ANALYSIS AND STUDY OF MULTI-SYMBOL ENCAPSULATED ORTHOGONAL FREQUENCY DIVISION MULTIPLEXING

A THESIS SUBMITTED IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR THE DEGREE OF

Bachelor of Technology
In
Electronics and Communication Engineering

By

JIGISHA MOHANTY

Department of Electronics & Communication Engineering
National Institute of Technology
Rourkela
2010

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Under the guidance of
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CERTIFICATE OF AUTHENTICITY

This is to certify that the project report titled "Analysis and study of Multi-Symbol Encapsulated OFDM" submitted by Jigisha Mohanty, Roll No. 10609028, in fulfillment of the requirements for the final year B. Tech. project in Electronics and Communication Engineering Department of National Institute of Technology, Rourkela is an authentic work carried out by them under my supervision and guidance.

DATE:

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JIGISHA MOHANTY

10609028

ABSTRACT

A secured communication with the least distortion and the least interference is the utmost requirement of the new-age wireless communication system. Various methods have been implemented to achieve a near-secure communication. But taking into consideration the multipath fading, inter-symbol interference, and the various fading and distortion factors, this condition is rarely achieved. So, with the available channel conditions and provided bandwidth for the exchange of information, orthogonal frequency division multiplexing has been found out to be the best option available for transmitting the maximum data possible through the channel. Though OFDM is very efficient in dealing with multi-path and intersymbol interference, it is very sensitive to frequency offset and Doppler shift as well as having high peak-to-average-power (PAPR) ratio. This makes the purpose of effective data communication incomplete. A recent modification of OFDM- multisymbol encapsulated OFDM can be used to neutralize all these disadvantages of OFDM and improve the performance of a wireless transmission system. This paper analyses the basic idea of OFDM and draws a conclusive statement about the advantages and disadvantages of OFDM. This paper also aims at discussing the new technology: MSE-OFDM as an improvement over OFDM with its simulated results and practical advantages.

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CHAPTER-1

INTRODUCTION TO OFDM AS A NEW TRANSMISSION TECHNIQUE

1.1 MODERN DAY COMMUNICATION AND OFDM

In the past few years, the telecommunication market has seen an explosive growth in the number of mobile/ wireless users in the network. So, it is expected to entertain increasing demands of extending the services available on wired public telecommunication networks to mobile non-wired telecommunication users. Barring a few service providers, mobile users, till date receive only voice services facilities along with low bit-rate data service. The demands for wireless broadband multimedia communication systems cannot be satisfied with wired networks because mobile communication channels are more contaminated than wired networks. The basic characteristics of the wireless communication are the **multipath reception**: we not only have a direct line-of-sight reception but also reception through a large number of reflected radio waves that arrive at the receiver at different times. This difference in arrival time is caused due to difference in contours and terrains: trees, vehicles, buildings etc. These reflected waves interfere with the direct received wave and the other reflected wave to generate **Inter-Symbol Interference** (ISI). This reduces the performance of the system significantly. So, the basic aim kept in mind while designing a wireless network is to minimize such adverse effects.

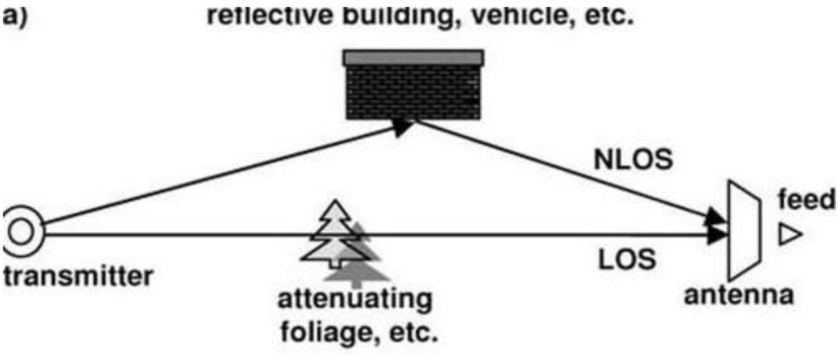


FIGURE-1: MULTIPATH

COMMUNICATION (LINE OF SIGHT AND NON-LINE OF SIGHT)

To operate and meet the requirements of broadband mobile communication systems, it is necessary to use high bit-rate transmission going up to several megabits per second. In a serial system, higher data rates can be achieved at the expense of degradation in performance, by using higher order modulation or at the expense of increased channel bandwidth, by decreasing the symbol interval. But, transmitting data at such a high rate makes the system prone to increased delay time of reflected waves (greater than 1 symbol time). However, delay spread imposes a waiting period that determines when the next pulse can be transmitted. This waiting period requires the signal to be reduced to a rate much less than the reciprocal of the delay spread to reduce the ISI. Decreasing the symbol interval to such a level makes the system more susceptible to delay spread impairments and hacking. We undergo practical and technical difficulties while trying to equalize these signals with compact, low-cost hardware. This leads to fading of data and thus, after successive attempts at equalizations the data is very corrupt and unsuitable for communication and usage. This is where it is proposed that OFDM can act as a better transmission scheme, reducing the influence of multipath fading thus rendering complex equalizers at the receiver quite unnecessary.

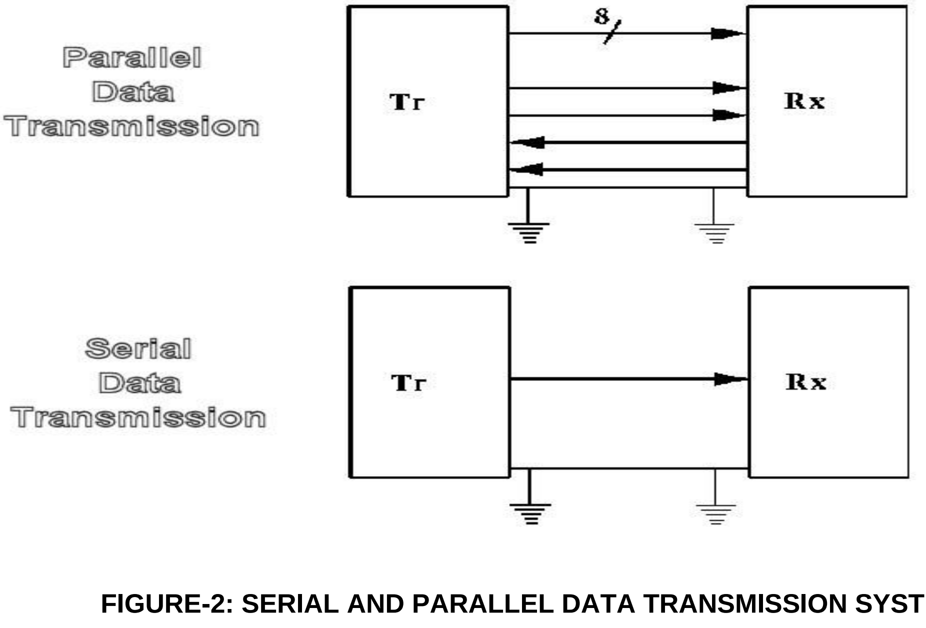


FIGURE-2: SERIAL AND PARALLEL DATA TRANSMISSION SYSTEMS

1.2 ORTHOGONAL FREQUENCY DIVISION MULTIPLEXING:

This is where we can implement a parallel data –transmission scheme. It is a system in which several sequential streams of data are transmitted simultaneously, so that at any instant many data elements can be transmitted without any discrepancies in the data. In such a system, the spectrum of an individual data element normally occupies only a small part of the available bandwidth. In a single-carrier system, a single fade or interference can cause he entire link to fail, but in a multi-carrier system, a small number of the subcarriers are affected, which can be corrected using various error-correction coding techniques OFDM is a special case of such multi-carrier transmission. In such a system, a single data stream is transmitted over a number of lower-rate subcarriers. OFDM has developed into a popular scheme for wideband digital communication, whether wireless or over copper wires, used in applications such as digital television and audio broadcasting, wireless networking and broadband internet access.

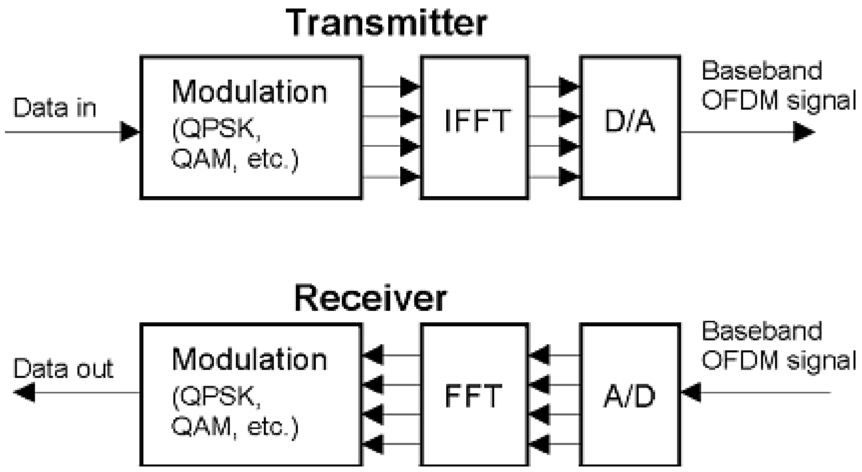


FIGURE-3: GENERAL BLOCK DIAGRAM OF OFDM SYSTEM

1.3. PRINCIPLE OF OPERATION OF OFDM:

In a classical parallel-data transmission system, the total signal frequency band is divided into N overlapping frequency sub-channels. Each sub-channel is modulated with a separate symbol, and then the N sub-channels are multiplexed by frequency. This was very efficient in sending the data over the channel effectively. But this leads to inefficient use of available spectrum. So, it was proposed later to use parallel data and FDM with overlapping sub-channels, each with a signaling rate b, is spaced apart in frequency by b units to avoid the necessity of using high-speed equalization. This also helps to combat impulsive noise and multipath distortion, all the while, effectively utilizing the available bandwidth. In OFDM, a large number of closely-spaced sub-carriers, which are orthogonal to each other, are used to carry data. Data to be sent is divided into several smaller parallel data streams or channels, one for each sub-carrier. Each sub-carrier is then modulated with a conventional modulation scheme (such as **Quadrature Amplitude Modulation** or P**hase-Shift Keying**) at a low symbol rate than that required for the whole data stream, but still maintaining total data rates similar to conventional single-carrier modulation schemes in the same bandwidth. A high-rate data stream is split into a number of lower rate streams to be transmitted simultaneously over a number of sub-carriers. Since the symbol duration increases for lower rate parallel sub-carriers, the amount of dispersion in time caused due to multipath delay is reduced. Intersymbol interference present in the system can be removed by introducing a guard time in every OFDM symbol. The added advantage of the guard time is that, in this interval, the OFDM symbol is cyclically extended to avoid Inter-carrier Interference, if any.

