A NOVEL SIGNAL SCRAMBLING TECHNIQUE FOR PAPR REDUCTION IN OFDM SYSTEMS

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CERTIFICATE

This is to certify that the work titled "**A Novel Signal Scrambling Technique for PAPR Reduction in OFDM Systems**" submitted by "**Prashant Singh**" in partial fulfillment for the award of degree of M. Tech at Jaypee University of Information Technology, Waknaghat has been carried out under my supervision. This work has not been submitted partially or wholly to any other University or Institute for the award of this or any other degree or diploma.

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Name of Student Prashant Singh
Date …………………….

ABSTRACT

Orthogonal Frequency Division Multiplexing (OFDM) forms the basis of the upcoming next generation technologies so as to achieve higher data rates within a given bandwidth effectively. It is one of the most popular multi-carrier transmission schemes among the researchers around the world. One of the major issues associated with OFDM is Peak to Average Power Ratio (PAPR) which needs to be minimized to get an efficient performance. The random variation in signal amplitude of the OFDM signal leads to additional interference in the system resulting in inter modulation among the sub-carriers and hence affecting the performance of High Power Amplifier (HPA) in non-linear region. In this paper, we propose a novel signal scrambling technique for the reduction of PAPR in OFDM systems with some increased complexity as it involves the employment of Inverse Discrete Fourier Transform (IDFT) blocks which works for any modulation type and any number of subcarriers. The simulation results show performance improvement with respect to the existing signal scrambling techniques.

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CHAPTER 1

INTRODUCTION

The world of today is advancing at a very faster rate and so is the need of higher data rates is increasing day by day. Wireless Communication being an indifferent part of the new generation has also seen a number of advancements from Global System for Mobile (GSM) to Enhanced data rate for global evolution (EDGE) to Wideband Code Division Multiple Access (WCDMA) to the fourth generation technologies of the current day so as to offer high speed communication for different application likes multimedia, voice and data.

1.1 A brief introduction

Orthogonal frequency Division Multiple Access (OFDM) is a modulation technique which has gained a significant attention in the recent years after its evolution in 1970's. It is an effective technique which offers a raw data rate of 6 to 54 Mbps and has been standardized as the physical layer for the wireless networking standard HIPERLAN2 in Europe and as the IEEE 802.11a, g standard in the United States. OFDM has also been used for Digital Audio Broadcasting (DAB), Digital Video Broadcasting (DVB) and Asymmetric Digital Subscriber Line (ADSL) [1].

OFDM converts wideband frequency selective channel into several narrowband flat fading channels by dividing the available bandwidth among number of subcarriers having equal bandwidth. Wideband channels are quite vulnerable to frequency selective fading and hence demand a complex equalizer at the receiver so as to efficiently get receive the transmitted OFDM signal. The subcarriers so formed are orthogonal to each other resulting in the overlapping and hence effectively utilizing the frequency band. Higher data rate is achieved as parallel transmission of the subcarriers is done. Single carrier modulation techniques offer a higher data rate at the expense of increase in occupied bandwidth because of shortening the symbol period [2].

The technique which makes OFDM feasible is Discrete Fourier transform (DFT) which can be obtained in a faster way by employing Fast Fourier Transform (FFT) algorithms using the new Digital Signal Processors (DSP) now a days. DFT in OFDM replaces the bank of modulators and demodulators employed at the transmitter and the receiver in the multi carrier transmission thereby reducing the complexity and bulkiness of the system [3-4].

OFDM systems have a number of advantages linked to them due to which they are employed in several applications to achieve high data rates within a given bandwidth. Some of them are spectral efficiency, no Inter Symbol Interference (ISI) and low cost .

1.2 Problem statement

Despite of all advantages of the OFDM systems, it suffers from some of the drawbacks also viz. Peak to Average Power Ratio (PAPR) and Inter Carrier Interference (ICI) due to Carrier Frequency Offset (CFO). The final OFDM signal to be transmitted over a channel using a High Power Amplifier (HPA) is the superposition of all the symbols mapped onto different orthogonal subcarriers which sometimes result in a peak power when added coherently in phase and cause the problem of PAPR. PAPR causes the HPA to move in its saturation region of operation i.e non-linear region which is quite sensitive to the random variations in the signal amplitude thereby introducing inter modulation of the subcarriers and hence interference. Also, the common DACs involved in the system offer low signal to quantization noise ratio which is undesirable [25].

