquist frequency is the symmetry point, so it cannot be part of a complex conjugate pair. The DC component also has no complex conjugate. These two points cannot be used as carriers so they are subtracted from the total available.

If the carriers are not defined in conjugate pairs, then the IFFT will result in a time domain signal that has imaginary components. This must be a viable option as there are OFDM systems defined with carrier counts that exceed the limit for real-valued time signals given in (1). Describesa system with IFFT size 256 and carrier count 216. This design must result in a complex time waveform. Further processing would require some sort of quadrature technique (use of parallel sine and cosine processing paths). In this report, only real-value time signals will be treated, but in order to obtain maximum bandwidth efficiency from OFDM, the complex time signal may be preferred (possibly an analogous situation to QPSK vs. BPSK). (1), for the complex time waveform, has all IFFT bins available as carriers except the DC bin.

Both IFFT size and assignment (selection) of carriers can be dynamic. The transmitter and receiver just have to use the same parameters. This is one of the advantages of OFDM. Its bandwidth usage (and bit rate) can be varied according to varying user requirements.

A simple control message from a base station can change a mobile unit's IFFT size and carrier selection.

1.3 APPLICATION OF OFDM

OFDM is the modulation/multiplexing technology for:

1. Broadband access via plain old telephone system (POTS) copper wiring. e.g. ADSL, SDSL, VDSL (OFDM is also called discrete multitone (DMT))

2. Certain Wi–Fi systems: IEEE 802.11a/g

3. Digital Audio Broadcasting (DAB): EUREKA 147, Digital Radio Mondiale, HD

4. Radio, T-DMB and ISDB-TSB.

5. Digital Video Broadcasting (DVB): Terrestrial digital TV systems like DVB-T,

6. DVB-H, T-DMB and ISDB-T.

7. IEEE 802.16 or WiMAX Wireless MANs.

8. IEEE 802.20 or Mobile Broadband Wireless Access (MBWA) systems.

9. Flash-OFDM cellular systems.

10. Certain Ultra wideband (UWB) systems.

11. Power line communication (PLC).

12. Multimedia over Coax Alliance (MoCA) home networking.

CHAPTER 2

OFDM COMMUNICATION SYSTEM

OFDM communications systems are able to more effectively utilize the frequency spectrum through overlapping sub-carriers. These sub-carriers are able to partially overlap without interfering with adjacent sub-carriers because the maximum power of each sub-carrier corresponds directly with the minimum power of each adjacent channel.

In order to use multiple sub-carriers to transmit an individual channel, an OFDM Communications system must perform several steps, described in the figure below.

Figure 2.1: Block diagram OFDM communication system

2.1 OFDM TRANSMITTER

The OFDM-based communication systems transmit multiple data symbols simultaneously using orthogonal subcarriers. Then various sets of parallel bits are generated and sent on different subcarriers for modulation. The modulator can be easily implemented using an Inverse Fast Fourier Transform (IFFT) block. After modulation they are transmitted simultaneously as transmitter data stream. A guard interval is added to mitigate the effect of Inter Symbol Interference. Each of the above mentioned steps are discussed in detail below.

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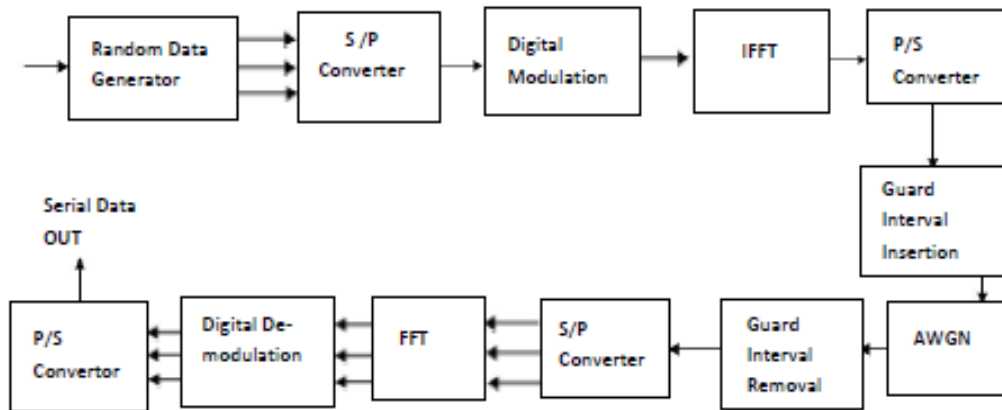

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2.2 SERIAL TO PARALLEL CONVERTOR
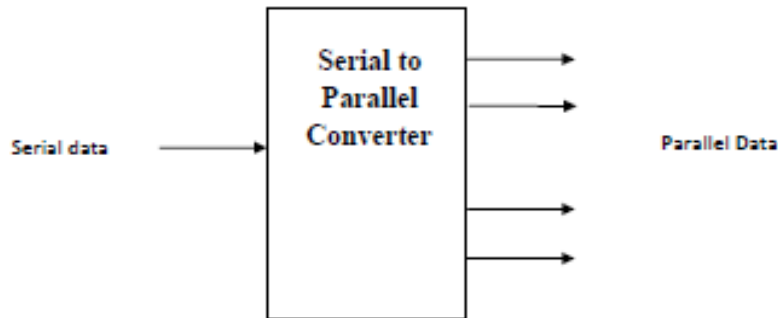
Figure 2.2: Serial to Parallel Converter

The various sets of parallel bits generated are sent on different subcarriers used for modulation. We shall understand the concept of serial to parallel conversion taking an example of an OFDM signal using four sub carriers. Let the input bit stream be:

$$1, 1, -1, -1, 1, 1, 1, -1, 1, -1, -1, -1, -1, 1, -1, -1, -1, 1, 1,\dots$$

– Serial to parallel conversion of data bits.

c_1	c_2	c_3	c_4
1	1	-1	-1
1	1	1	-1
1	-1	-1	-1
-1	1	-1	-1
-1	1	1	-1
-1	-1	1	1

The serial data is converted to parallel and sent on four sub-carriers. Each column represents the bits that will be carried by one sub-carrier. Let's start with the first carrier, c_1. From the Nyquist sampling Theorem, we know that smallest frequency that can convey information has to be twice the information rate. In this case, the information rate per carrier will be 1/4 or 1 symbol per second total for all 4 carriers. So the smallest frequency that can carry a bit rate of 1/4 is 1/2 Hz. But we picked 1 Hz for convenience.

If we would have picked 1/2 Hz as starting frequency, then the harmonics would have been 1, 3/2 and 2 Hz.