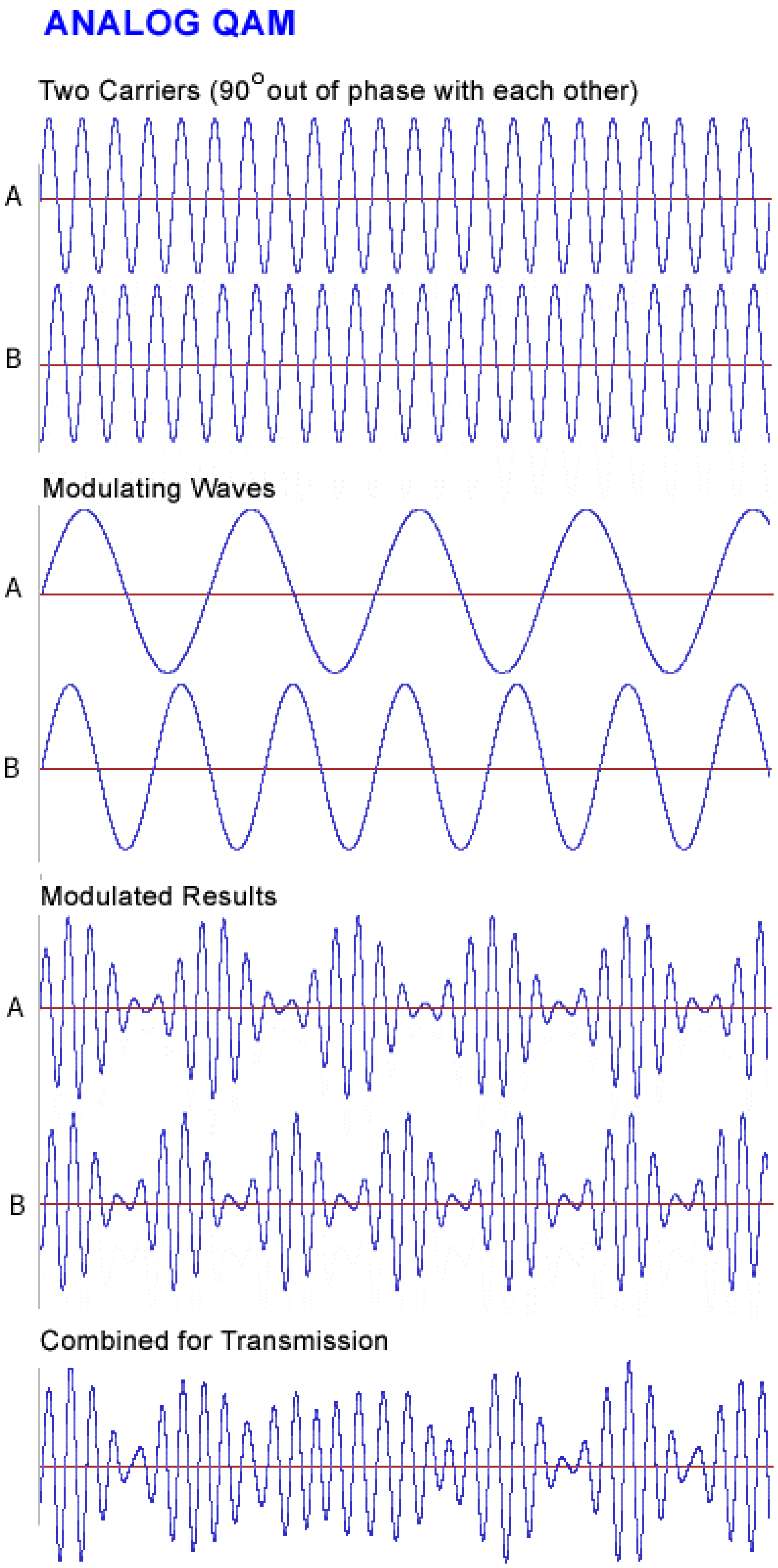


FIGURE-4: QAM TECHNIQUE OF MODULATION WHICH CAN BE IMPLEMENTED IN OFDM SIGNALS

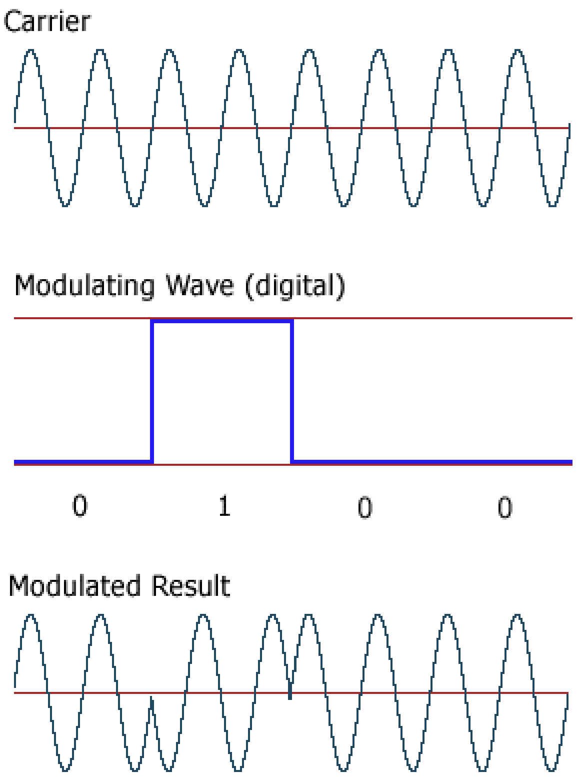


FIGURE-5: PHASE SHIFT KEYING FOR OFDM SYSTEM MODULATION

1.4 FACTORS UNDER CONSIDERATION WHILE IMPLEMENTING OFDM:

There are a few control factors which need to be considered while implementing OFDM transmission scheme-

1. Number of sub-carriers
2. Guard time
3. Symbol duration
4. Sub-carrier spacing
5. Modulation type per sub-carrier
6. Type of forward error correction coding

1.5: SALIENT FEATURES OF OFDM SIGNALS

1.5.1: ORTHOGONALITY:

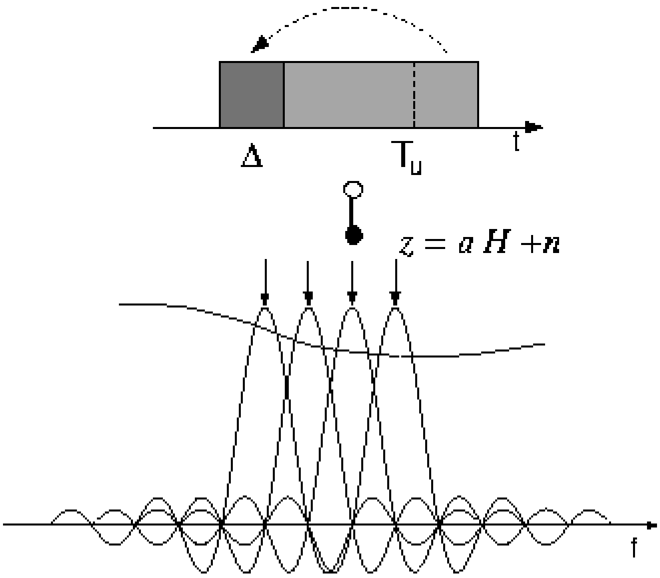


FIGURE-6: DEPICTING ORTHOGONALITY IN CHANNEL

In OFDM, the sub-carriers are chosen orthogonal to each other. This leads to reduction in cross-talk between sub-channels, so eliminating the requirement of inter-carrier bands. This greatly simplifies the design of the system as it doesn't require separate filter for all the sub-channels. The orthogonality condition requires that the sub-carrier spacing is $\Delta f = k\ (T_U)$ Hertz, where T_U seconds is the symbol duration (the receiver window size), and k is a positive integer, typically equal to 1. So, for N sub-carriers, the total pass-band bandwidth will be $B \approx N \cdot \Delta f$ (Hz). Orthogonality gives the advantage of high spectral efficiency, with a total symbol rate near the Nyquist rate for the equivalent baseband signal. OFDM requires very accurate frequency synchronization between the receiver and the transmitter. In the presence of frequency deviation, the sub-carriers will no longer be orthogonal causing **inter-carrier interference** (ICI). This leads to cross-talk between the sub-carriers. This kind of frequency offset is caused by mismatched transmitter and receiver oscillators. Frequency offset can also be caused by Doppler shift due to movement. The effect of Doppler Shift can be neutralized by synchronizing the receiver. But the effect of such action becomes worse when combined with multipath and fading effect. This effect increases as the speed increases, thus worsening the situation.

The principle of orthogonality can be given as below:

By using an IFFT for modulation, we choose the spacing of the subcarriers in such a way that at the frequency where we desire to evaluate the received signal all other signals are zero.

In order to preserve orthogonality the following must be true:

1. There must be perfect synchronization between transmitter and receiver they both must assume exactly the same modulation frequency for transmission.
2. The analog components present anywhere as parts of transmitter and receiver, must be of very high quality.
3. There should be no multipath channel.

if d_i are complex QAM signals

$N_{s=}$ number of subcarriers

T=symbol duration

f_c=carrier frequency

Then the OFDM signal starting at t=t_s is

$$s(t) = Re[\sum_{i=1}^{\frac{Ns}{2}-1} d_{i+\frac{Ns}{2}} e^{j2\pi\left(fc-\frac{i+0.5}{T}\right)(t-t_s)}\,]\ when\ t_s \le t \le t_s + T$$

$$s(t) = 0\ when\ t < t_s\ and\ t > t_s + T$$

In this representation, the real and imaginary parts correspond to the in-phase and Quadrature parts of the OFDM signal, which are to be multiplied by cos and sine of the desired carrier frequency to produce the final OFDM signal.

$s(t) = \sum_{i=\frac{Ns}{2}}^{\frac{Ns}{2}-1} d_{i+\frac{Ns}{2}} e^{j2\pi(t-t_s)\frac{i}{T}}$ When $t_s \le t \le T + t_s$

= 0 when $t < t_s and\ t > T + t_s$

Each subcarrier occupies exactly an integral number of cycles in the interval T and the number of cycles between adjacent subcarriers differs by exactly one. In other words, we can say that all subcarriers have same phase and amplitude.

If the j^{th} subcarrier is demodulated by down converting the signal with a frequency j/T and then integrating the signal over T seconds, the result is

$$\int_{t_s}^{t_s+T} e^{-j2\pi 1/T(t-t_s})\sum_{i=\frac{Ns}{2}}^{\frac{Ns}{2}-1} d_{i+\frac{Ns}{2}}\, e^{j2\pi i/T(t-t_s})dt = \sum_{i=\frac{Ns}{2}}^{\frac{Ns}{2}-1} d_{i+\frac{Ns}{2}} \int_{t_s}^{t_s+T} e^{j2\pi(i-\frac{j)}{T(t-t_s)}}\, dt$$

For all other subcarriers, the integration is 0, because the frequency difference (i-j)/T produces an integral number of cycles within integration interval T, such that the integration is always 0. Each OFDM signal symbol contains subcarriers that are non-zero over a T-second interval. Hence, the spectrum of a single symbol is a convolution of a group of Dirac pulses located at the subcarriers frequencies with the spectrum of a square pulse that is 1 for a T-second period and 0 otherwise.

The amplitude spectrum of a square pulse is equal to sin(πfT), which becomes zero for all frequencies that are integral multiples of 1/T. At the maximum of each subcarrier spectrum, all other subcarrier spectra are 0. An OFDM receiver calculates the spectrum values at those points that correspond to maximum of individual subcarriers. It can demodulate each subcarrier free from any interference. OFDM spectrum fulfils Nyquist criterion for an intersymbol interference free pulse shape. The pulse shape is present in the frequency domain, so instead of ISI, inter-carrier interference is avoided by having maximum of one subcarrier spectrum correspond to zero crossing of all the others.

1.5.2: IMPLEMENTATION USING THE FFT ALGORITHM

The orthogonality allows efficient modulator and demodulator implementation using the FFT algorithm on the receiver side, and inverse FFT on the transmitter side. A N-point FFT using radix-4 algorithm requires only 3/8N($\log_2 N$-2) complex multiplications and N$\log_2 N$ complex additions.

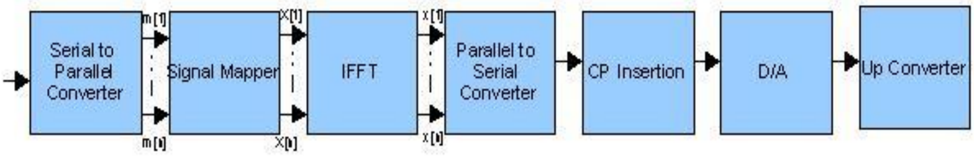


FIGURE-7:DEPICTING FFT IMPLEMENTATION IN OFDM SYSTEM

1.5.3: GUARD INTERVAL FOR ELIMINATION OF INTERSYMBOL INTERFERENCE

Since low symbol rate modulation schemes suffer less from intersymbol interference caused by multipath propagation, it is advantageous to transmit a number of low-rate streams in parallel instead of a single high-rate stream. This is one of the basic principles of OFDM system. Since the duration of each symbol is long, it is advisable to insert a guard between the OFDM symbols. This eliminates the chances of intersymbol interference. The guard interval also eliminates the need for a pulse-shaping filter. It reduces the sensitivity to time synchronization problems. The cyclic prefix, which is transmitted during the guard interval, consists of the end of the OFDM symbol copied into the guard interval, and the guard interval is transmitted followed by the OFDM symbol. The reason for the presence of cyclic prefix is so that the receiver will integrate over an integer number of sinusoid cycles for each of the multipath when it performs OFDM demodulation with the FFT.

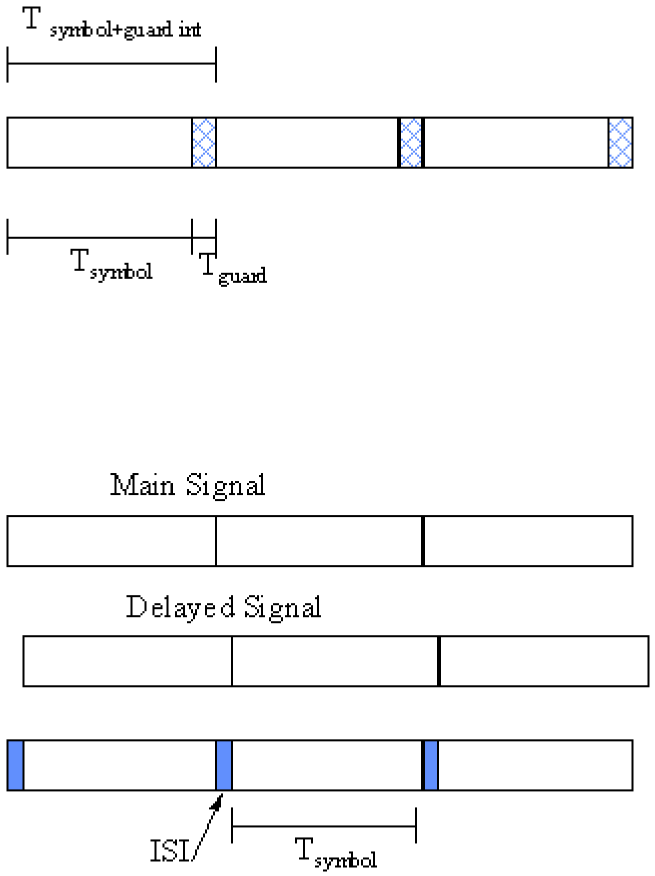


FIGURE-8: GUARD INTERVAL DENOTED IN OFDM SYSTEM

Guard interval is such that multipath components from one symbol cannot interfere with the next symbol. The guard time consists of no signal at all. When an OFDM receiver tries to demodulate the first subcarrier, it will encounter same interference from the second subcarrier because within FFT interval, there is no integral number of cycles different between subcarriers 1 and 2. At the same time, there will be cross-talk from the first to second subcarrier.

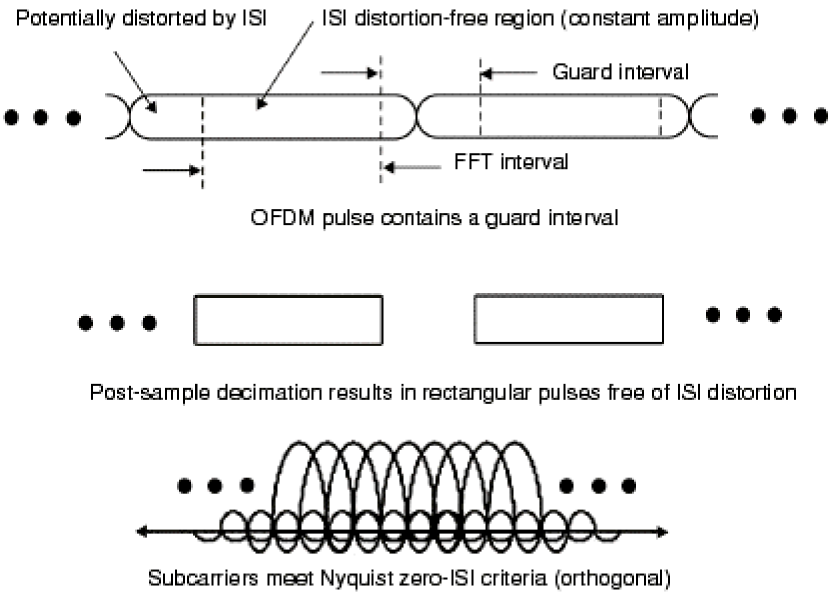


FIGURE-9: GUARD INTERVAL AND ISI IN OFDM SYSTEM

1.5.4: SIMPLIFIED EQUALIZATION

The effects of frequency-selective channel conditions caused by multipath propagation can be considered as constant (flat) over an OFDM sub-channel if the number of sub-channels is sufficiently large. This makes equalization far simpler at the receiver in OFDM. The equalizer only has to multiply each detected sub-carrier by a constant complex number, or a rarely changing value. Some of the sub-carriers in some of the OFDM symbols may carry pilot signals for measurement of the channel conditions, *i.e.* the equalizer gain and phase shift for each sub-carrier. Pilot signals and training symbols may also be used for time synchronization (to avoid intersymbol interference, ISI), and frequency synchronization (to avoid inter-carrier interference, ICI, caused by Doppler shift).