To deal with this problem of high PAPR in OFDM systems, large dynamic range amplifiers are employed but they have very expensive and less efficient. Some of the techniques and algorithms for PAPR reduction have been described in[19] the recent past by the researchers and turned out to be quite effective. In this dissertation, a novel signal scrambling technique for the reduction of PAPR in time domain with a little increase in the complexity of the system has been proposed.

1.3 Organization of the dissertation

The rest of the dissertation is organized as described below:

- Chapter 2 includes the history and detailed study into the OFDM systems. Its properties and principle of operation are discussed. Further in this chapter, OFDM schematic and the block diagram of a typical OFDM system is explained. In the end , we conclude by describing some applications, advantages and disadvantages of the OFDM systems.
- Chapter 3 gives an insight into the problem of PAPR. Complimentary cumulative distribution function (CCDF) as a measure of the PAPR depending upon the number of subcarriers and the threshold PAPR value is described.
- Chapter 4 gives a brief description of the existing PAPR reduction techniques with their performance and results are shown concluded with the influencing factors that affect PAPR.
- Chapter 5 details the proposed technique for reducing the PAPR in OFDM systems with the block diagram and simulation results having CCDF curve showing performance improvement as compared to the existing signal scrambling techniques.
- Chapter 6 in the end concludes the dissertation mentioning the future scope.

CHAPTER 2

ORTHOGONAL FREQUENCY DIVISION MULTIPLEXING

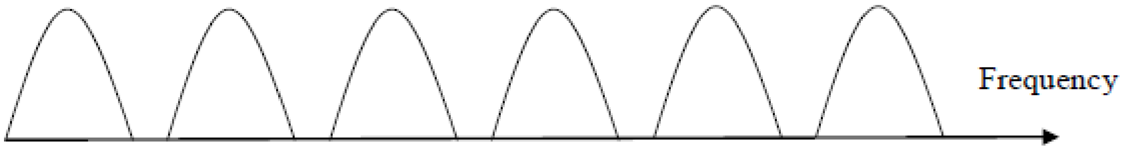
2.1 History of OFDM

In 1950’s Frequency Division Multiplexing was the backbone of multi carrier modulation where the whole bandwidth got divided into a number of carriers having different frequency separated by In 1960, Chang [5] gave a of transmitting messages simultaneously through a linear band-limited channel without suffering from Inter Carrier Interference (ICI) and Inter Symbol Interference (ISI). After a few years, Saltzberg [6] analyzed the performance of such systems and said that we need to reduce the cross talk among the adjacent channels rather than distinguishing each channel itself as imperfections due to cross talk tends to dominate in such systems. It was an important observation which was proved after a few years in case of baseband digital signal processing. The most important contribution for the discovery of OFDM technique goes to Weinstein and Ebert [4] for demonstrating the use of the discrete Fourier transform (DFT) instead of using the modulation and demodulation at the transmitter and receiver respectively. Use of the DFT resulted in increased efficiency of the modulation and demodulation processing and less complexity.

2.2 Comparison of FDM and OFDM

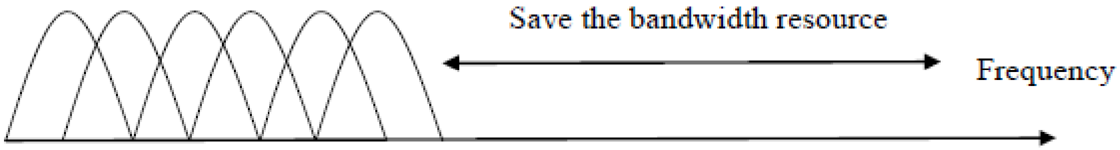
FDM divides the available bandwidth into number of carriers separated by a guard band so as to avoid inter carrier interference. A big amount of available bandwidth gets wasted in FDM because of the guard interval between the carriers as shown in Fig. 2.1(a). At the receiver, band pass filters are required to extract the original information and this also results in low frequency efficiency. Whereas the OFDM system saves the bandwidth up to a large extent as compared to the FDM modulation technique. The overlapping sub carriers are orthogonal to each other and so can be easily extracted at the receiver without suffering from the inter carrier interference. This scheme achieves orthogonality by providing a null value to one carrier at the peak of the adjacent sub carrier as shown in Fig. 2.1(b).