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We could have chosen 7/8 Hz to start with and in which the harmonics would be 7/4, 7/2, 21/2 Hz. We pick BPSK as our modulation scheme for this example. (For QPSK, just imagine the same Thing going on in the Q channel, and then double the bit rate while keeping the symbol rate the same. Carrier 1 - We need to transmit 1, 1, 1 -1, -1, -1 which I show below superimposed on the BPSK carrier of frequency 1 Hz. First three bits are 1 and last three -1. If I had shown the Q channel of this carrier (which would be a cosine) then this would be a QPSK modulation.
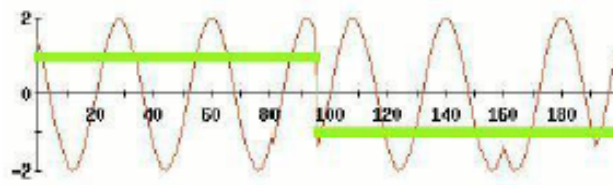
Figure 2.3: Sub-carrier 1 and the bits it is modulating

2.3 FFT AND IFFT

The key components of an OFDM system are the inverse FFT at the transmitter and FFT at the receiver. These operations performing linear mappings between N complex data symbols and N complex OFDM symbols result in robustness against fading multipath channel. The reason is to transform the high data rate stream into N low data rate streams, each experiencing a flat fading during the transmission. Inverse Fast Fourier Transform (IFFT) is used to realize Orthogonality. The signal or the data already in time domain, But here it is pretended that the input bits are not time domain representations but are frequency amplitudes. In this way, these bits are taken and by using the IFFT, an output signal is created which is actually a time-domain OFDM signal. The IFFT is a mathematical concept and does not really care what goes in and what goes out. As long as what goes in is amplitudes of some sinusoids, the IFFT will crunch these numbers to produce a correct time domain result. Both FFT and IFFT will produce identical results on the same input. We make sure that only spectrums go inside the IFFT. IFFT quickly computes the time-domain signal instead of having to do it one carrier at time and then adding. Calling this functionality IFFT may be more satisfying because we are producing a time domain signal, but it is also very confusing. Because FFT and IFFT are linear processes and completely reversible, it should be called a FFT instead of an IFFT.

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The results are the same whether you do FFT or IFFT. IFFT and FFT algorithms are the faster implementation for the IDFT and DFT. Orthogonality is realized by IFFT block.

Mathematical Definition

$$\text{IDFT } x[n] = \frac{1}{N}\sum_0^{N-1} X[k]e^{\frac{2\pi j kn}{N}} \qquad (2.1)$$

$$\text{DFT } X[k] = \sum_0^{N-1} x[n]e^{-j\frac{2\pi kn}{N}} \qquad (2.2)$$
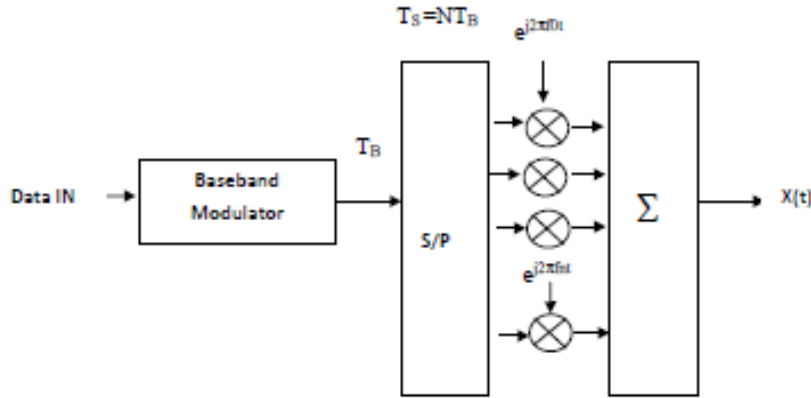
Figure 2.4: IFFT Implementation

2.3.1 BIT ERROR RATE OF OFDM

In digital transmission, the number of bit errors is the number of received bits of a data stream over a communication channel that has been altered due to noise, interference, distortion or bit synchronization errors. The bit error rate or bit error ratio (BER) is the number of bit errors divided by the total number of transferred bits during a studied time interval. BER is a unit less performance measure, often expressed as a percentage. The bit error probability p_e is the expectation value of the BER. The BER can be considered as an approximate estimate of the bit error probability. This estimate is accurate for a long time interval and a high number of bit errors.

The bit error rate (BER) of BPSK in AWGN can be calculated as:

$$P_b = Q\ (\sqrt{E_b/N_0}) \qquad (2.3)$$

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Since there is only one bit per symbol, this is also the symbol error rate. For determining error-rates mathematically, some definitions will be needed:

Where,

P_b =probability of error

Eb = energy per bit

No / 2 = noise power spectral density

Q(x) will give the probability that a single sample taken from a random process with zero-mean and unit-variance Gaussian probability density function will be greater or equal to x

$$Q(x) = \frac{1}{\sqrt{2\pi}} \int_x^\infty e^{-\frac{t^2}{2}} dt = \frac{1}{2} erfc\left(\frac{x}{\sqrt{2}}\right) \quad x \geq 0 \qquad (2.4)$$

2.4 MODULATION

In electronics and telecommunications, modulation is the process of varying one or more properties of a high-frequency periodic waveform, called the carrier signal, with a modulating signal which typically contains information to be transmitted.

2.4.1 Need For Modulation

The primary purpose of modulation in a communication system is to generate a modulated signal suited to the characteristics of the transmitted channel. Several practical benefits and applications of modulation are mentioned below:

a.Efficient Transmission

b.To overcome hardware limitations

c.Reduce noise and interference

d.Frequency assignment

e.Multiplexing

2.5 INTER SYMBOL INTERFERNCE

Intersymbol interference (ISI) is a form of distortion of a signal in which one symbol interferes with subsequent symbols. This is an unwanted phenomenon as the previous symbols have similar effect as noise, thus making the communication less reliable. ISI is usually caused by multipath propagation or the inherent non-linear. Frequency response of a channel causing successive symbols to "blur" together

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The presence of ISI in the system introduces errors in the decision device at the receiver output.

2.5.1 Causes of Intersymbol Interference

Multipath Propagation

One of the causes of intersymbol interference is what is known as multipath propagation in which a wireless signal from a transmitter reaches the receiver via many different paths. The causes of this include reflection (for instance, the signal may bounce off buildings), refraction (such as through the foliage of a tree) and atmospheric effects such as atmospheric ducting and ionospheric reflection.

Since all of these paths are of different lengths, this results in the different versions of the signal arriving at the receiver at different times. These delays mean that part or all of a given symbol will be spread into the subsequent symbols, thereby interfering with the correct detection of those symbols. Additionally, the various paths often distort the amplitude and/or phase of the signal thereby causing further interference with the received signal.

Band limited Channels

Another cause of intersymbol interference is the transmission of a signal through a bandlimited channel, i.e,one where the frequency response is zero above a certain received signal. Frequency (the cutoff frequency). Passing a signal through such a channel results in the removal of frequency components above this cutoff frequency; in addition, the amplitude of the frequency components below the cutoff frequency may also be attenuated by the channel.