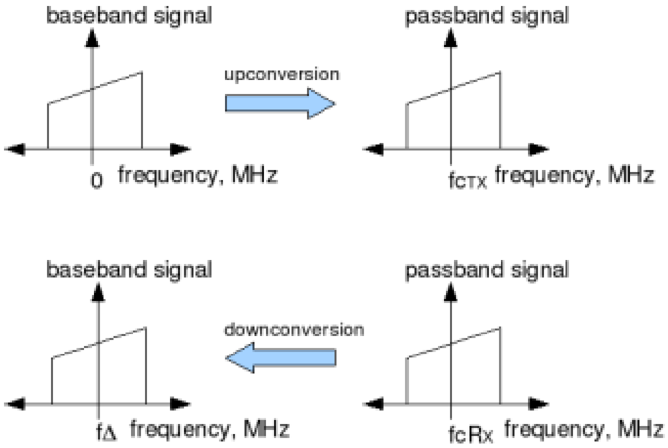


Figure 10:

If differential modulation such as DPSK or DQPSK is applied to each sub-carrier, equalization can be completely omitted, since these non-coherent schemes are insensitive to slowly changing amplitude and phase distortion.

1.5.5: CHANNEL CODING AND INTERLEAVING

OFDM is invariably used along with channel coding and almost always uses frequency and/or time interleaving.

Frequency (subcarrier) interleaving increases resistance to frequency-selective channel conditions such as fading. When a part of the channel bandwidth is faded, frequency interleaving ensures that the bit errors that would result from those subcarriers in the faded part of the bandwidth are spread out in the bit-stream rather than being concentrated to one part of the bandwidth. Similarly, time interleaving ensures that bits that are originally close together in the bit-stream are transmitted far apart in time.

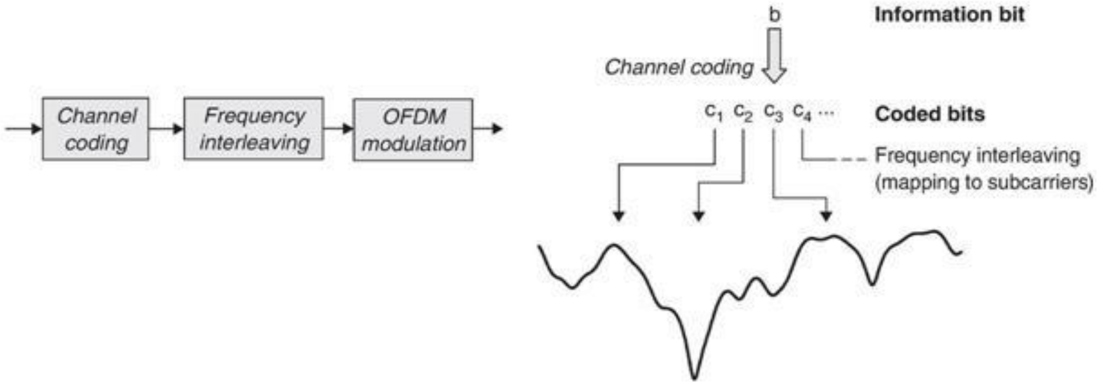


FIGURE-11: CHANNEL CODING AND INTERLEAVING

1.5.6: CYCLIC PREFIX:

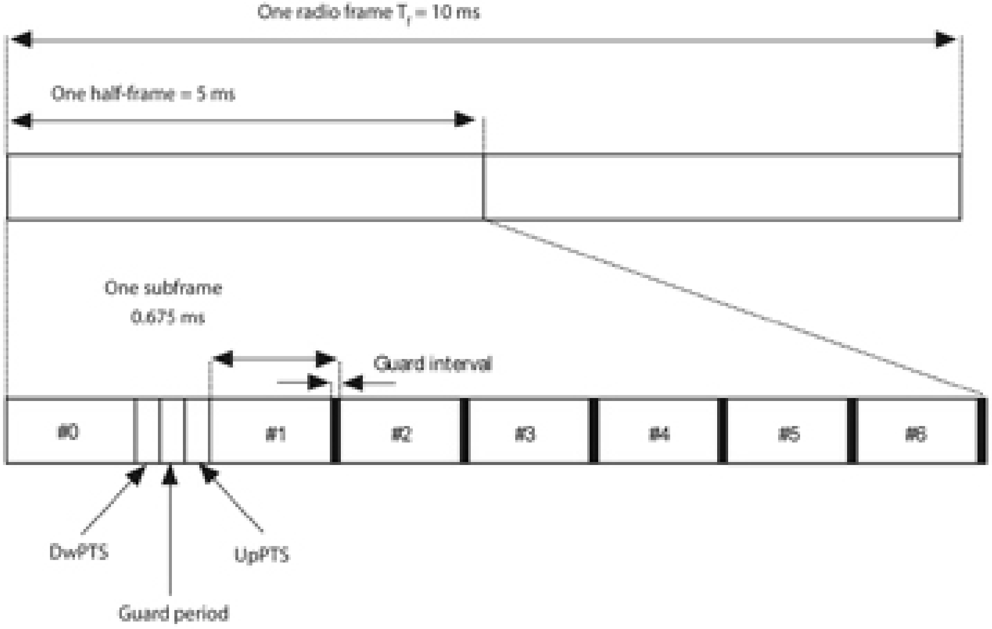


FIGURE-12: GUARD INTERVAL AND CYCLIC PREFIX

The term cyclic prefix refers to the prefixing of a symbol with a repetition of the end. The cyclic prefix which is transmitted during the guard interval consists of the end of the OFDM symbol copied into the guard interval, and the guard interval is transmitted followed by the OFDM symbol.

The cyclic prefix serves two purposes.

- As a guard interval, it eliminates the intersymbol interference from the previous symbol.
- As a repetition of the end of the symbol, it allows the linear convolution of a frequency-selective multipath channel to be modelled as circular convolution, which in turn may be transformed to the frequency domain using a discrete Fourier transform. This approach allows for simple frequency-domain processing, such as channel estimation and equalization.

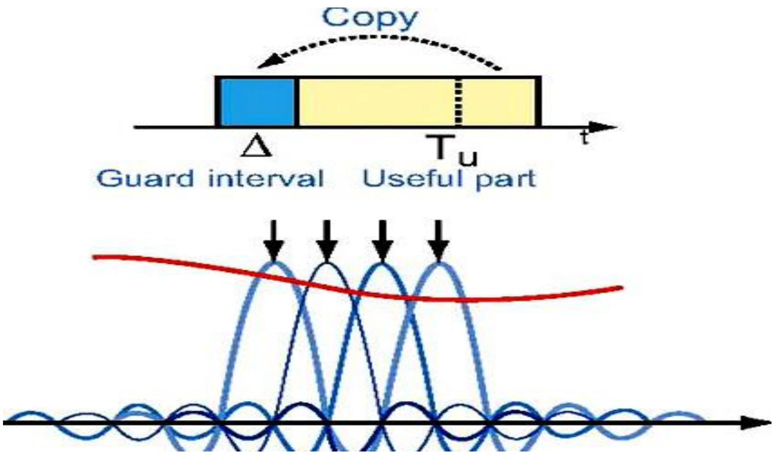


FIGURE-13: CYCLIC PREFIX IN GUARD INTERVAL

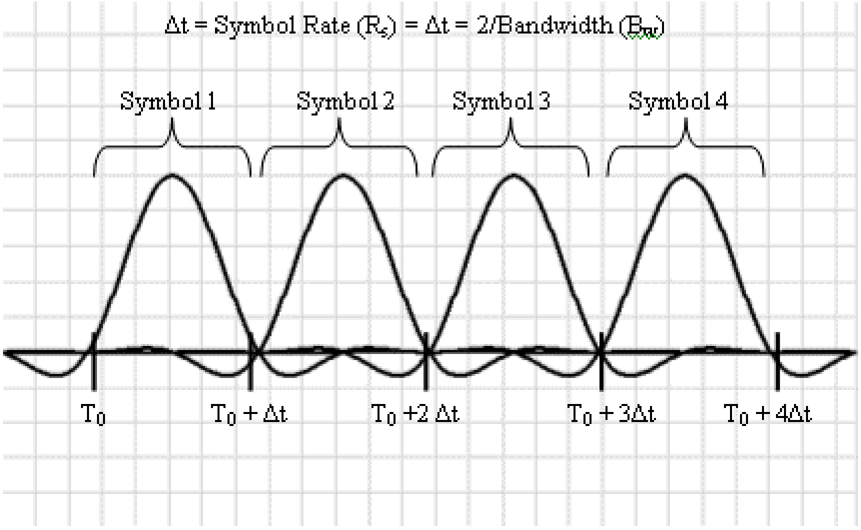


FIGURE-14: CYCLIC PREFIX AND ISI

1.6: CONCLUSION:

So far, we have seen the implementation of OFDM in various situations. There is an utmost need of correct transmission of data inspite of all the destructive conditions. This chapter provides us an insight to the basic features of OFDM system that makes it such a versatile and compatible system

CHAPTER-2

OFDM TRANSMISSION TECHNIQUE

2.1: OFDM TRANSMISSION SYSTEM MODEL

An OFDM carrier signal is the sum of a number of orthogonal sub-carriers, with baseband data on each sub-carrier being independently modulated commonly using some type of Quadrature amplitude modulation (QAM) or phase-shift keying (PSK). This composite baseband signal is typically used to modulate a main RF carrier.

2.1.1: TRANSMITTER:

$s[n]$ is a serial stream of binary digits. By inverse multiplexing, these are first de-multiplexed into N parallel streams, and each one mapped to a (possibly complex) symbol stream using some modulation constellation (QAM, PSK, etc.). An inverse FFT is computed on each set of symbols, giving a set of complex time-domain samples. These samples are then Quadrature-mixed to passband in the standard way. The real and imaginary components are first converted to the analog domain using digital-to-analog converters (DACs); the analog signals are then used to modulate cosine and sine waves at the carrier frequency, f_c, respectively. These signals are then summed to give the transmission signal, $s(t)$.

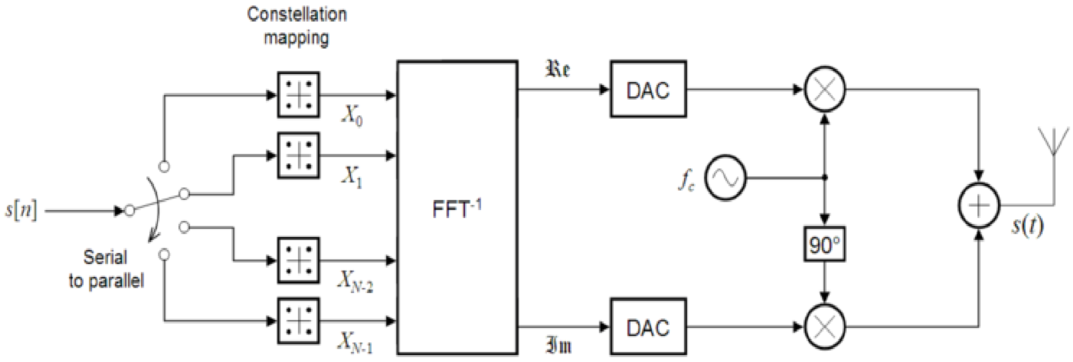


FIGURE 15: OFDM TRANSMITTER

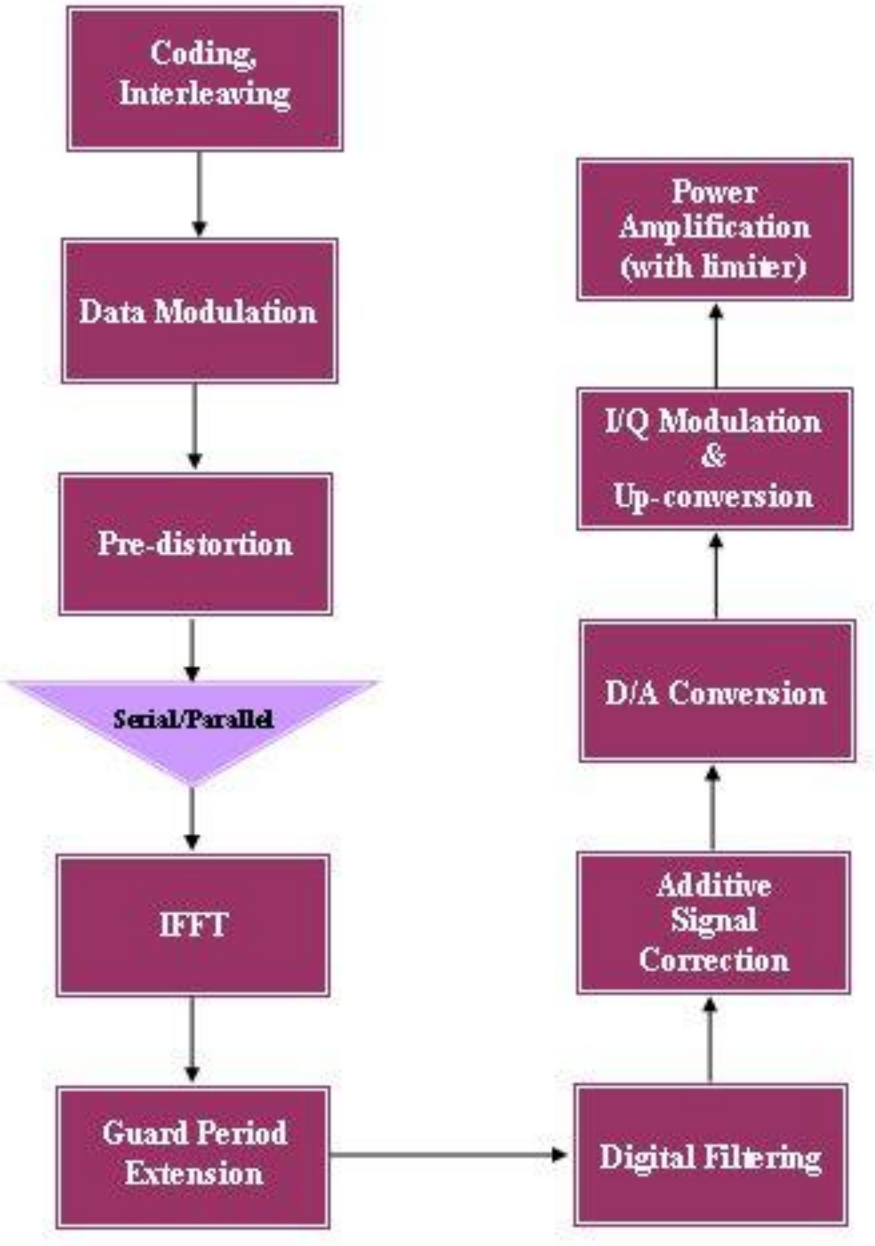


FIGURE-16: FLOWCHART FOR THE OFDM TRANSMITTER

2.1.2: RECEIVER:

The receiver picks up the signal *r* (*t*), which is then Quadrature-mixed down to baseband using cosine and sine waves at the carrier frequency. Low-pass filters can be used to reject signals centered at 2f_c,. The baseband signals are then sampled and digitized using analog-to-digital converters (ADCs), and a forward FFT is used to convert back to the frequency domain. This returns *N* parallel streams, each of which is converted to a binary stream using an appropriate symbol detector. These streams are then re-combined into a serial stream, $\hat{s}[n]$, which is an estimate of the original binary stream at the transmitter.

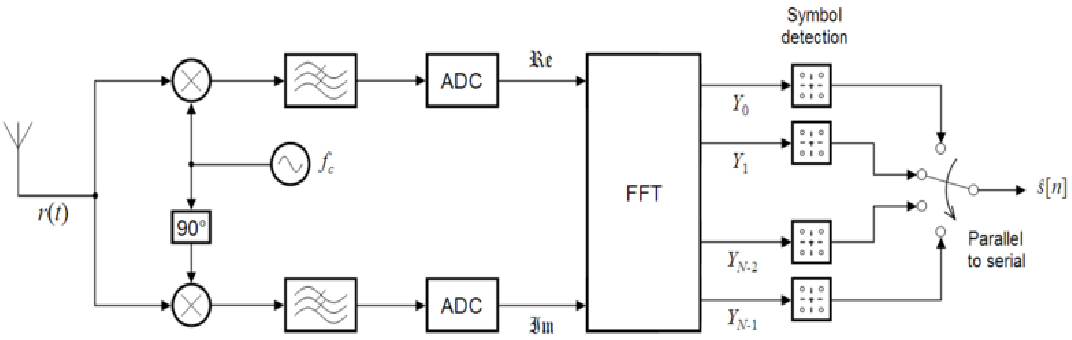


FIGURE-17: OFDM RECEIVER

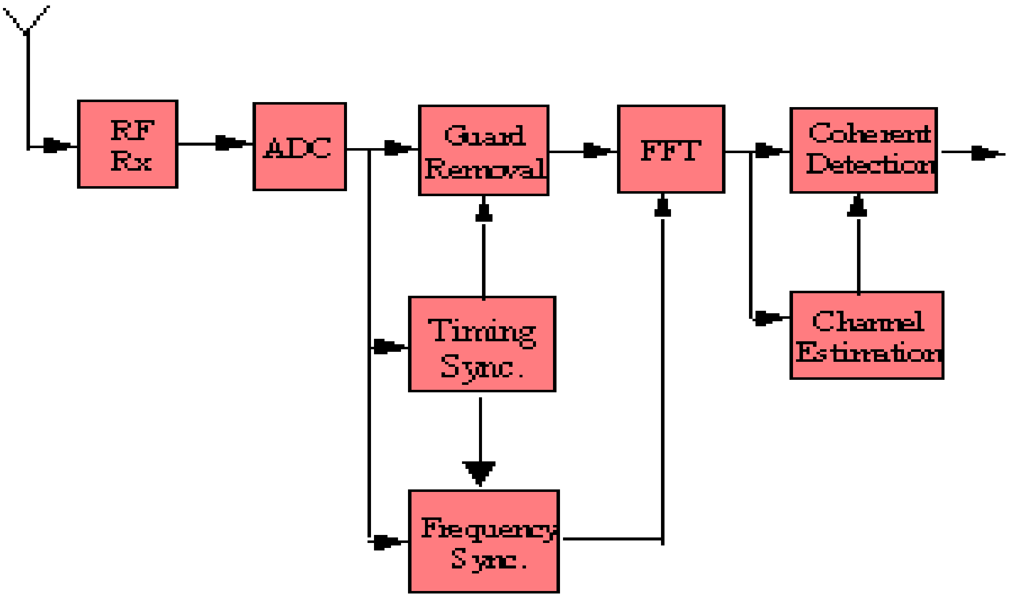


FIGURE-18: FIGURATIVE FLOWCHART FOR OFDM RECEIVER

2.2: MATHEMATICAL EXPRESSION FOR OFDM

If N subcarriers are used, and each subcarrier is modulated using M alternative symbols, then the OFDM signal consists of M^N combined symbols.

The low-pass equivalent OFDM signal is expressed as:

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

Where $\{X_k\}$ are data symbols

N= number of subcarriers

T= OFDM symbol time

The subcarrier spacing of 1/T makes them orthogonal over each symbol period. This is expressed as

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

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_g≤t<0 equals the signal in the interval ($T - T_g$)≤ t <T.

The OFDM signal with cyclic prefix is given by:

$v(t) = \sum_{k=0}^{N-1} X_k e^{\frac{j2\pi kt}{T}} \ -T_g \leq t < T$

Assuming complex valued signals:

$s(t)$ =Re$\{v(t)e^{j2\pi f_c t}\}$

=$\sum_{k=0}^{N-1} [X_k] \cos\left[2\pi\left(f_c + \frac{k}{T}\right)t + \arg[X_k]\right]$

2.3: IMPLEMENTATION OF OFDM

Generally, the implementation of the principles of OFDM is done in an ideal channel to recognize the pattern and understand the properties of OFDM. Similar conditions are being followed here. We recognize the signal-to-noise ratio and the bit-error-rate characteristics for the OFDM system

2.4: ALGORITHM

- Taking the number of subcarriers S=10000 and the number of bits Nb=64
- Designing a random signal with BPSK modulation(modulation like QAM or PSK can also be used)
- The IFFT of the input signal gives us the signal form that will pass through the channel
- We can get the received signal by adding AWGN noise to the channel signal
- We can then plot the SNR-vs-BER plot for the OFDM signal while comparing the error in the transmitted and the received signal

2.5: SIMULATION RESULT

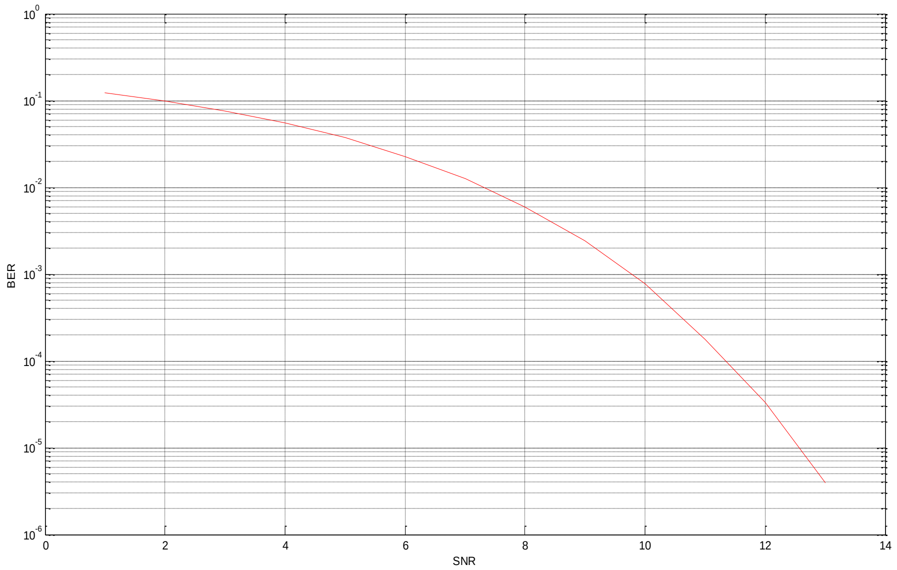


FIGURE-19: SNR-BER PLOT FOR OFDM SIGNALS

This gives us the output of the BER-vs-SNR plot for the OFDM signal in ad ideal channel. We can see the BER decreases with improvement in SNR. This ideal situation provides us with a very good SNR-BER condition.

2.6: ADVANTAGES AND DISADVANTAGES OF OFDM

OFDM scheme has the following **advantages**:

As a multicarrier scheme:

- Copes with several channel conditions like attenuation at high frequencies
- Reduces narrow-land interference and frequency-selective fading due to multi-path fading

As a transmission scheme:

- OFDM is an efficient way to deal with multipath; for a given delay spread, the implementation complexity is significantly lower than that of a single-carrier system with an equalizer. Robust against intersymbol interference (ISI) and fading caused by multipath propagation.
- In relatively slow time-varying channels, it is possible to enhance capacity significantly by adapting the data rate per subcarrier according to the signal-to-noise ratio of that particular subcarrier
- OFDM is robust against narrowband interference, because such interference affects only a small percentage of the subcarriers
- OFDM makes single-frequency networks possible, which is especially attractive for broadcasting applications
- Can easily adapt to severe channel conditions without complex equalization.
- High spectral efficiency as compared to conventional modulation schemes, spread spectrum, etc.
- Efficient implementation using Fast Fourier Transform (FFT).
- Low sensitivity to time synchronization errors.

But OFDM seems to have the following **disadvantages** also:

- OFDM is more sensitive to frequency offset and phase noise
- OFDM has a relatively large peak-to-average-power ratio, which tends to reduce the power efficiency of the radio frequency amplifier. High Peak-to-Average-Power Ratio (PAPR), requiring linear transmitter circuitry, which suffers from poor power efficiency.
- Sensitive to Doppler shift and sensitive to frequency synchronization problems.
- Loss of efficiency caused by cyclic prefix/Guard interval.
- Almost half the spectral efficiency offered by vestigial sideband modulation

2.7: CONCLUSION:

In this chapter, we got the idea of the OFDM transmission system, with is block diagrams and data flowchart. We can, very convincingly conclude that OFDM systems are more efficient than the earlier conventional systems used. This chapter provides us an insight to the mathematical description of OFDM system and its implementation. In spite of the disadvantages presented by OFDM systems, it has proven to be highly useful technique for data transmission.

CHAPTER-3

MULTI SYMBOL ENCAPSULATED OFDM

3.1: WHY MSE-OFDM?

One of the very important advantages of OFDM system lies in its simple receiver structure. It utilizes a frequency domain equalizer which performs only one complex multiplication per subcarrier, thus leading to simpler calculations and furthermore simpler circuits. This process of frequency domain equalization is achieved by introducing a time domain cyclic prefix (CP) which enables the receiver to separate the steady-state response from the transient response of the communication channel. The cyclic prefix which is transmitted during the guard interval consists of the end bits of the OFDM symbol which are copied into the guard interval, and the guard interval is transmitted followed by the OFDM symbol. The Cyclic Prefix is the cyclic extension of the sequence obtained after the inverse discrete Fourier transformation (IDFT) of the input sequence. There are a few restrictions on the length of the CP. The minimum length of CP should be equal to the channel impulse response (CIR) so as to avoid ISI and inter-carrier interference (ICI). But, this introduction of CP unwillingly yet unavoidably introduces redundancy into the conventional OFDM system. This wholly undermines the principle of OFDM system and reduces the system throughput. The bandwidth which can be achieved in the cases of OFDM systems gets restricted especially for channels with very long CIR.

To counter this problem, in many channels OFDM receivers took to implementing a finite-impulse response time-domain equalizer before the discrete Fourier transform. This shortens the effective length of the cyclic prefix. But, on the whole it undermines the basic advantage of OFDM system-simple receiver structure and simpler frequency domain equalization.

Another disadvantage of OFDM is its high PAPR. This limits the efficiency of the power amplifier to a very small range. As a result, OFDM signal covers a wide range of amplitudes and dwell mostly at small values. This allows the use of only linear region of the amplifiers. For this reason, high PAPR is synonymous to low efficiency of the amplifier. So, high PAPR implies the need for more precise resolution for the A/D converter at the receiver side.

3.2: MSE-OFDM AS AN IMPROVEMENT OVER OFDM

An MSE-OFDM using a different type of cyclic prefix is presented for the improvement of the system performance: in place of using one cyclic prefix for each OFDM symbol, a number of OFDM symbols are grouped together to denote a frame and only one cyclic prefix is used for the frame of OFDM symbols. The cyclic prefix is the cyclic extension of the last OFDM symbol in the same frame. The number of OFDM symbols in one frame is limited by the stability of the channel.