Each subcarrier in OFDM system signal has a very narrow bandwidth with as compared to other modulation schemes employed for same bandwidth. At the receiving end, correlation technique can be employed to separate different sub-carriers, the subcarrier corresponding to the desired symbol is coherently demodulated. Since OFDM is a parallel transmission scheme, it offers a higher data rate without experiencing the ISI [3].



Spectrum of traditional FDM modulation scheme

(a)



Spectrum of OFDM Multicarrier modulation

(b)

Fig. 2.1 Comparison of spectrum in FDM and OFDM

2.3 Single carrier modulation vs. multi carrier modulation

Let B is the two sided bandwidth of a system and we transmit one symbol every T seconds such that

$$T = 1/B \tag{2.1}$$

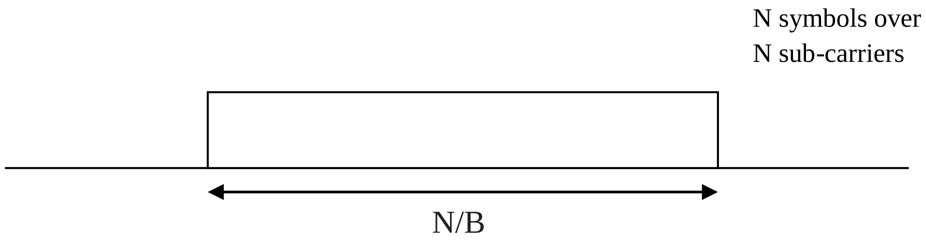
$$\text{Symbol rate } = \frac{1}{1/B} = B \tag{2.2}$$

When B= 100MHz ; Symbol rate = 100 Mbps

Considering a multicarrier modulation where we have N number of sub carriers such that N symbols are transmitted in every time period N/B

Such that , $$\text{Symbol rate} = \frac{N}{N/B} = B \tag{2.3}$$

So, we see that single carrier as well as multi carrier modulation schemes offer same symbol data rate for a given bandwidth. The question that arises is why employ this much of complexity by introducing so many number of subcarriers if we may get same symbol rate with single carrier modulation technique. Fig. 2.2 shows symbols/time



(a) Multi Carrier Modulation

(b) Single Carrier Modulation

Fig. 2.2 Number of symbols transmitted upon number of carriers for different schemes

This may be explained with the help of example shown below:

Consider a system with bandwidth of 1.024 Mhz. Then for single carrier modulation

Bandwidth(1.024MHz) >> Coherence Bandwidth(200-300 KHz)

Hence, Single carrier system experiences frequency selective fading that further results in Inter Symbol Interference (ISI).

Now, consider the multicarrier system with the same bandwidth having

No. of Sub-carriers (N) = 256

Bandwidth of each sub-carrier (B/N) = 1024/256

= 4 KHz

Bandwidth (4KHz) << Coherence Bandwidth (200-300KHz)

This shows that multicarrier systems experience frequency flat fading and hence, no ISI is there.

This is the main reason behind using the multi carrier modulation schemes for transmission instead of single carrier modulation for an available bandwidth because ISI is undesirable in the communication systems. Fig. 2.3 shows the multicarrier modulation scheme having n number of sub-carriers.