2.5.2 GUARD INTERVAL

Inter symbol interference is removed by adding guard interval in the signal this simply make the symbol period longer, so that the demodulator does not have to be so precise in picking the period beginning and end, and decoding is always done inside a single period. This would fix the ISI problem, but not the ICI problem.
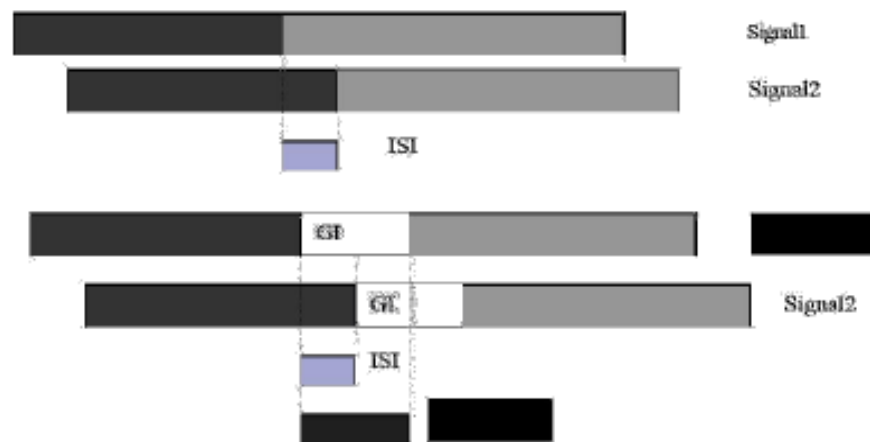
Figure 2.5: Intersymbol Interference

2.6 INTER CARRIER INTERFERENCE

In a typical wireless communication system, the signal to be transmitted is upconverted to a carrier frequency prior to transmission. The receiver is expected to tune to the same carrier frequency for down-converting the signal to baseband, prior to demodulation. However, due to device impairments the carrier frequency of the receiver need not be same as the carrier frequency of the transmitter. When this happens, the received baseband signal, instead of being centered at DC (0MHz), will be centered at a frequency f_δ, where $f_\delta = f_{Tx} - f_{Rx}$ his distortion due to interference with other subcarriers is known as inter carrier interference.

2.6.1 Causes of Inter Carrier Interference

Doppler Effect

The relative motion between receiver and transmitter, or mobile medium among them, would result in the Doppler effect, a frequency shift in narrow-band communications. For example, the Doppler effect would influence the quality of a cell phone conversation in a moving car. In general, the Doppler frequency shift can be formulated in a function of the relative velocity, the angle between the velocity direction and the communication link, and the carrier frequency as shown in figure.
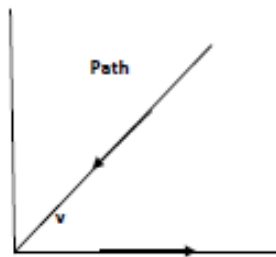

Figure 2.6: Doppler's effect

The value of Doppler shift could be given as $fd = v/\lambda * 2\pi\cos(\theta)$ (2.5)

Where is the angle between the velocity and the communication link, which is generally modeled as a uniform distribution between 0 and 2, v is the receiver velocity, and the is the carrier wavelength.

Synchronization Error

It can be assumed that most of the wireless receivers cannot make perfect frequency synchronization. In fact, practical oscillators for synchronization are usually unstable, Which introduce frequency offset. Although this small offset is negligible in traditional communication systems, it is a severe problem in the OFDM systems. In most situations, the oscillator frequency offset varies from 20 ppm (Parts Per Million) to 100 ppm. Provided an OFDM system operates at 5 GHz, the maximum offset would be 100 KHz to 500 KHz (20-100 ppm.). However, the subcarriers frequency spacing is only 312.5 KHz. Hence; the frequency offset could not be ignored. In most literatures, the frequency offset can be normalized by the reciprocal of symbol duration. For example, if a system has a bandwidth of 10 MHz, and the number of subcarriers is 128, then the subcarrier frequency spacing would be 10M/128 = 78 KHz. If the receiver frequency offset is 1 KHz, then the normalized frequency offset will be 1/78=1.3%. If the normalized frequency offset is larger than 1, only the decimal part needs to be considered, as shown in figure.

Multipath Fading

The influence of multipath fading on ICI is seldom discussed before. As a matter of fact, the multipath fading does not cause ICI, but it will make the ICI problem worse. Since ICI cannot be neglected in practice, the impact of multipath fading should be discussed. It is recognized that the cyclic prefix has been used to eliminate ISI entirely and therefore only ICI needs to be concerned. Because there are many time-delayed versions of received signals with different gains and different phase offsets, the ICI is more complicated to calculate.

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2.6.2 Cyclic Prefix

In order to avoid ICI, the guard period is formed by a cyclic extension of the symbol period. This is done by taking symbol period samples from the end of the period and appending them to the front of the period. The concept of being able to do this, and what it means, comes from the nature of the IFFT/FFT process. When the IFFT is taken for a symbol period (during OFDM modulation), the resulting time sample sequence is technically periodic. This is because the IFFT/FFT is an extension of the Fourier Transform which is an extension of the Fourier series for periodic waveforms. All of these transforms operate on signals with either real or manufactured periodicity. For the IFFT/FFT, the period is the number of samples used.

With the cyclic extension, the symbol period is longer, but it represents the exact same frequency spectrum. As long as the correct number of samples are taken for the decode, they may be taken anywhere within the extended symbol. Since a complete period is integrated, orthogonality is maintained. Therefore, both ISI and ICI are eliminated.

Here is an example to explain cyclic prefix. You are driving in rain, and the car in front splashes a bunch of water on you. What do you do? You move further back, you put a little distance between you and the front car, far enough so that the splash won't reach you. If we equate the reach of splash to delay spread of a splashed signal then we have a better picture of the phenomena and how to avoid it.
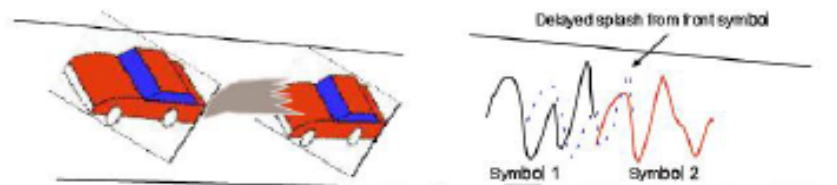
Figure 2.7: Delay spread due to car

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Increase distance from car in front to avoid splash. The reach of splash is same as the delay spread of a signal. Fig. 2.7 shows the symbol and its splash.
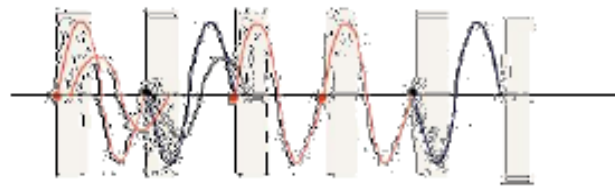
Figure 2.8 :The PSK symbol and its delayed version.