The main aim of introducing a new implementation of OFDM i.e. MSE-OFDM was to counter the following disadvantages of the OFDM system:

- Sensitivity to frequency offset
- High peak-to-average-power ratios(PAPR)

3.3: IMPLEMENTATION OF MSE-OFDM:

MSE-OFDM can be realized for different purposes:

- ➢ To improve the bandwidth efficiency for static channels: **CP-reduced system**
- ➢ To improve the robustness to synchronization errors and to reduce the PAPR of the MSE-OFDM system: **FFT- size reduced systems**

3.3.1: CP-reduced systems:

- CP- reduced system is designed with the same MSE-OFDM symbol duration as the conventional OFDM system.
- Bandwidth efficiency of CP-reduced system is increased by decreasing the number of CP insertions.
- Generally used for static or slowly varying channels.
- This may lead to the reduction in robustness of time-selective channels.
- The bandwidth efficiency is improved as the MSE-OFDM frame size increases.
- The CP insertion redundancy for MSE-OFDM, which is the ratio between the CP duration and the MSE-OFDM frame duration, decreases with a longer frame size.

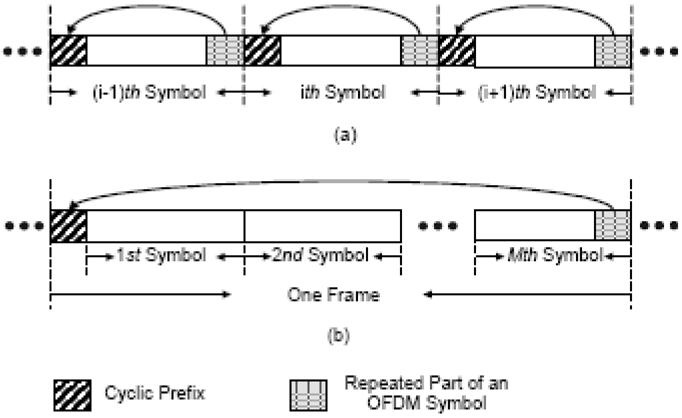


FIGURE 20: CP reduced MSE-OFDM with Improved Bandwidth Efficiency. (a) Conventional OFDM System, (b) MSE-OFDM System

3.3.2: FFT-sized reduced systems:

- This system is designed to keep the frame duration of MSE-OFDM same as the symbol duration of conventional OFDM signal.
- Although bandwidth efficiency remains unchanged, the symbol duration of each MSE-OFDM symbol is reduced. All this occurs with constant bandwidth.
- However, reducing the OFDM symbol duration while keeping its bandwidth unchanged is equivalent to reducing the number of sub-carriers, and the FFT-size of OFDM system. By doing so, the PAPR and the robustness against frequency offset of the MSE-OFDM can be substantially improved.
- The system robustness problem over a time-selective channel doesn’t exist for the FFT-size reduced MSE-OFDM, since the system is designed with the same CP ratio as conventional OFDM

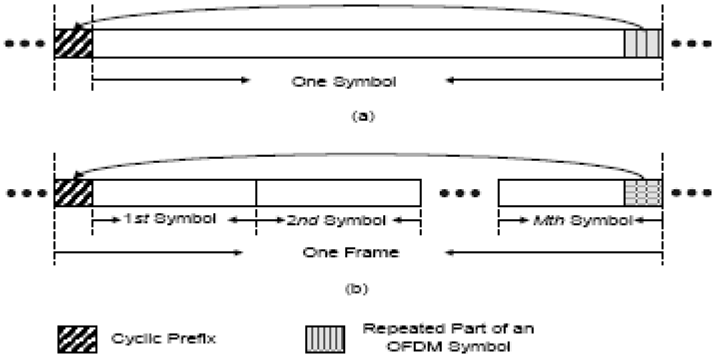


FIGURE 21: FFT-size reduced MSE OFDM with more robustness to synchronization error and lower PAPR (a) Conventional OFDM (b) MSE-OFDM system

3.4: TRANSMITTER:

Similar to conventional OFDM systems, MSE-OFDM system relies on coherent Quadrature amplitude modulation for a higher spectral efficiency. To support the proposed MSE-OFDM system, modifications have to be made to the conventional OFDM transceiver. Modifications from the conventional OFDM system to the MSE-OFDM system are minimal at the transmitter side. Only a larger buffer is needed, since the CP is the cyclic extension of the last OFDM symbols in the frame. Therefore, all the OFDM symbol samples in the same frame have to be stored before insertion of the CP. This indicates a buffer size is (MN+P), where N,M,P are the IFFT size of the modulator, the number of OFDM symbols in one frame and the length of the CP for the MSE-OFDM system respectively. M OFDM symbols have to be generated before the CP insertion at the transmitter side. Each OFDM symbol is given by the N-point complex modulation sequence through an IDFT as

$x(n) = 1/\sqrt{N}\sum_{k=0}^{N-1} X(k)\, e^{j2\pi nk/N}$ n=0,1,2,3,.......,N-1

The signal consists of N complex exponentials or sub-carriers, which have been modulated with the complex data X. The *l*th frame MSE-OFDM signal with M symbols can be generated as

$$S_l = \sum_{k=0}^{N-1} X_{l,M-1}(k)\varphi_1(n,k) + \sum_{i=0}^{M-1}\ \sum_{k=0}^{N-1} X_{l,i}(k)\varphi_2(n-iN-P,k)$$

Where the two subscripts i ϵ[0,M-1] and

l= mean the i^{th} OFDM symbol of the l^{th} frame.

$\varphi_1(n,k), \varphi_2(n,k)$ are two rectangular signals multiplexing window functions corresponding to the CP and the M information carrying OFDM symbols defined as

$$\varphi_1(n,k) = 1/\sqrt{N} e^{j2\pi k(N-P+n)/N} \quad 0 \le n \le P-1$$

=0 otherwise

And

$$\varphi_2(n-iN-P,k) = 1/\sqrt{N}\left(e^{\frac{j2\pi k(n-P-iN)}{N}}\right), \text{P≤n≤MN+P-1}$$

= 0, otherwise

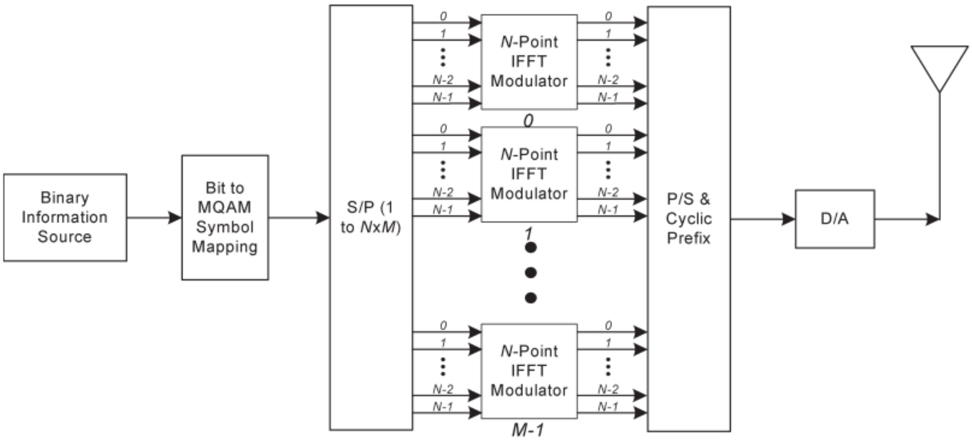


FIGURE20: BLOCK DIAGRAM OF TRANSMITTER OF MSE-OFDM

3.5: RECEIVER:

Using the concept of unknown CP, simple frequency-domain equalization can be realized for the MSE-OFDM system. However, a new FEQ has to be implemented due to the modifications to the frame structure of the OFDM signal. We can rewrite sl as a vector

$$S_l = [x_{l,M-1}(N-p+1), \dots\dots x_{l,M-1}(N-1) \qquad x_{l,0}(0), \dots., x_{l,0}(N-1), x_{l,1}(0), \dots.. x_{l,1}(N-1), \dots\dots.. x_{l,M-1}(0), \dots. x_{l,M-1}(N-1)]T$$

The receiver signal corresponding to the above transmitted signal can be expressed as

$$\mathbf{r}_l = \begin{bmatrix} h_0 & 0 & \cdots & \cdots & \cdots & 0 \\ h_1 & h_0 & & & \ddots & \vdots \\ \vdots & \ddots & \ddots & \ddots & & \vdots \\ h_{P-1} & \cdots & h_1 & h_0 & \ddots & \vdots \\ 0 & \ddots & & \ddots & \ddots & 0 \\ \vdots & & h_{P-1} & \cdots & h_1 & h_0 \\ \vdots & & \ddots & h_{P-1} & \cdots & h_1 \\ \vdots & \ddots & & \ddots & \cdots & \vdots \\ 0 & \cdots & \cdots & \cdots & 0 & h_{P-1} \end{bmatrix} \cdot \mathbf{s}_l + \mathbf{w}$$

Where the size of the channel matrix is [MN+2P,MN+P],

and w is an additive white Gaussian noise(AWGN) vector with the same size as s_l.

The received signal $\tilde{\mathbf{r}}_l$ after the CP removal is actually the cyclic convolution between $\tilde{\mathbf{s}}_l$ and CIR h when the AWGN noise is neglected. The following DFT transform pair holds:

$$\tilde{\mathbf{s}}_l \otimes \mathbf{h} + \tilde{\mathbf{w}} \Leftrightarrow \mathrm{DFT}(\tilde{\mathbf{s}}_l) \cdot \mathbf{H} + \tilde{\mathbf{W}}$$

where $\otimes$ denotes the cyclic convolution, while W and $\tilde{\mathbf{W}}$ are the Fourier transforms of hand w’ respectively. The size of DFT here is MN points.

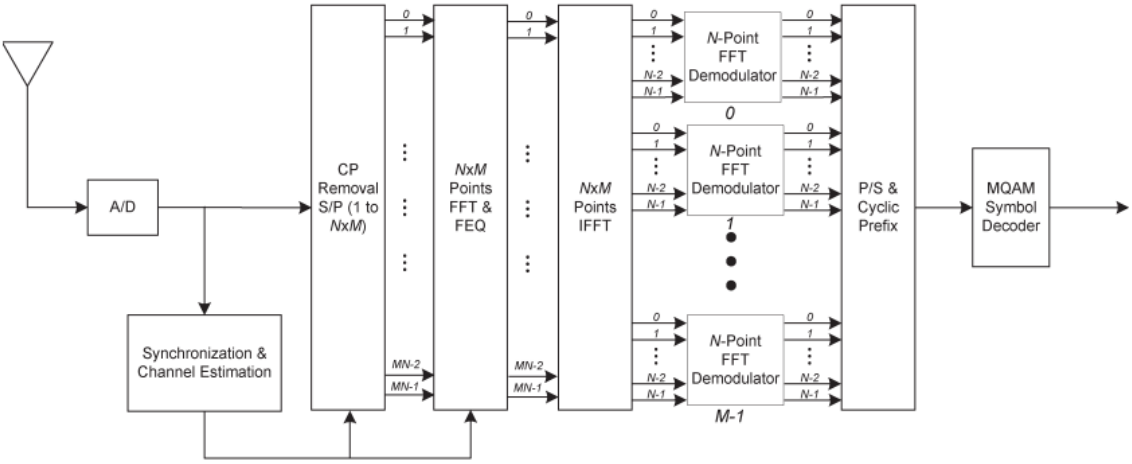


FIGURE 21: BLOCK DIAGRAM FOR RECEIVER OF MSE-OFDM

Assuming that the channel transfer function H is obtained from the channel estimation, channel shortcomings can be compensated using a FEQ. For the demodulation of the OFDM symbols in the same-frame, the equalized frequency-domain signal has to be converted back into the time domain for the IDFT demodulation. The equalization process can be formulated as:

$$\tilde{r}_l^{FEQ} = \mathrm{IDFT}\left\{\frac{\mathrm{DFT}(\tilde{r}_l)}{\mathrm{H}}\right\} + \tilde{w}_l^{FEQ}$$

Where

$\tilde{w}_l^{FEQ}$ Is the AWGN noise after the equalization process. The equalized signal

$\tilde{r}_l^{FEQ}$ Is then split into M OFDM symbols for demodulation with an N-point FFT.This way the frequency-domain equalization can be done on each individual OFDM symbols or the OFDM symbols required, rather than on the whole frame of MSE-OFDM symbols.