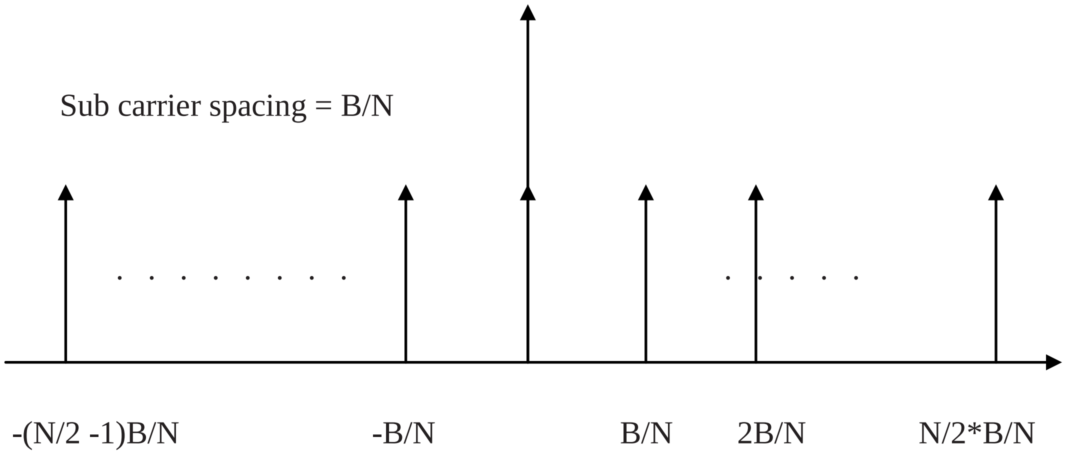


Fig. 2.3 Sub-carrier distribution in a multi carrier system

2.4 Orthogonality in multi-carrier modulation schemes

A number of non-zero subcarriers are included in an OFDM symbol period which last *T* seconds. Therefore, the frequency spectrum of the OFDM symbol can be seen to be a result of convolution between the spectrum of rectangular pulse and a group of sub-carriers at different frequencies. The duration of rectangular pulse is *T*. The spectrum of rectangular pulse is sinc($f \cdot T$).The zero points of this function only take place at integer multiples of *1/T*. For an assigned sub-carrier frequency point, only the corresponding sub-carrier can have a maximum value with all the other sub-carriers taking the value of zero at this point [1-3].

This can be signified by the Fig. 2.4 which shows the spectrum of OFDM symbols.

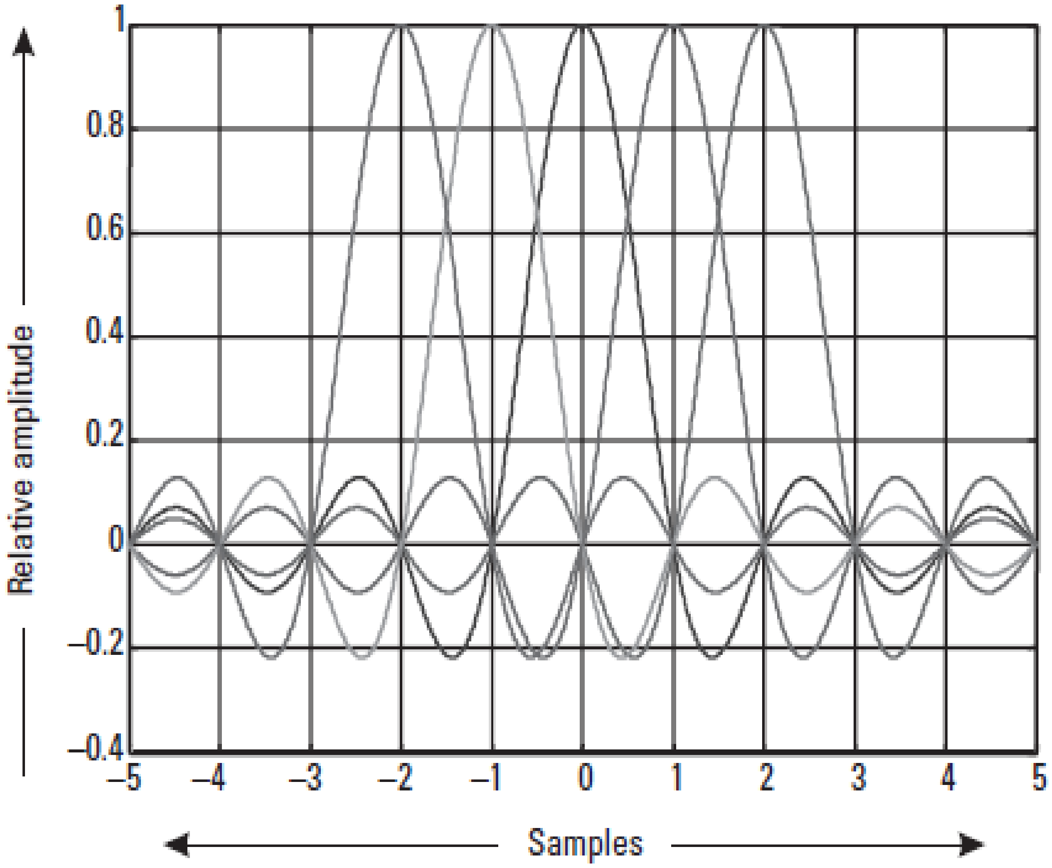


Fig. 2.4 Different overlapping sub-carriers showing Orthogonaility.