To mitigate this noise at the front of the symbol, we will move our symbol further away from the region of delay spread as shown in Fig.2.9. A little bit of blank space has been added between symbols to catch the delay spread.
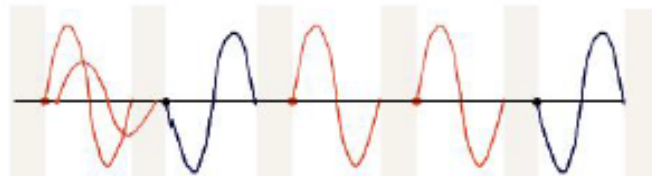
Figure 2.9: Symbol is moved back so that the arriving delayed signal doesn't face any interference

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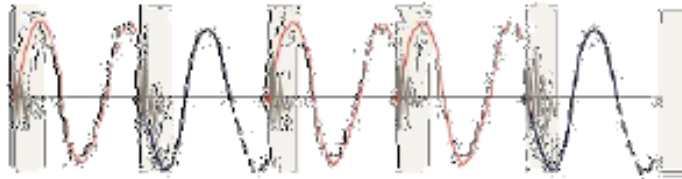
Figure 2.10: Phase corrupt by Splash

We extend the symbol into the empty space, so that the actual symbol exist in more than one cycle. But now the start of the symbol is still in the danger zone, and this start is the most important thing about our symbol since the slicer needs it in order to make a decision about the bit. We do not want the start of the symbol to fall in this region, so we just slide the symbol backwards, so that the start of the original symbol lands at the outside of this zone,and then fill this area with something.
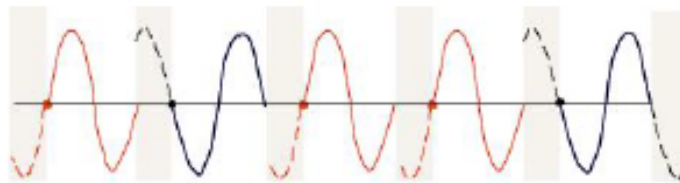
Figure 2.11 Formation of continuous Signal

This procedure is called adding a cyclic prefix. Since OFDM, has a lot of carriers, we do this to each and every carrier. But that's only in theory. In reality since the OFDM signal is a linear combination, we can add cyclic prefix just once to the composite OFDM signal. The prefix is anywhere from 10% to 25% of the symbol time
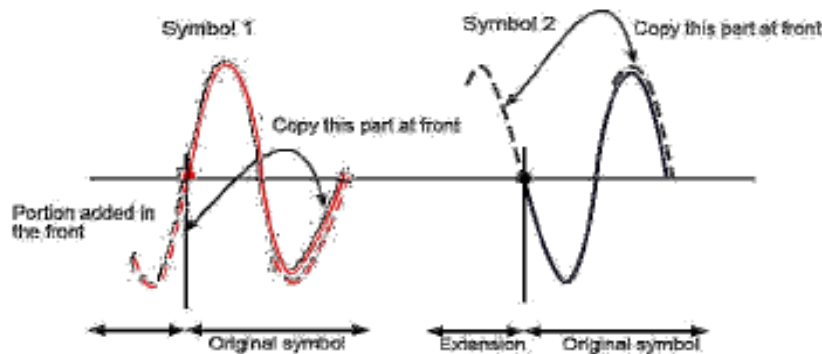
Figure 2.12: Cyclic Prefix

2.7 COMMUNICATION CHANNEL

Radio propagation in mobile communication is mainly determined by its multipath nature. Multiple reflections and an LOS component of the transmitted signal arrives at the receiver via different propagation paths and therefore with different amplitudes and delay times. As a result of this, the narrowband received power fluctuates dramatically when observed as a function of location and frequency. In OFDM, the channels variability in the frequency domain has the similar role as the time variance in narrowband system.(flat–fading). Usually channel can be assumed to be static during the transmission of at least one OFDM symbol.

2.7.1 AWGN (ADDITIVE WHITE GAUSSIAN NOISE) CHANNEL

Additive white Gaussian noise (AWGN) is a channel model in which the only impairment to communication is a linear addition of wideband or white noise with a constant spectral density (expressed as watts per hertz of bandwidth) and a Gaussian distribution of amplitude.

The model does not account for fading, frequency selectivity, interference, nonlinearity or dispersion. However, it

produces simple and tractable mathematical models which are useful for gaining insight into the underlying behavior of a system before these other phenomena are considered.

$$y = \frac{1}{\sigma\sqrt{2\pi}}\, e^{-\frac{x^2}{2\sigma^2}}$$
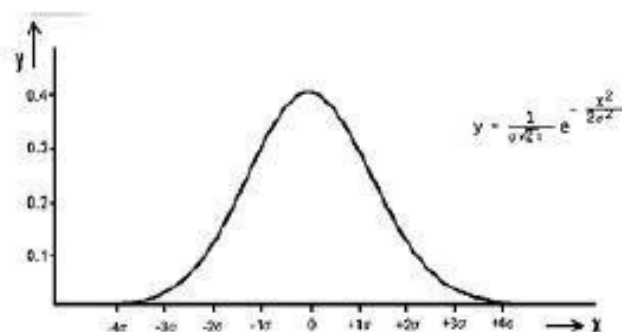
Figure 2.13: Gaussian distribution

2.8 OFDM RECIEVER

The design of an OFDM receiver is open; i.e., there are only transmission standards. With an open receiver design, most of the research and innovations are done in the receiver. For example, the frequency sensitivity drawback is mainly a transmission channel prediction issue, something that is done at the receiver; therefore, we shall only present a transmission process. Fig.2.14 is the block diagram of an OFDM receiver

.
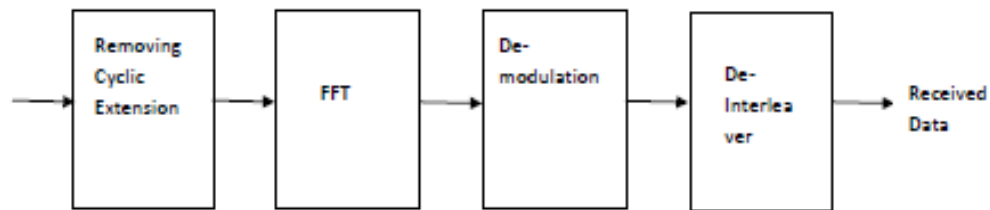
Figure 2.14: OFDM Receiver

First of all, the length of symbol period added earlier as cyclic prefix is removed. The serial bits are then converted to parallel bit stream which form the input of the FFT block. The Fast Fourier Transform (FFT) converts the time domain samples back into a frequency domain representation. The output of the transform contains the symbol values mapped onto each of the carriers. The demodulator plucks out the (complex-valued) amplitudes of each of the carriers of interest and passes those on to any further decoding logic. For the case of BPSK and QPSK demodulation, phase synchronization has to be assured if we wish to design a coherent receiver. For this purpose, the demodulator input is convolved with a matched filter over a time period to yield the demodulated output.

2.9 ADVANTAGES OF OFDM

OFDM possesses some inherent advantages for Wireless Communications. This section glances on few of the most important reasons on why OFDM is becoming more popular in the Wireless Industry today.

Multi-path Delay Spread Tolerance

As discussed earlier, the increase in the symbol time of the OFDM symbol by N times (N being the number of sub-carriers), leads to a corresponding increase in the effectiveness of OFDM against the ISI caused due to multi-path delay spread. Further, using the cyclic extension process and proper design, one can completely eliminate ISI from the system.