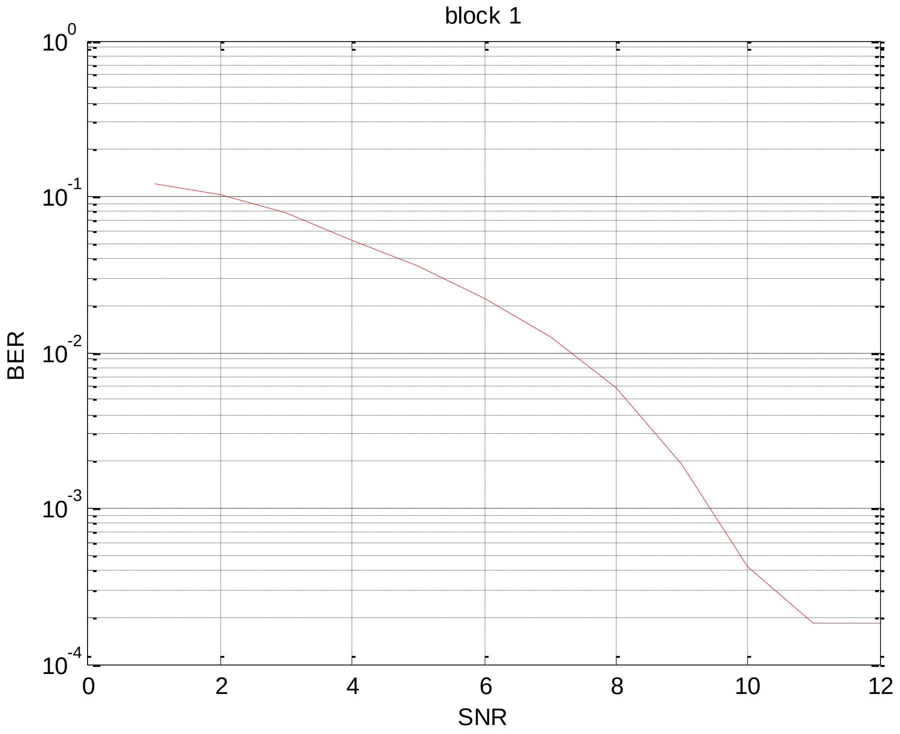
3.6: REALIZATION OF MSE-OFDM:

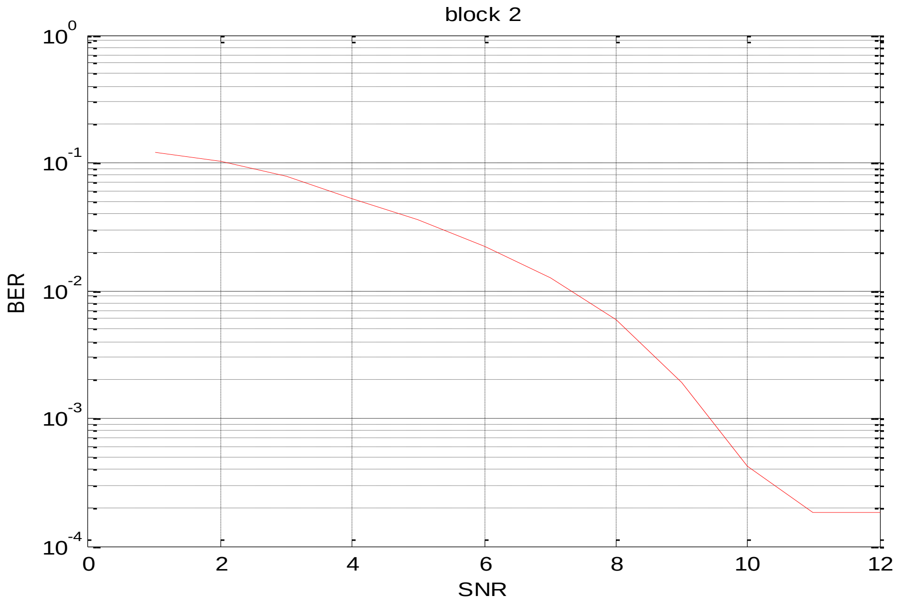
The basic difference of MSE-OFDM and OFDM signals is the way the bits are operated upon. In OFDM signal, there is one cyclic prefix for every bit , i.e. every bit is operated on individually. In MSE-OFDM, several bits are grouped together as a frame, which is guarded by a single cyclic prefix. This whole frame of bits is operated as one thereby reducing the number of complex calculations.

3.7: ALGORITHM:

- The number of subcarriers and bits were taken the same i.e. 128
- A random signal was generated which was divided into four frames(for easier programming purposes: we can divide into as many frames as we like)
- IFFT is performed on eachof the frames separately.
- The four operated matrices are then combined to give a total operated matrix
- The last 16 bits of this total matrix is concated to the beginning of the matrix as cyclic prefix.
- The received signal can be obtained by adding AWGN noise to the transmitted signal
- The cyclic prefix is removed from the received signal by removing the first 16 bits.
- The matrix is then again divided into 4 frames and FFT is performed on each of the frames
- The SNR-BER comparison can be done for each individual block or for the combined received signal
- This gives us the visual comparison between the effect of MSE-OFDM on the signal as compared to OFDM signal

3.8: SIMULATION RESULT:





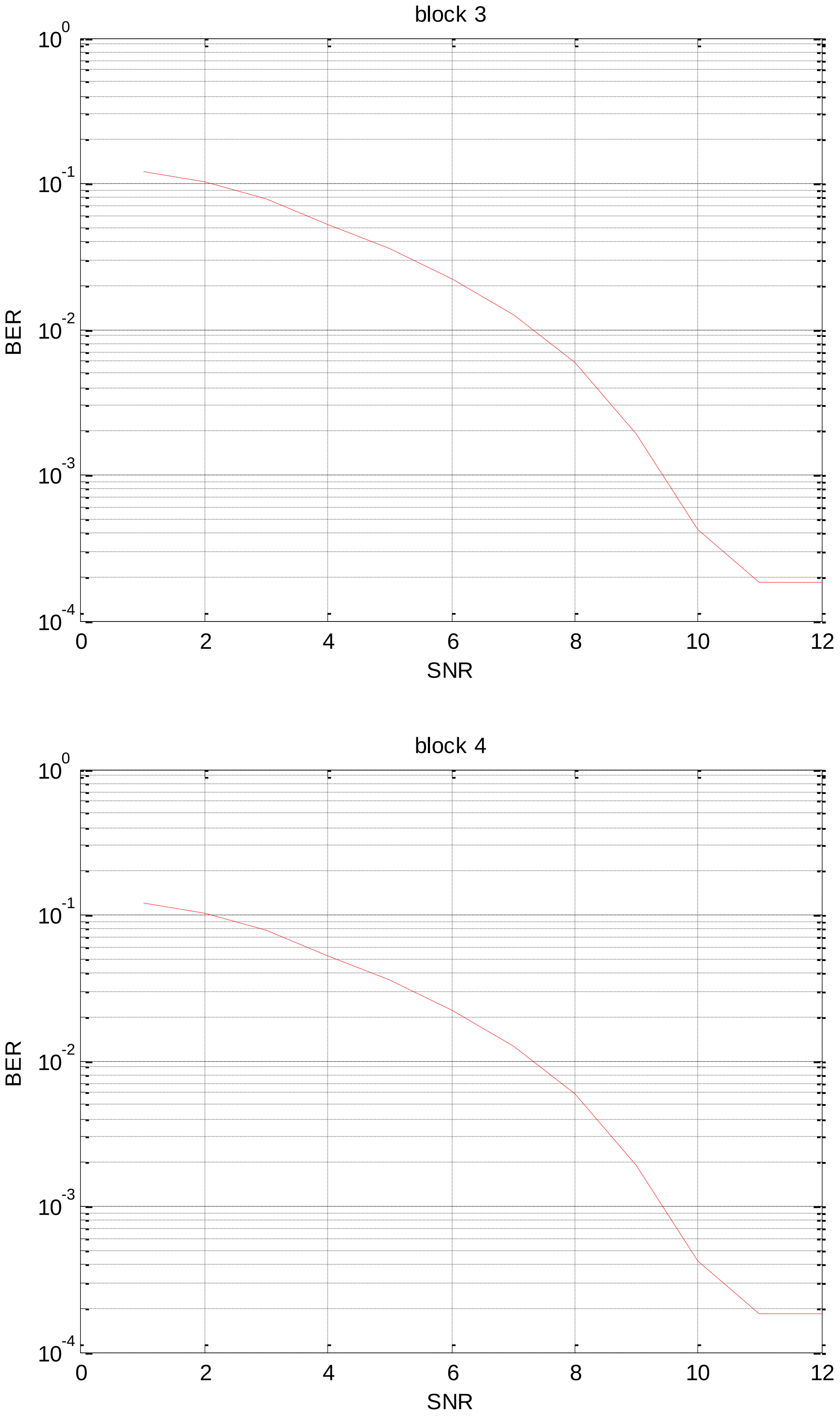


FIGURE 22: SNR-BER PLOT FOR MSE-OFDM SYSTEM

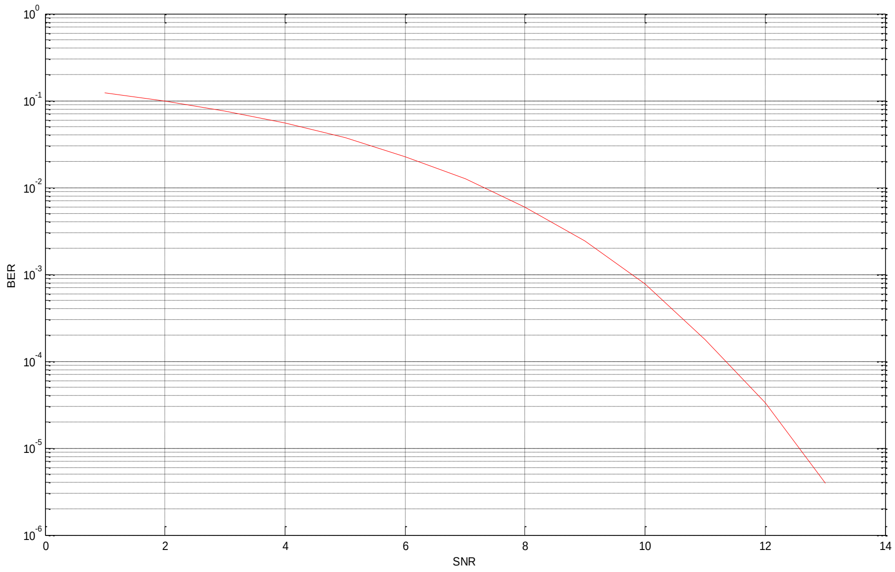


FIGURE 23: SNR-BER PLOT FOR OFDM SYSTEM

As we can see the SNR-BER plot is less steep in case of MSE-OFDM. This implies that the error in MSE-OFDM is less as compared to OFDM systems.

- A channel estimation has to be realized before equalization and demodulation of the OFDM signal.
- The accuracy of the channel estimation is also crucial to the performance os the overall system in terms os the bit error rate.
- The frequency offset of the OFDM system should also be estimated and corrected to avoid ICI due to the loss of orthogonality arising amongst the subcarriers.

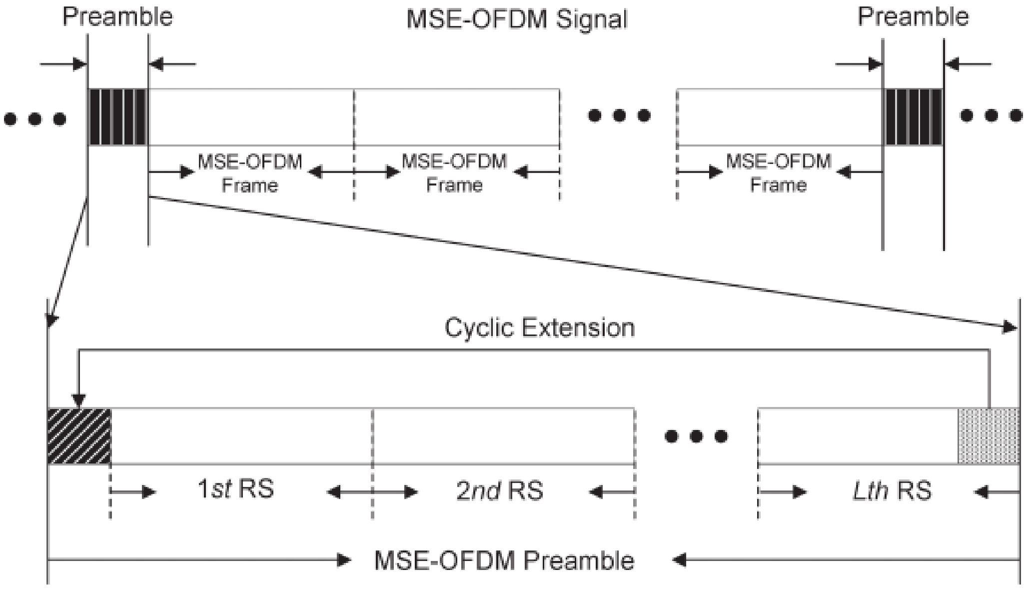


FIGURE 26: STRUCTURE OF A MSE-OFDM PREAMBLE

3.9 ADVANTAGES OF MSE-OFDM

3.9.1: Frequency Domain equalizer

One of the major advantages of the OFDM systems is their simple frequency domain equalization. The use of the frequency domain equalizer is valid only in the absence of ISI. With the proposed MSE-OFDM frame structure, ISI will be eliminated when the CP is longer than the CIR. With the help of the CP, simple frequency domain equalization can be realized for the MSE-OFDM system. However, a new frequency domain equalizer has to be used due to the modifications made to the frame structure compared to the conventional OFDM systems.

$$\overline{s_l} = \big[x_{l,M-1}(N-p+1), \dots \dots, x_{l,M-1}(N-1), x_{l,0}(0), \dots\dots x_{l,0}(N-1), \,|\, \dots \\ x_{l,1}(0), \dots\dots x_{l,1}(N-1), \dots\dots, x_{l,M-1}(0), \dots\dots, x_{l,M-1}(N-1) \big]$$

There exists a cyclic convolution between

s_l and h And the following DFT transform pair holds:

$$s_l \otimes h \Leftrightarrow \langle DFT(s_l) \rangle \cdot \langle H \rangle$$

Where $\otimes$ denoted the cyclic convolution and H is the Fourier transform of h. For demodulation of OFDM symbols in the same frame, the equalized frequency domain signal needs to be converted back into the time domain for the IDFT demodulation. This process can be formulated as:

$$s_l = IDFT\left\{\frac{DFT\langle r_l' \rangle}{H}\right\}$$ Where, r_l' is the CP removed version for r_l

3.9.2: Bandwidth Efficiency

For conventional OFDM systems, ISI/ICI free transmission is achieved at the cost of reduced bandwidth efficiency both for conventional OFDM systems and MSE-OFDM system. Since the CP inevitably introduces some delay in the transmission time, the system throughput is reduced. The reduction in the bandwidth efficiency can be related to the duration of the cyclic prefix and effective data transmission time. If we consider that each carrier conveys a symbol taken in a 2-D constellation with 2^a points and is modulated during T seconds for ideal OFDM system (without CP), the bit-rate can be shown as

$$D = Na/T \text{ bits/s}$$

The total bandwidth occupied by the N carriers is then given by

$$W = N/T$$

Bandwidth efficiency is given by

$$\eta = \frac{D}{W} = a\frac{bits}{sec}/Hz$$

If we take the CP duration into consideration, the equation reduces to

$$\eta_1 = \frac{D_1}{W} = aN/(N+P) \text{ bits/sec/Hz}$$

For MSE-OFDM system, the bandwidth efficiency is

$$\eta_2 = \frac{D_2}{W} = aMN/(MN+P)bits/sec/Hz$$

The improvement which we can calculate with respect to the bandwidth efficiency of MSE-OFDM system in regards to the conventional OFDM systems is

$$\Delta\eta = \eta_2 - \eta_1 = aPN(M-1)/(N+P)(MN+P)$$

It can be easily concluded that the bandwidth efficiency of the CP- reduced MSE-OFDM system will be improved, while the bandwidth efficiency of the FFT size reduced MSE-OFDM will be the same as the conventional OFDM system.