Analytically,

If

$$y(t) = s(t) = \sum_i X_i e^{j2\pi {}^{B}\!/_{N} t} \tag{2.4}$$

represents the composite transmit signal where

X_i is the *i*th symbol modulated onto the *i*th sub-carrier

B is the bandwidth of the system

N is the number of sub-carriers

When each stream is coherently demodulated with its corresponding sub-carriers i.e correlating the composite signal with the coherent sub-carrier

$$\frac{B}{N}\int_0^{{}^{N}\!/_{B}} y(t)(e^{j2\pi f_i t})^* \, dt \tag{2.5}$$

$$\frac{B}{N}\int_0^{{}^{N}\!/_{B}} (\sum_i X_i e^{j2\pi i {}^{B}\!/_{N} t}) e^{-j2\pi f_i t} \, dt \tag{2.6}$$

$$\frac{B}{N}\sum_i \int_0^{{}^{N}\!/_{B}} X_i e^{j2\pi (i-l) {}^{B}\!/_{N} t} \, dt \tag{2.7}$$

Let $(i-l) = k$

All the other frequencies are some $(i\text{-}l)^{\text{th}}$ multiple of the fundamental frequency(according to fourier series)

$$\int_0^{{}^{N}\!/_{B}} e^{j2\pi (i-l) {}^{B}\!/_{N} t} \, dt = \left\{ \begin{matrix} 0; i \neq l \\ {}^{N}\!/_{B}; i = l \end{matrix} \right\} \tag{2.8}$$

So, all the subcarriers except l^{th} sub-carrier are orthogonal to the l^{th} sub-carrier.

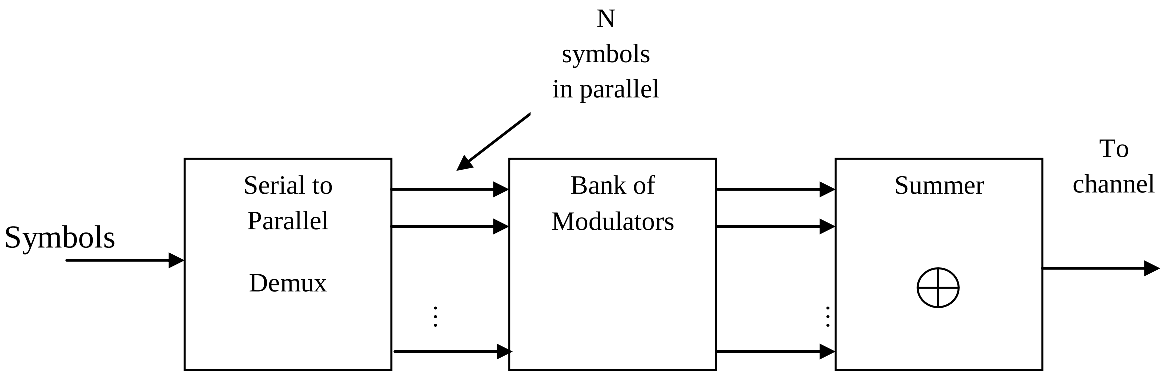
Hence, we coherently demodulate with l^{th} sub-carrier