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Effectiveness against Channel Distortion

In addition to delay variations in the channel, the lack of amplitude flatness in the frequency response

of the channel also causes ISI in digital communication systems. A typical example would be the twister-pair used in telephone lines. These transmission lines are used to handle voice calls and have a poor frequency response when it comes to high frequency transmission. In systems that use single-carrier transmission, an equalizer might be required to mitigate the effect of channel distortion. The complexity of the equalizer depends upon the severity of the channel distortion and there are usually issues such as equalizer non-linearities and error propagation etc that cause additional trouble. In OFDM systems on the other hand, since the bandwidth of each sub-carrier is very small, the amplitude response over this narrow bandwidth will be basically flat (of course, one can safely assume that the phase response will be linear over this narrow bandwidth).

Even in the case of extreme amplitude distortion, an equalizer of very simple structure will be enough to correct the distortion in each sub-carrier.

Throughput Maximization (Transmission at Capacity)

The use of sub-carrier modulation improves the flexibility of OFDM to channel fading and distortion makes it possible for the system to transmit at maximum possible capacity using a technique called channel loading. Suppose the transmission channel has a fading notch in a certain frequency range corresponding to a certain sub-carrier. If we can detect the presence of this notch by using channel estimation schemes and assuming that the notch doesn't vary fast enough compared to the symbol duration of the OFDM symbol, it can be possible to change (scale down/up) the modulation and coding schemes for this particular sub-carrier (i.e. increase their robustness against noise), so that capacity as a whole is maximized over all the sub-carriers. However, this requires the data from channel-estimation algorithms. In the case of single-carrier systems, nothing can be done against such fading notches. They must somehow survive the distortion using error correction coding or equalizers.

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Robustness against Impulse Noise

Impulse noise is usually a burst of interference caused usually caused in channels such as the return path HFC (Hybrid-Fiber-Coaxial), twisted-pair and wireless channels affected by atmospheric phenomena such as lightning etc. It is common for the length of the interference waveform to exceed the symbol duration of a typical digital communication system. For example, in a 10 MBPS system, the symbol duration is 0.1ms, and an impulse noise waveform, lasting for a couple of micro-seconds can cause a burst of errors that cannot be corrected using normal error-correction coding. Usually complicated Reed-Solomon codes in conjunction with huge interleaves are used to correct this problem. OFDM systems are inherently robust against impulse noise, since the symbol duration of an OFDM signal is much larger than that of the corresponding single-carrier system and thus, it is less likely that impulse noise might cause (even single) symbol errors. Thus, complicated error-control coding and interleaving schemes for handling burst-type errors are not really required for OFDM Systems simplifying the transceiver design.

2.10 DISADVANTAGES OF OFDM

Peak-to-Average Power Ratio (PAPR)

One of the significant drawbacks of OFDM system is the possibility to experience large peaks since the signal shows a random variable characteristic since it is sum of N independent complex random variables. These different carriers may all line up in phase at some instant and consequently produce a high peak, which is quantified by peak-to-average-power ratio (PAPR). This distorts the transmitted signal if the transmitter contains nonlinear components such as power amplifiers (PAs). Since PA is forced to operate in the nonlinear region. The nonlinear effects may cause in-band or out-of-band distortion to signals such as spectral spreading, intermodulation, or change the signal constellation. Out-of-band distortion is detrimental even if the in-band distortion is tolerable. To have distortion less transmission, the PAs require a back off, which is approximately equal to the PAPR. This decreases the efficiency for amplifiers and increases the cost.

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High PAPR also requires high range and precision for the analog-to-digital converter (ADC) and digital-to-analog converter
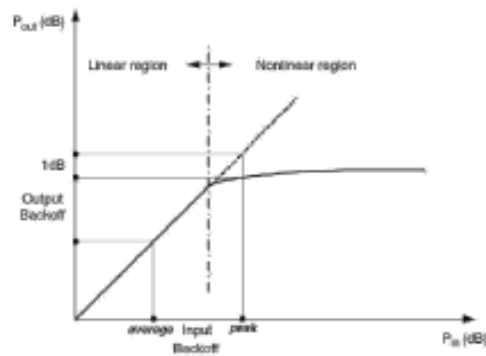(DAC), as a result, reducing the PAPR of practical interest.

Figure 2.15: Characteristic of Power Amplifier

We can see the nonlinear behavior of the PA. It is desired to operate the PA in the linear region. To avoid the high peaks, average input power may be decreased. Operating region of the PA is called input back-off and the resultant signal is guaranteed to be in output back-off range. High input back off reduces the power efficiency and would mandate the cost of the PA higher, since input back off is usually greater than or equal to the PAPR of the signal. Ideally the average and peak values should be as close as can be in order to maximize the efficiency of the PA. PAPR mitigation relaxes the PA back off requirements as well as the high resolution requirements on ADC and DAC. PAPR mitigation may fall into three categories: signal distortion, coding, and scrambling. Signal distortion basically distorts the signal around peaks with either clipping or peak windowing or peak cancelation. Coding utilizes forward error correction coding schemes to achieve signals with low PAPR. Scrambling also similar to coding utilizes scrambling sequences to achieve low PAPR.

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CHAPTER 3

INTRODUCTION TO SC-FDMA

3.1 Introduction

SC-FDMA is a new multiple access technique. It utilizes single carrier modulation, DFT-spread orthogonal frequency multiplexing and frequency domain equalization. It has similar structure and performance to OFDM.SC-FDMA is currently adopted as the uplink multiple access scheme in 3GPP-LTE.This technique can be generated in the time domain or frequency domain. The performance of SC-FDMA,in relation to OFDM has been the subject of various studies. Although the performance gap is not much,SC-FDMA's additional advantage of low PAPR makes it a favorite especially for uplink wireless transmission in future mobile communication systems where transmitter power efficiency is of paramount importance .It is a slight modification in OFDM system, all the blocks are same as OFDM with introduction of few new blocks , We employ an M-point FFT block and subcarrier mapping before the N-point IFFT block where M<N,this reduces PAPR which is the limitation we are dealing with.

As wireless multimedia applications become more widespread, demand for higher data rate is leading to utilization of a wider transmission bandwidth. With a wider transmission bandwidth, frequency selectivity of the channel becomes more severe and thus the problem of inter-symbol interference (ISI) becomes more serious. In a conventional single carrier communication system, time domain equalization in the form of tap delay line filtering is performed to eliminate ISI. However, in case of a wide band channel, the length of the time domain filter to perform equalization becomes prohibitively large since it linearly increases with the channel response length. One way to mitigate the frequency-selective fading seen in a wide band channel is to use a multicarrier technique which subdivides the entire channel into smaller sub-bands, or subcarriers. Orthogonal frequency division multiplexing (OFDM) is a multicarrier modulation technique which uses orthogonal subcarriers to convey information. In the frequency domain. since the bandwidth of a subcarrier is designed to be smaller than the coherence bandwidth, each sub-channel is seen as a flat fading channel which simplifies the channel equalization process. In the time domain, by splitting a high-rate data stream into a number of lower-rate data stream that are transmitted in parallel, OFDM resolves the problem of ISI in wide band communications.