3.9.3: Impact of Synchronization Errors

The comparison of performance between the MSE-OFDM and the conventional systems is done in two different ways i.e. either keeping the OFDM symbol duration unchanged and increasing the bandwidth efficiency or keeping the bandwidth efficiency constant and increasing the flexibility of the system. To evaluate the impact of the synchronization error on the system performance, a symbol error analysis can be conducted. Let Δk be the relative frequency offset (the ratio of the actual frequency offset to the sub-carrier spacing) and Δn be the relative timing offset (the ratio of the timing offset to the sampling interval). The decision variable can be normalized as

$$R_k = X_k + n_{syn} + I_k' + W_k'$$

With

$$n_{syn} = \sum_{n=1}^{\infty} \frac{\left[\left(j\pi\Delta k(N-1) + j2\pi k\Delta n + j2\pi\Delta k\Delta n\right)/N\right]^n}{n!} X_k$$

$$I_k' = \sum_{\substack{l=-K \\ l\neq k}}^{K} \frac{X_l H_l}{H_k} \cdot \frac{\sin(\pi\Delta k/N)}{\sin(\pi(l-k+\Delta k)/N)} \times e^{-j\pi(l-k)/N} e^{j\pi\Delta k(N-1)/N} . e^{j2\pi k\Delta n/N} . e^{j2\pi\Delta k\Delta n/N}$$

and

$$W_k' = \frac{W_k N \sin(\pi\Delta k/N)}{H_k \sin(\pi\Delta k)}$$

Variance can be determined as

$$\sigma_{W_{k'}}^2 = \frac{\sigma_W^2}{|H_k|^2}$$

$$\sigma_{I_{k'}}^2 \simeq \sum_{\substack{l=-K \\ l\neq k}}^{K} \left\langle \left(\frac{X_l H_l}{H_k}\right)^2 \right\rangle \cdot \left\langle \frac{\pi^2 \sigma_{\Delta k}^2}{N^2 \sin^2(\pi(l-k+\Delta k)/N)} \right\rangle$$

and

$$\sigma_{n_{syn}}^2 = \left| \sum_{n=1}^{\infty} \frac{\left[\left(j\pi\Delta k(N-1) + j2\pi k\Delta n + j2\pi\Delta k\Delta n\right)/N\right]^n}{n!} \right|^2 E(X_k)$$

It can be determined by examination that the decision variable R can be simplified as the summation of the desired signal component and a Gaussian noise with variance which is known using the above equations. The symbol error rate (SER) of the OFDM systems with synchronization errors can then be evaluated.

It is clearly observed that the SER performance with synchronization error is determined by the relative frequency offset(the ratio of the actual frequency offset to the sub-carrier spacing) and the relative timing offset(the ratio of the timing offset to the sampling interval). Therefore, it can be predicted that FFT size reduced MSE-OFDM system will be more robust to synchronization errors. This is because the relative frequency offset becomes smaller when the number of sub-carriers in the MSE-OFDM is reduced. The relative timing offset will remain unchanged.

3.9.4: PAPR AND Quantization Noise:

The PAPR for the baseband OFDM signal s(t) can be defined as:

$PAPR = \frac{\max\left\{|s(t)|^2\right\}}{P_s}$ where P_s corresponds to the average power of the base-band

For the mathematical convenience, we can take into account the crest factor(C), defined as:

$$C = \sqrt{PAPR} = \frac{\max|s(t)|}{\sqrt{P_s}} = \max|r(t)|$$

$$r(t) = \frac{|s(t)|}{\sqrt{P_s}} = \sqrt{\frac{x^2(t) + y^2(t)}{P_s}}$$
.

Where r(t) is the envelope of the complex baseband OFDM signal normalized by the average power.

We can assume that the real and imaginary part of s(t), i.e. x(t) and y(t) are asymptotically Gaussian for large N, and the uncorrelated samples of x(t) and y(t) become independent Gaussian random variables. This is because uncorrelated Gaussian random variables are statistically independent. This allows r(t) to be Rayleigh random distribution of which the cumulative distribution function can be given by

$F_c(r) = \Pr\left(|s(t)| < r\right) = \exp\left[-\sqrt{\frac{\pi}{3}} N r e^{-r^2}\right]$ In practice the complementary cumulative distribution function $\Pr(C > r) = 1 - F_c(r)$.

The approximated complementary cumulative distribution of PAPR depends only on the number of the subcarriers N for an OFDM system. In the MSE-OFDM system given, if the symbol duration is kept the same as the OFDM system, the bandwidth efficiency increases and the peak to average power ratio will be the same for the two systems, as the number of the sub-carriers are the same for the two systems.

But, if the ratio between the cyclic prefix and the data transmission time is constant, the symbol duration of the MSE-OFDM will be reduced to 1/M of the conventional system. This indicates that the number of subcarriers becomes 1/M of the original system. Therefore, it is expected that the PAPR will be reduced pertaining to the smaller number of subcarriers.

Another disadvantage caused by the high PAPR is the quantization noise. OFDM signals have to be normalized to conversion range of the D/A and A/D converters for transmission and reception purpose. Higher PAPR implies a higher resolution requirement for D/A and A/D converters.

The variance of the quantization error can be determined as:

$$\sigma_q^2 = \frac{Q^2}{12} = \frac{\left(\frac{A}{2^{L-1}}\right)^2}{12}$$

where A, Q, and L are the maximum of the OFDM signal, quantization interval and wordlength of A/D converter, respectively.

The signal-to-quantization noise ratio (SQNR) can be determined as:

$$SQNR = \frac{E_s}{\sigma_q^2} = \frac{12 \cdot 2^{2L-2}}{PAPR}$$

where E_s is the average power.

It is clear that as the PAPR increases, the SQNR decreases.

With the proposed MSE- OFDM system, the $SQNR$ can be improved by $10\log_{10} \Delta PAPR$.

The reduction of the wordlength can be calculated as:

$$\Delta L = \frac{\log_2 PAPR - \log_2 PAPR'}{2}$$

where $PAPR'$ is the peak-to-average power ratio for the MSE-OFDM system.

Implementation cost can therefore be reduced with a less expensive ADC or DAC

CHAPTER-4

CHANNEL FADING AND FREQUENCY OFFSET IN MSE-OFDM

4.1: MSE-OFDM SYSTEM AND FADING CHANNEL:

All the studies and analysis done so far for the MSE-OFDM or the OFDM signals were assuming an ideal channel with no distortion. This is the initial condition assumed when we need to study the basic parameters of a transmission scheme. But practically, no channel is ideal. Every channel introduces some or the other defect or error in the system. Such channels are termed generally as fading channels. Fading is often modeled as a random process which depends n various parameters like position, frequency etc. Fading can be described as the deviation of the attenuation that a carrier-modulated signal experiences over certain communication media. A fading channel is a communication pathway that experiences fading. Fading can occur either due to multipath propagation or due to shadowing from obstacles affecting the direct wave propagation. The presence of reflectors in the environment of the transmitter and receiver create multiple paths that a transmitted signal can traverse through. As a result, the receiver perceives the superposition of all such copies of the transmitted signal, each coming through a different path. Each form of the signal will experience differences in attenuation, delay and phase shift while it travels from the source to the receiver. This may result in either constructive or destructive interference, correspondingly amplifying or attenuating the signal power at the receiver. Strong destructive interference is frequently referred to as a **deep fade** and may result in temporary loss of communication and data due to a severe drop in the signal-to-noise ratio of the channel. Fading channel models are often used to study the effects of electromagnetic transmission of information over the air in wireless networks and broadcast communication.

4.2: SLOW FADING AND FAST FADING

The terms slow and fast fading refer to the rate at which the magnitude and phase can change when imposed by the channel on the changes in the signal. The **coherence time** can be denoted as a measure of the minimum time required for the change in magnitude of the channel to become uncorrelated from its previous value.

- **Slow fading** arises when the channel's coherence time is large as compared to the delay in the channel. In this condition, the amplitude and phase change imposed by the channel can be assumed constant over the period of usage. Slow fading is generally caused by events such as **shadowing**, when a large structure, such as a hill or large building blocks the main signal path between the transmitter and the receiver. The amplitude change due to shadowing is often depicted using a log-normal distribution with a standard deviation.
- **Fast fading** occurs when the channel's coherence time is smaller than the delay constraint of the channel. In this situation, the amplitude and phase change imposed by the channel vary considerably over the period of usage.

In a fast-fading channel, the robustness of the system to deep fade can be increased by constructively using the variations in the channel conditions through time diversity. Although a deep fade temporarily erases some of the transmitted information, the use of an error-correcting code coupled with successfully transmitted bits can allow for the erased bits to be recovered. In a slow-fading channel, we cannot use time diversity as the transmitter realizes only a single realization of the channel within its delay limit. A deep fade therefore can last the entire duration of transmission. Such a fade cannot be corrected through coding.

Doppler spread is one of the main parameters related to the coherence time of a channel. The movement of the user or the user's velocity of travelling or commutation causes a shift in the frequency of the signal transmitted along the signal path. This phenomenon is known as the Doppler shift. The difference in Doppler shifts between different signal components contributing to a single fading channel tap is known as the Doppler spread. Channels with a large Doppler spread have signals that change in an independent manner in phase over time.

In general, coherence time is inversely related to Doppler spread, typically expressed as

$$T_c = \frac{k}{D_s}$$

where T_c is the coherence time, D_s is the Doppler spread, and k is a constant taking on values in the range of 0.25 to 0.5.

4.3: FLAT FADING VS FREQUENCY-SELECTIVE FADING

When the carrier frequency of the signal is varied, the magnitude of the change in amplitude of the signal in the channel will vary. The **coherence bandwidth** determines the frequency difference after which two signals will experience uncorrelated fading.

- In **flat fading**, the channel coherence bandwidth is larger than the signal bandwidth. So, all frequency components of the signal will experience the same magnitude of fading.
- In **frequency-selective fading**, the channel coherence bandwidth is smaller than the signal bandwidth. Various frequency components of the signal therefore experience uncorrelated fading.

We can see that different components in frequency of the signal are affected in an independent manner. So, it is highly unlikely that all parts of the signal will be simultaneously affected by a deep fade. Modulation schemes such as OFDM and CDMA are used to employ frequency diversity which provides robustness against fading. OFDM divides the wideband signal into many slowly modulated narrowband subcarriers. Thus, each subcarrier is exposed to flat fading rather than frequency selective fading. This effect can be checked by means of error coding, simple equalization or adaptive bit loading. Inter-symbol interference is avoided by introducing a guard interval between the symbols.

Frequency-selective fading channels are dispersive. This is in the sense that the signal energy associated with each symbol is spread out in time. This dispersion causes transmitted symbols that are adjacent in time to interfere with each other. Thus, equalizers are often deployed in such channels to compensate for the effects of the intersymbol interference.

4.4: Fading channel in MSE-OFDM:

Let us assume the time and frequency synchronization is achieved and the maximum multi-path is not as long as CP.

If N is the size of IFFT modulator

M is the total number of OFDM symbols

N_{cp} is the duration of CP,

Then one OFDM symbol from each user is taken in one frame, each symbol having N samples and N_{cp} sample of the last OFDM symbol are used as cyclic prefix. So, one frame consists of MN+N_{cp} samples.

4.5: OVERVIEW OF TRANSMITTER:

To generate one frame of MSE-OFDM signal, one OFDM symbol from each user is taken and then a cyclic extension of N_{cp} samples of the last OFDM symbol in the same frame is inserted as cyclic prefix. The OFDM signal consists of N complex exponentials or subcarriers which have been modulated with the complex input data X(k). Each OFDM symbol is given by the N-point complex modulation sequence through IDFT.

$$x(n) = \sum_{k=0}^{N-1} X(k) \exp\left(\frac{j2\pi nk}{N}\right) \quad \text{n=0,1,2,....,N-1}$$

The l^{th} frame of MSE-OFDM signal with M symbols is generated as

$$s(l) = \sum_{k=0}^{N-1} X(l, n-1, k) \exp\left(\frac{j2\pi k\left(N - N_{cp} + n_1\right)}{N}\right) + \sum_{k=0}^{N-1} X(l, m, k) \exp\left(\frac{j2\pi k\left(n_2 - N_{cp} - mN\right)}{N}\right)$$

$$0 \le n_1 < N_{cp} \quad and \qquad N_{cp} \le n_2 \le MN + N_{cp}$$

Reviewing earlier mentioned structure of MSE-OFDM we can summarise it again as below:

Assuming, time and frequency synchronization, and that the maximum multi-path delay is not as long as CP. Binary information which is generated by the source is mapped to QPSK or QAM signal. The transmitted signal in frequency domain can be expressed as {X(k)}, its length being the number of subcarriers. After IFFT transformation, time domain signal can be expressed as {x(n)}, where

$$x(n) = IFFT\{X(k)\} = \sum_{k=0}^{N-1} X(k)\, e^{j2\pi kn/N} \quad \text{n=0,1,2,.....,N-1}$$

N is the length of one OFDM symbol.