$$\frac{B}{N}X_l*\frac{N}{B}+0=X_l \tag{2.9}$$

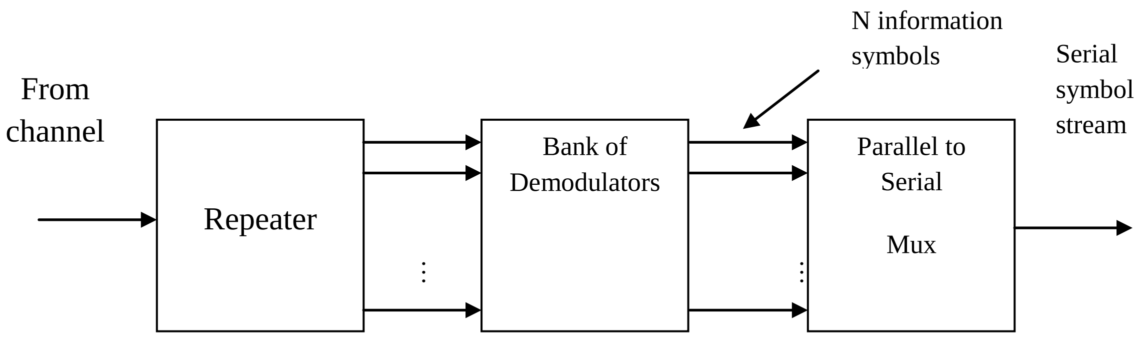
X_l in (2.9) represents the information symbol transmitted on the l_{th} sub-carrier [3].

2.5 OFDM

(2.4-2.9) represent the formulation of a multicarrier signal modulation in which the i^{th} symbol is modulated onto the i^{th} sub-carrier and the symbol is coherently demodulated with the corresponding sub-carrier at the receiver side to get an efficient reception. Fig. 2.5 shows the transmitter and receiver schematic for the same.



(a) Transmitter end



(b) Receiver end

Fig. 2.5 Schematic of Multi Carrier Modulation

OFDM differ from that of the multi carrier modulation scheme as it employs IFFT and FFT block instead of the bank of modulators and demodulators employed in multi carrier modulation schemes making it quite unfeasible and bulky as the no. of modulators or demodulators increase with the number of sub-carriers used in the system [1-3].

The composite signal for the multi carrier modulation may be given by (2.4)

We will do the sampling and consider the u^{th} sample. So,

$$t = uT_s = \frac{u}{B} \tag{2.10}$$

Where T_s represents the sampling period

$$S(uT_s) = x(u) = \sum_i X_i e^{j2\pi i \frac{B}{N}\frac{u}{B}} \tag{2.11}$$

$$= \sum_i X_i e^{j2\pi i \frac{u}{N}} \tag{2.12}$$

(2.12) represents the DFT of the u^{th} information symbol.

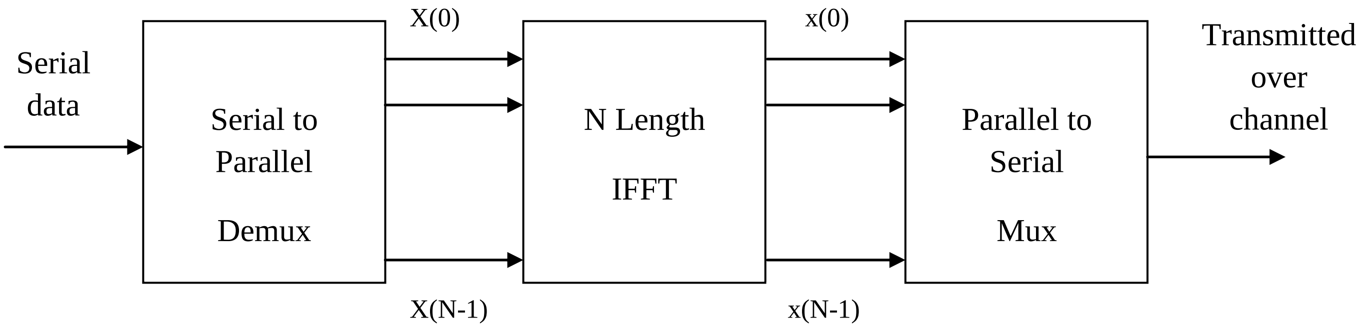
So, we may infer from this that we don’t need a bank of modulators and demodulators. All we need to do is consider the sampled signal which represents the DFT of the information signal. The DFT of information symbols gives us the samples that are a multi carrier transmitted signal. This scheme of generating the composite transmit signal has much lower implementation complexity compared to using the ban of modulators. Fig. 2.6 shows the schematic of a traditional OFDM system.

In this schematic, a high rate serial data stream is fed as input into the serial to parallel converter which converts it into N parallel data streams. Parallel data streams are then mapped onto the orthogonal sub-carriers by taking N point IDFT which is done here using the IFFT algorithm because it is quite fast and reliable. OFDM signal after the IFFT block processing is to be converted into a serial data stream to be transmitted over the channel.