But OFDM has its disadvantages:

High peak-to-average power ratio (PAPR) and high sensitivity to frequency offset. Single Carrier Frequency Division Multiple Access (SC-FDMA) is

modified version of OFDM. Like all other orthogonal frequency division techniques, it also employs a discrete set of orthogonal subcarriers distributed across the system bandwidth. They all include discrete transforms to move signals between time domain and frequency domain. In cellular system LTE (long term evolution) OFDM is used for downlink transmission and SC-FDMA for uplink transmission. One of the main disadvantages of OFDM is high peak-to-average power ratio (PAPR) which raises the cost and lowers the power efficiency of a transmitter's power amplifier. With lower PAPR, the power amplifiers at mobile terminals employing SC-FDMA can be simpler and more power efficient than they would be with OFDM transmission. On the other hand, with its high signaling rate, the frequency domain equalizer of SC-FDMA link is far more complicated than an OFDM equalizer. With SC_FDMA transmission confined to the LTE uplink, complicated equalizers are required only at base stations and not at mobile terminals.

3.2 SUBCARRIER MAPPING

There are two methods to choose the subcarriers for transmission; distributed subcarrier mapping and localized subcarrier mapping.In the distributed subcarrier mapping mode, DFT outputs of the input data are allocated over the entire bandwidth with zeros occupying the unused subcarriers, whereas consecutive subcarriers are occupied by the DFT outputs of the input data in the localized subcarrier mapping mode. Localized subcarrier mapping mode of SC-FDMA is referred to as localized FDMA (LFDMA) and distributed subcarrier mapping mode of SC-FDMA as distributed FDMA (DFDMA). The case of $M = Q \cdot N$ for the distributed mode with equidistance between occupied subcarriers is called Interleaved FDMA (IFDMA) . IFDMA is a special case of SC-FMDA and it is very efficient in that the transmitter can modulate the signal strictly in the time domain without the use of DFT and IDFT.

Depending on the subcarrier mapping method, the SCFDMA modulated symbols in the time domain differ. For IFDMA, the modulated time symbols are simply a repetition of the original input symbols

with a scaling factor of 1/Q and some phase rotation. DFDMA and LFDMA have the same time symbol structure, they have exact copies of input time symbols with a scaling factor of 1/Q in the N-multiple sample positions and in-between values are sum of all the time input symbols in the input block with different complex weighting. Because of this, we can expect to see more fluctuation and higher peak in amplitude for DFDMA and LFDMA.

3.3 COMPARISON OF SC-FDMA WITH OFDM

The difference in SC-FDMA and OFDM transmitter is the presence of DFT block in SC-FDMA. For this reason SC-FDMA is sometimes referred to as DFT-spread or DFT-precoded OFDMA . Other similarities between the two include: Block-based data modulation and processing division of the transmission bandwidth into narrower sub-bands, frequency domain channel equalization process and the use of CP.However, there are distinct differences that make the two systems perform differently. In terms of data detection at the receiver, OFDMA performs it on a sub-carrier basis whereas SC-FDMA does it after additional IDFT operation. Because of this difference, OFDMA is more sensitive to a null in the channel spectrum and it requires channel coding or power/rate control to overcome this deficiency. Also, the duration of the modulated time symbols are expanded in the case of OFDMA with parallel transmission of the data block during the elongated time period whereas SC-FDMA modulated symbols are compressed into smaller chips witserial transmission of the data block.

3.4 SC-FDMA PEAK TO AVERAGE POWER RATIO

PAPR is the performance measure that indicates power efficiency of transmitter. In case of ideal linear power amplifier maximum power efficiency is attained, when power amplifier is operating at saturation point. Positive PAPR in decibels indicates the need of power back off for operating in the linear region of power amplifiers. High PAPR leads to the degradation of transmitter power efficiency performance.

SC-FDMA is a tradeoff between multi carrier and single carrier so the reduction of PAPR occurs.

In OFDM PAPR occurs mainly because of IFFT block which is compensated in SC-FDMA by

FFT block which has number of subcarriers less than IFFT, as the PAPR depends directly on number of sub carriers so as the number of sub carriers decreases, PAPR Also decreases .This is the main advantage of SC-FDMA over OFDM, With low PAPR, the power amplifiers at mobile terminals can be simpler and more power efficient than in OFDM transmission. Due to low PAPR it has drawn great attention for the uplink communications, where it benefits the mobile terminal in transmit power efficiency.

3.5 SC-FDMA BER(BIT ERROR RATE)

The BER is the ratio of number of error bits divided by the total number of bits transmitted in particular time interval.

BER= number of error bits/total number of transmitted bits

It is the main parameter for depicting system performance of any data link. The errors occur due to noise, interference, distortion etc.BER is a unit less performance measure. It can be improved by strong signal strength.In SC-FDMA the BER is highly improved as compared to OFDM .

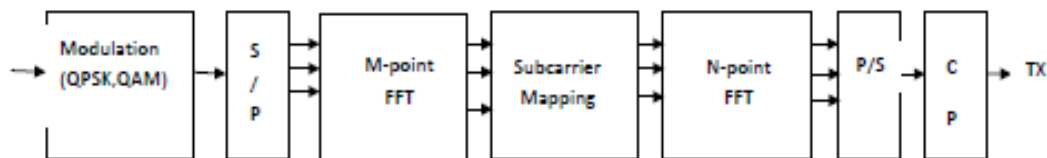## 3.6 SC-FDMA COMMUNICATION SYSTEM

Figure 3.1: SC-FDMA transmitter

Fig.3.1 shows a block diagram of an SC-FDMA system. SC-FDMA can be regarded as DFT-spread orthogonal frequency division multiple access (OFDMA), where time domain data symbols are transformed to frequency domain by DFT before going through OFDMA modulation. The orthogonality of the users stems from the fact that each user occupies different subcarriers in the frequency domain, similar to the case of OFDMA. Because the overall transmit signal is a single carrier signal, PAPR is inherently low compared to the case of OFDMA which produces a multicarrier signal .

The transmitter of an SC-FDMA system first groups the modulation symbols into blocks each containing N symbols. Next it performs an N-point DFT to produce a frequency domain representation of the input symbols. It then maps each of the N-DFT outputs to one of the $M (> N)$ orthogonal subcarriers that can be transmitted. If $N = M/Q$ and all terminals transmit N symbols per block, the system can handle Q simultaneous transmissions without co-channel interference. Q is the bandwidth expansion factor of the symbol sequence. As in OFDMA, an M-point IDFT transforms the subcarrier amplitudes to a complex time domain signal. The transmitter performs two other signal processing operations prior to transmission. It inserts a set of symbols referred to as a cyclic prefix (CP) in order to provide a guard time to prevent inter-block interference (IBI) due to multipath propagation. CP is a copy of the last part of the block, which is added at the start of each block for a couple of reasons. First, CP acts as a guard time between successive blocks. If the length of the CP is longer than the maximum delay spread of the channel, or roughly, the length of the channel impulse response, then, there is no IBI. Second, since CP is a copy of the last part of the block, it converts a discrete time linear convolution into a discrete time circular convolution. Thus transmitted data propagating through the channel can be modelled as a circular convolution between the channel impulse response and the transmitted data block, which in the frequency domain is a point-wise multiplication of the DFT frequency samples. Then, to remove the channel distortion, the DFT of the received signal can simply be divided by the DFT of the channel impulse response point-wise or a more sophisticated frequency domain equalization technique can be implemented.The receiver transforms the received signal into the frequency domain via DFT, de-maps the subcarriers, and then performs frequency domain equalization.