The l^{th} frame MSE-OFDM signal with M OFDM symbols can be generated as

$$s_l = \sum_{k=0}^{N-1} X_{l,M-1}(k)\, \psi_1(n,k) + \sum_{i=0}^{M-1} \quad \sum_{k=0}^{N-1} X_{l,i}(k)\, \psi_2(n - iN - p, k)$$

Where the 2 subscripts $i\epsilon[0, M-1] and\ l\ mean\ the\ i^{th}\ ofdm\ symbol\ of\ the\ l - th\ frame.$

P is the length of the CP. $\psi_1(n,k) and\ \psi_2(n,k) are$ two rectangular signal window functions corresponding to the CP and the M information carrying OFDM symbols be defined as follows:

$$\varphi_1(n,k) = 1/\sqrt{N} e^{j2\pi k(N-P+n)/N} \quad 0 \leq n \leq P-1$$

=0 otherwise

And

$$\varphi_2(n - iN - P, k) = 1/\sqrt{N}(e^{\frac{j2\pi k(n-P-iN)}{N}}), \text{ P≤n≤MN+P-1}$$

= 0, otherwise

$$S_l = [x_{l,M-1}(N-p+1), \ldots \ldots x_{l,M-1}(N-1) \qquad x_{l,0}(0), \ldots.., x_{l,0}(N-1), x_{l,1}(0), \ldots\ldots x_{l,1}(N-1), \ldots\ldots.. x_{l,M-1}(0), \ldots. x_{l,M-1}(N-1)]T$$

While signal s_l passes through the channel, the received signal r_l is the convoluted output of the system.

$$r_l = s_l \otimes h + w$$

Where w is an AWGN noise vector with mean zero, and h is the channel impulse response.

h(n) can be expressed as:

$$h(n) = \sum_{i=0}^{r-1} h_i \exp\left(\left(\frac{j2\pi}{N}\right) f_{Di} T n \delta(\lambda - \tau_i)\right)$$

where r is the number of multipath, h_i, f_{Di} and τ_i are the i^{th} path channel impulse response, Doppler frequency shift and time delay respectively and T is the sample period.

4.6: EFFECT OF FADING CHANNEL ON MSE-OFDM SYSTEM:

Let us consider an MSE-OFDM training sequence as

b=$[b_{0,}b_{1,} \ldots \ldots . b_{N-1}]$

, N is the length of the training sequence. The training sequence b passes through the channel

h=$[h_0, h_1, \ldots \ldots \ldots h_{P-1}]$

then the received training sequence or the output sequence is $y_{1,}y_{2,\ldots\ldots} \ldots \ldots, y_{N-P+1}$. This sequence can be obtained by using the following formula:

$$y_i = \sum_{k=0}^{P-1} b_{i-k+P-1}\, h_k + w_i$$

Where w_i is AWGN with zero mean and variance δ^2.

The above equation can be re-written an

Y=Bh+W

E$[WW^H]$= δ^2I, where B is NXP matrix

$[B]_{i,j} = b_{P+(i-j)}$, P is the length of the CP and W^H denotes the hermitian response and I is the unitary matrix.

So, we can represent vector y as a zero-mean Gaussian vector with Bh and variance δ^2I.

The conditional likelihood function of the received signal can be denoted as:

$$\Lambda(y|h) = (1/(\delta_n^2\pi)^N)\exp\{-\frac{1\{[y-Bh]^H[y-Bh]\}}{\delta^2}$$

Maximum likelihood function channel estimation can be achieved by choosing h, such that it results in minimizing the exponential term in the previous equations.

The channel estimate based on maximum likelihood principle can be obtained as:

$$h' = (B^H B)^{-1} B^H y'$$

the mean square error for this channel estimation can be evaluated by:

MSE=E[Tr{$[h^{'} - h][h^{'} - h]^T$}

=δ^2 Tr{$(B^H B)^{-1}$}

From extensive study we can examine that noise in both the channel and the training sequence affect the output. So it is always advisable to look for a training sequence which gives the minimum mean square error. A good feasible training sequence should satisfy this criteria along with having flat amplitude. Its PAPr in time-domain should be very small.

4.7: REALIZATION OF FADING CHANNEL IN MSE-OFDM SYSTEM:

- The fading channel is recognised by taking the impulse response of the channel as

  H=[0.9285 0 0.3714]

- The function which can be used to describe the output of the channel is given as

  Y=filter(b,a,x) and can be expressed as

  a(1)*y(n)=b(1)*x(n) + b(2)*x(n-1) +...........

- We perform similar functions as we did for OFDM :taking a random signal and dividing it into 4 frames and the operating IFFT on them.
- The four frames are now combined to generate a total matrix to which the last 16 bits are added at front as cyclic prefix
- The output of the fading channel is obtained by performing the filter operation on the transmitted signal using the filter parameters as stated above.
- The received signal is then divided into 4 frames and then bit error rate comparison is done to obtain the SNR-BER plot.

4.8: Simulation for fading channel in MSE-OFDM system:

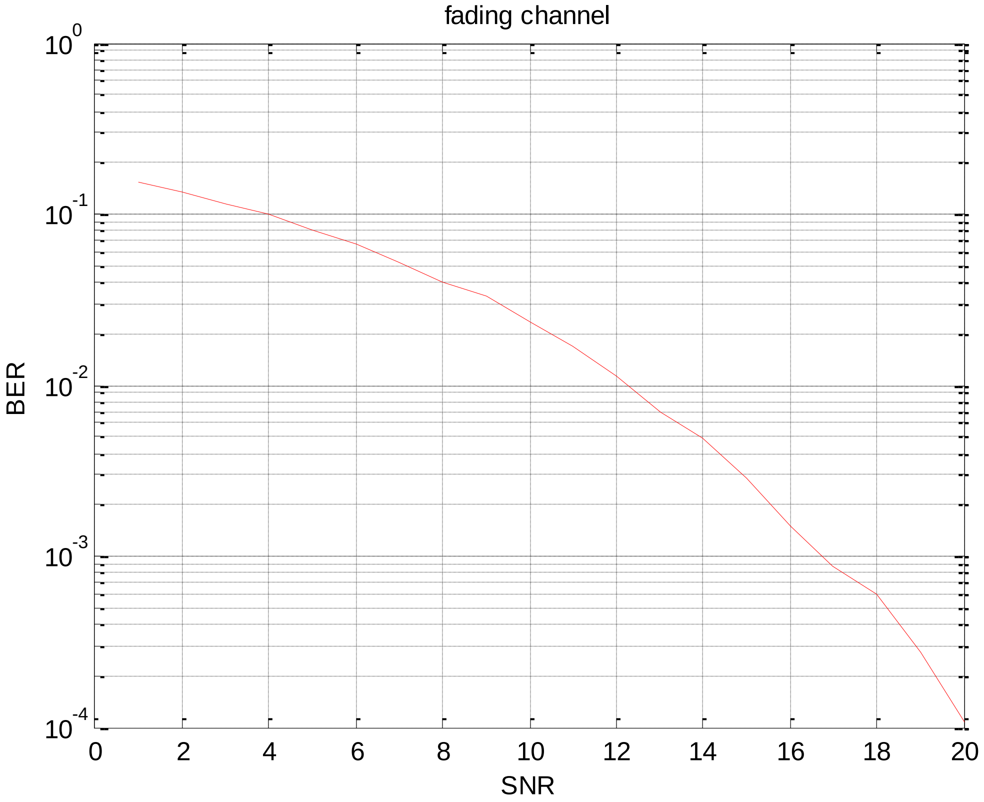


FIGURE 27: MSE-OFDM SIGNAL WITH CHANNEL FADING

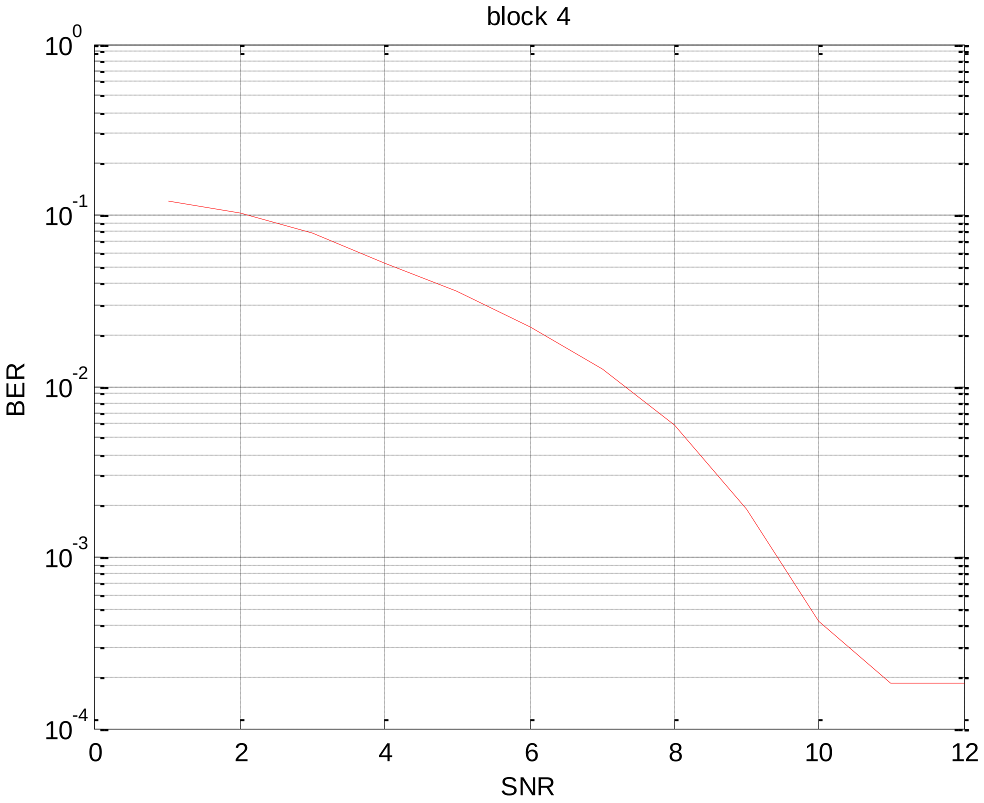


FIGURE 28 :MSE-OFDM SIGNAL WITHOUT CHANNEL FADING

We can see the difference between the MSE-OFDM signal with and without channel fading. The fading channel makes the plot more steep and less smooth than the ideal channel plot.

also

4.9: FREQUENCY OFFSET:

MSE-OFDM system renders the data in the channel stable against frequency selective fading. OFDM enables high data rate transmission over frequency selective channels at a relatively low complexity. The basic principle of the OFDM signal is to divide a higher-rate data-stream into a bigger number of lower rate streams that are transmitted simultaneously over numerous subcarriers. Although, the total channel is frequency-selective for each channel to say that is flat-fading. To account for the intersymbol interference, OFDM system relies on CP inserted at the transmitter, after IFFT modulation. The length of the CP chosen is generally larger than the channel memory. But this entire thing still doesn’t manage to negate the adverse effect of the OFDM system: its sensitivity to carrier frequency offset which is greater than that for single carrier modulation.

Carrier frequency offset results in the following destructive effects:

- Reduction of signal amplitude
- Introduction of inter-carrier interference from other carriers. This interference degrades the bit error rate performance severely on the channel.

Frequency offset typically exists in the channel due to transmitter and receiver oscillator mismatch. This problem may be further compounded by Doppler shifts in the mobile communication systems.

Of all the various techniques used in frequency offset estimation, there are few which can be used for simultaneous carrier and frequency offset estimation. Such a technique is ML estimation

4.10: MAXIMUM LIKELIHOOD ESTIMATION:

Consider a communication system with a preamble containing N training symbols: x(n)}n=0 to N-1. The training symbols are assumed to be chosen at random from a binary signaling source.

Let f_0 be the frequency offset at the receiver. In the absence of any inter-symbol interference, the received signal at the output can be given as:

$$r(n) = x(n)\exp(j2\pi f_0 n + j\phi) + w(n)$$

So the ML estimation can be given as :

$\Lambda(f_0) = -\sum_{n=0}^{N-1} \quad [|r(n) - x(n)\text{exp}\ (j2\pi f_0 n + j\phi)|]^2$

And hence we have the ML estimate f_0^{ML} as

$$f_0^{ML} = \arg min_{f_0'} min_{\phi} \sum_{n=0}^{N-1} |r(n) - x(n)\text{exp}\ (j2\pi f_0' n + j\phi)|^2$$

$= \arg max_{f_0'} max_{\phi} 2\ Re(\sum_{n=0}^{N-1} r(n)x(n)^* \exp\left(-j2\pi f_0' n - j\phi\right)$

$= \arg max_{f_0'} \quad |\sum_{n=0}^{N-1} r(n)\, x(n)^* \exp\left(-j2\pi f_0' n - j\phi\right)|$

Considering a frequency selective fading channel, the direct path gain h(0) is Ricean distributed while the multipath gain h(k) 1≤k≤L are Rayleigh distributed.

The log-likelihood function $\Lambda(f_0, h)$ is given by:

$$\Lambda(f_0, h) = -\sum_{n=0}^{N-1} |r(n) - \left(\sum_{k=0}^{L-1} x(n-k)h(k)\text{exp}\ (-j2\pi\, f_0 k)\right) \text{exp}\ (j2\pi f_0 n)|^2$$

The Ml estimate can be obtained by jointly maximizing the likelihood function over f_0 *and h*

$$f_0^{ML} = \arg max_{f_0} max_h\ \Lambda(f_0, h)$$

4.11: DRAWBACKS OF ML ESTIMATION:

ML estimation provides the most effective solution, i.e. the one having maximum likelihood. But it is very impractical. This is because of the complexity in the required design and the cumbersome process of designing. There are various methods presently under study for accurately estimating the carrier frequency offset in a channel for an MSE-OFDM system, which are an improvement over this basic ML estimation method.

CHAPTER-5

CONCLUSIONS AND DISCUSSIONS

We studied the wireless communication system with regards to conventional systems, OFDM systems and the new technology- MSE-OFDM systems. There have been various comparisons of the pros and cons of each system. The OFDM system seems to provide an ideal platform for transmitting data with the minimum error. The defects or disadvantages presented by OFDM systems can be effectively corrected by a simple change in the structure leading to MSE-OFDM systems. The MSE-OFDM system deals with every kind of situation that might arise in a communication channel. MSE-OFDM has proven to be very effective in fading channels in the presence of frequency offset also. Is the future, we can expect to see extensive use of MSE-OFDM for signal transmission in various communication channels. Thus, MSE-OFDM study can lead us to easier and cheaper yet practically applicable ways of combating all communication channel problems. So, it will be useful in future to implement MSE-OFDM in communication channels. The MSE-OFDM system appears to be robust to frequency and timing offset. So, we can utilize this feature of MSE-OFDM in dispersive environments also.

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