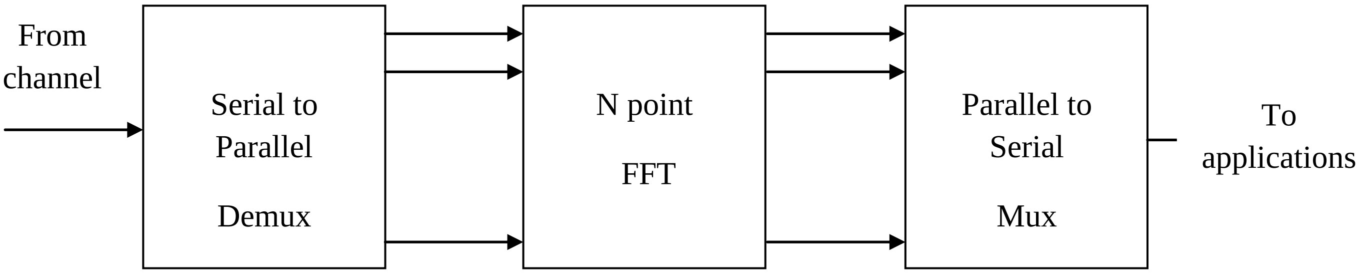
At the receiver, serial to parallel conversion of the received OFDM signal is done so as to detect each symbol effectively over each sub-carrier. Since, the sub-carriers are orthogonal to each other, coherent demodulation of the parallel data is performed using the FFT block. Parallel data is then converted into serial data and sent to the applications.

The serial data at the output of the receiver can be represented as $X(0)\ X(1)\ X(2) \ldots\ldots\ldots X(N-1)$

Where $X(i)$ denotes the i^{th} symbol modulated onto the i^{th} sub-carrier.



(a) Transmitter end



(b) Receiver end

Fig. 2.6 Schematic of OFDM

One OFDM symbol comprises of N samples transmitted successively i.e $x(0)\ x(1)\ x(2) \ldots\ldots x(N-1)$ which corresponds to IFFT of $X(0)\ X(1)\ X(2) \ldots\ldots\ldots X(N-1)$.

2.5.1 Cyclic prefix

Consider a frequency selective channel such that

$$\overline{x(0)}, \overline{x(1)}, \overline{x(2)}, ... \overline{x(N-1)}, x(0), x(1), x(2) .... x(N-1)$$

Where $\overline{x(i)}$ represents previous OFDM symbol and $x(i)$ represents current OFDM symbol.

Frequency selective channels can be modelled as

$$h(0)h(1)h(2)............h(L-1) \qquad (2.13)$$

This can be called as a multi tap channel having L taps.

First symbol corresponding to current OFDM symbol block is

$$y(0) = h(0)x(0) + h(1)\overline{x(N-1)} + h(2)\overline{x(N-2)} + ... + h(L-1)\overline{x(N-L+1)} \qquad (2.14)$$

where all the terms in (2.14) except *h(0)x(0)* correspond to previous OFDM symbol. And similarily

$$y(1) = h(0)x(1) + h(1)x(0) + h(2)\overline{x(N-1)} + h(3)\overline{x(N-2)} + ... + h(L-1)\overline{x(N-L+2)}$$
(2.15)

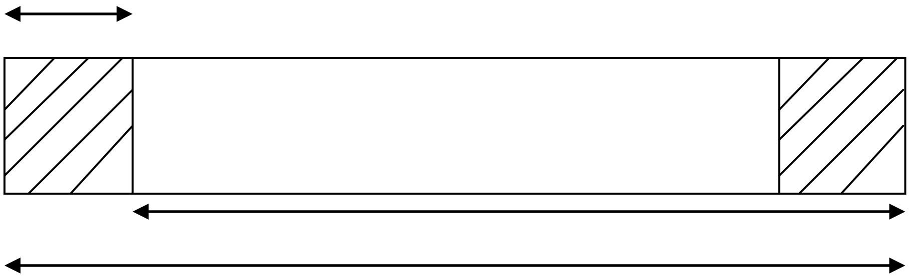
So, we can say that the initial samples are being subject to ISI (from (2.13 and 2.14)). ISI is there in the initial part of the large symbol as each symbol is big consisting of N samples.