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CHAPTER 4
PAPR AND BER PERFORMANCE
ANALYSIS OF SC-FDMA AND OFDM

4.1 BIT ERROR RATE (BER)

In digital transmission, the number of bit errors is the number of received bits of a data stream over a communication channel that has been altered due to noise, interference, distortion or bit synchronization errors. The bit error rate or bit error ratio (BER) is the number of bit errors divided by the total number of transferred bits during a studied time interval. BER is a unit less performance measure, often expressed as a percentage. The bit error probability p_e is the expectation value of the BER. The BER can be considered as an approximate estimate of the bit error probability.

4.2 PEAK TO AVERAGE POWER RATIO (PAPR)

PAPR is the performance measure that indicates power efficiency of transmitter. In case of ideal linear power amplifier maximum power efficiency is attained, when power amplifier is operating at saturation point. Positive PAPR in decibels indicates the need of power back off for operating in the linear region of power amplifiers. High PAPR leads to the degradation of transmitter power efficiency performance.
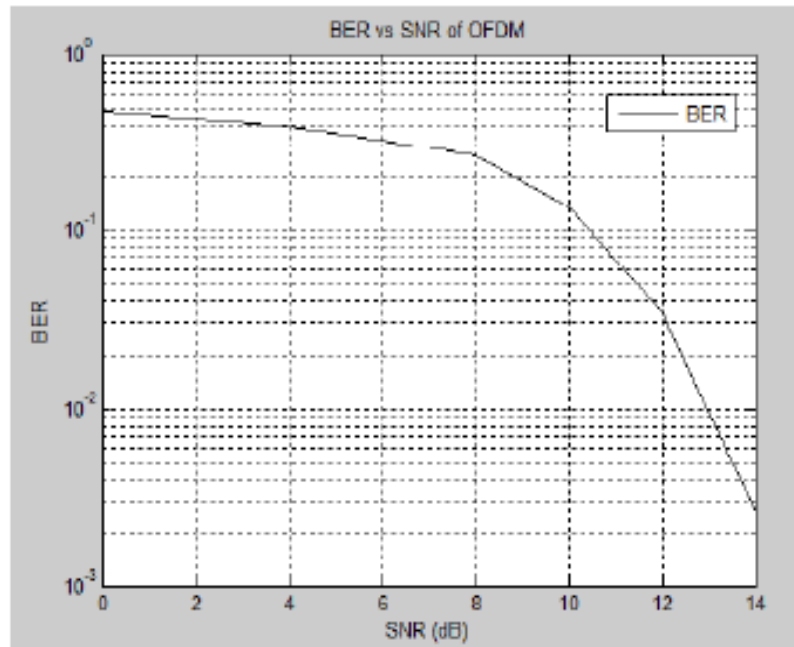
4.3 SIMULATION RESULTS OF OFDM AND SC-FDMA(BER)

Figure 4.1: plot of BER vs SNR (16-QAM) in OFDM

For achieving BER of 10^-2 SNR is coming out to be around 13dB. That is for one bit error in 100 bits the signal to noise ratio is 13dB.
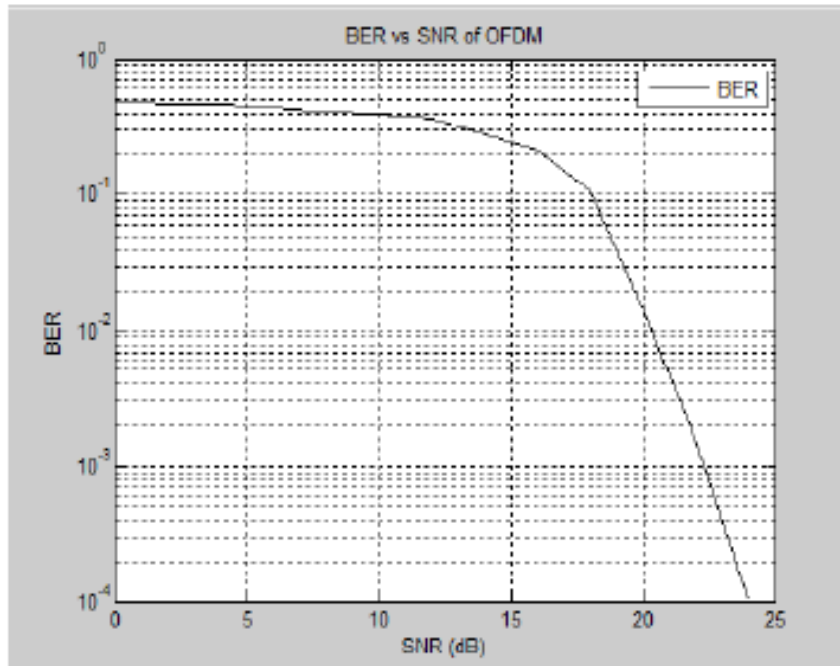
Figure 4.2: plot of BER vs SNR (PSK) in OFDM

For achieving BER of 10^-2 SNR is coming out to be around 20 dB.That is for one bit error in 100 bits the signal to noise ratio is 20 dB.This SNR is more as compared to the SNR of 16 QAM. Thus one can achieve same BER at lower power in QAM modulation technique.
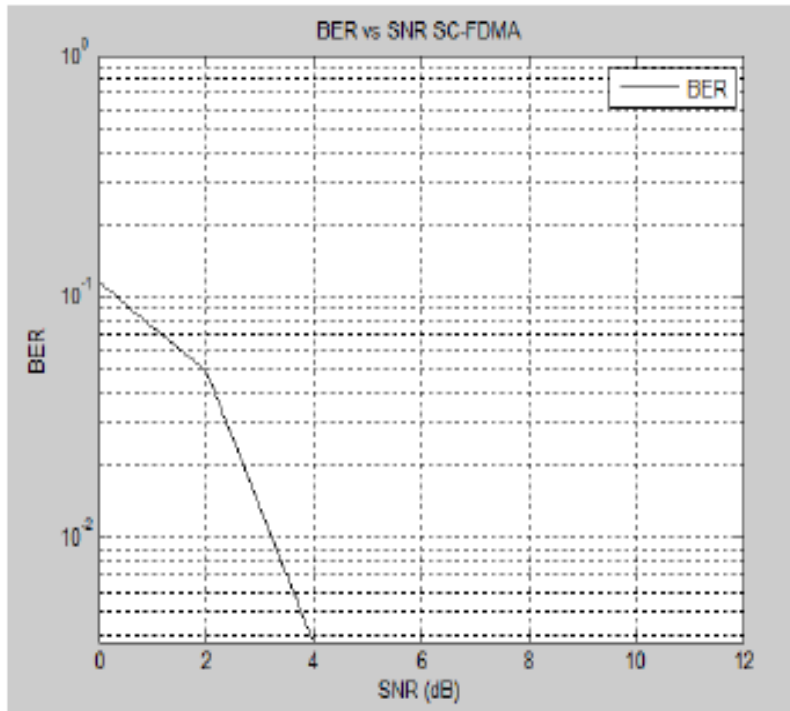
Figure 4.3: plot of BER vs SNR of SC-FDMA (16 QAM)

BER of SC-FDMA is much better than OFDM as it lies in the range of 0 to 4 dB while in OFDM the BER range lies between 0 to 25 dB. For one bit error in 100 bits the corresponding SNR is in between 3 to 4 dB.

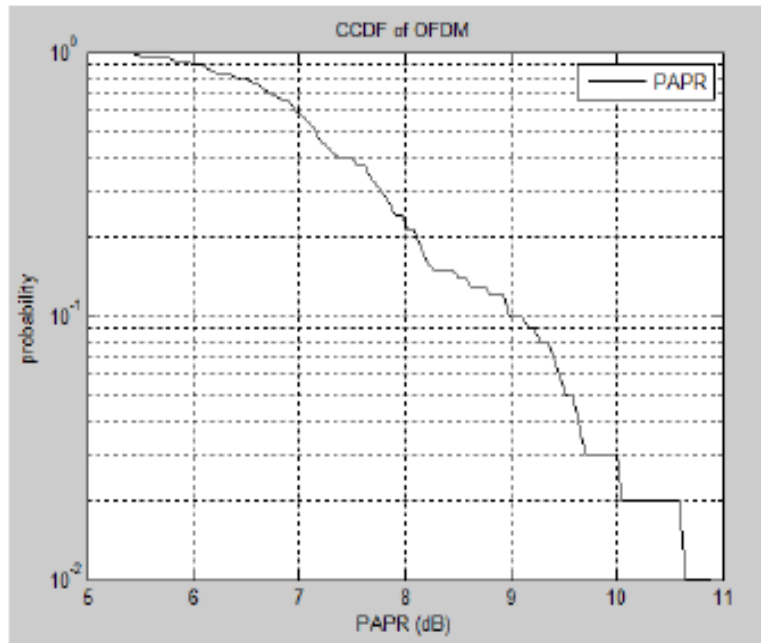## 4.4 SIMULATION RESULTS OF OFDM AND SC-FDMA(PAPR)

Figure4.4: plot of probability vs PAPR (16-QAM) IN OFDM

CCDF of OFDM lies in the range of 0 to 11 dB. In this Fig.4.4, there is 10 % chance of the signals to lie above 8dB from the average PAPR.

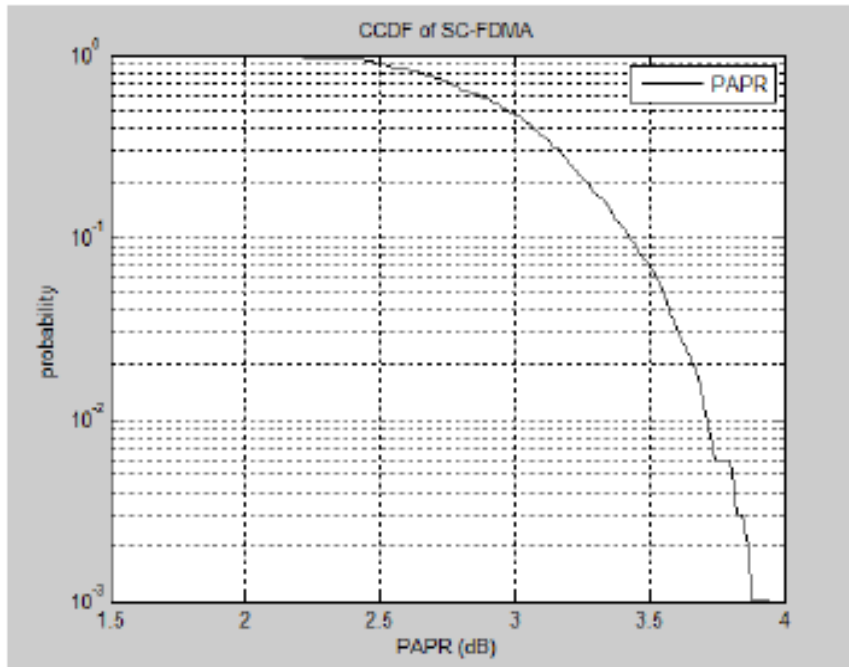Figure 4.5: plot of probability vs PAPR of SC-FDMA(16 QAM)

In CCDF graph,there is huge PAPR reduction as the range lies between 0 to 4 dB. There is 10 % chance of the signals to lie above ~3.5 dB from the average PAPR.

CHAPTER 5

CONCLUSION AND FUTURE SCOPE

OF SC-FDMA

5.1 CONCLUSION

Orthogonal frequency division multiplexing is an important technology because so many developing communications standards require the high throughput and multi-path advantages that are possible. OFDM has developed into a popular scheme for wideband digital communication, wireless as well as over copper wires. The primary advantage of OFDM over single-carrier schemes is its ability to cope with severe channel conditions. 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. Implementation of OFDM in MATLAB was successfully completed and various results were obtained. Variation in different input parameters like modulation technique is concluded. QAM has better results compared to PSK.SC-FDMA has an advantage over OFDM which is low PAPR, which was a big limitation of OFDM system the PAPR result of SC-FDMA came out to be comparatively very low than that of OFDM. BER of SC-FDMA was also very much improved it is due to the tradeoff between multi carrier and single carrier .

5.2 FUTURE SCOPE

The idea of SC-FDMA is to add an M-point fast Fourier transform block before the N-point inverse fast Fourier transform of the OFDM system. Usually, M is chosen to be much smaller N, so that the FFT only partially cancels the final IFFT, resulting in a single carrier type of signal with, obviously, a lower PAPR. There are basically two ways to map the M symbols that are output by the FFT to the input of the IFFT. The first solution, which is called localized SC-FDMA, is to use M consecutive subcarriers of the IFFT and zero-pad the other ones. The second option, called *d*istributed SC-FDMA, distributes the subcarriers over the entire bandwidth and again uses zeros for the unused bins. Interleaved SC-FDMA is a special case of the distributed version where the subcarriers are evenly distributed over the whole bandwidth. In that case, the separation between each subcarrier is typically equal to the number users. There are many studies that compare the pros and cons of each mapping method, but we can generally conclude that interleaved SC-FDMA leads to lower PAPR and also naturally benefits from more frequency diversity than localized SC-FDMA. However, by using an intelligent resource allocation that assigns the subcarriers with the best propagation conditions for each terminal, it is possible to achieve better performance using localized SC-FDMA.The fact that SC-FMDA has a lower PAPR with performance very close to that of OFDMA explains why this scheme has been selected by the 3GPP as the uplink multiple access scheme in LTE. By more efficiently using the power amplifier, LTE terminals are able to increase coverage and reduce their power consumption, which is extremely important in battery powered devices.

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