To combat this ISI in the initial part of the OFDM symbol we will take a small portion of the OFDM symbol and prefix it at the starting of the symbol.

$$x(n-L+1)................x(N-2)x(N-1)x(0)x(1)............x(N-1)$$
(2.16)

Fig. 2.7 shows the addition of CP at the starting of symbol increasing symbol period.

CP copied from the end of the symbol



Actual Symbol

Extended Symbol with CP added

Fig. 2.7 Cyclic Prefix in an OFDM symbol

As a result of adding cyclic prefix, we will get

$$y(0) = h(0)x(0) + h(1)x(N-1) + h(2)x(N-2) + ... + h(L-1)x(N-L+1) \qquad (2.17)$$

In this case, all samples belong to current OFDM symbols.

Similarly for $y(1)$

$$y(1) = h(0)x(1) + h(1)x(0) + h(2)x(N-1) + ... + h(L-1)x(N-L+2) \qquad (2.18)$$

$$y(N-1) = h(0)x(N-1) + h(1)x(N-2) + h(2)x(N-3) + ... + h(L-1)x(N-L) \; (2.19)$$

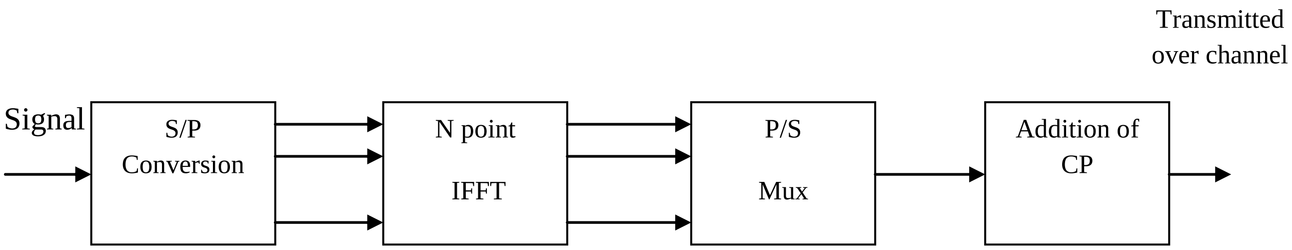
(2.17,2.18,2.19) can be viewed as the circular convolution.

So, the received samples may be represented as

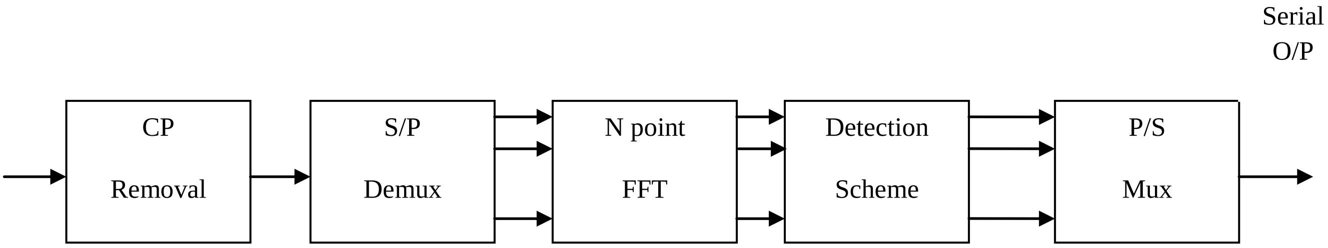
$$\left[y(0)y(1)................y(N-1)\right] = \left[h(0)h(1)...............h(L-1)\right] * \left[x(0)x(1)...............x(N-1)\right]$$
(2.20)

Where y(i) represents the received samples h(i) represents multi tap channel and x(i) represents the N samples of the current OFDM symbol generated after the IFFT block.

Fig. 2.8 shows the block diagram of an OFDM system with added CP.



(a) Transmitter end



(b) Receiver end

Fig. 2.8 Schematic of OFDM with Cyclic Prefix

Hence, the received samples can be modelled as

$$y = h * x \tag{2.21}$$

This is possible only because of addition of CYCLIC PREFIX.

Taking the DFT of (2.20), we get

$$Y(k) = H(k)X(k) \tag{2.22}$$

Where k corresponds to the k^{th} sub-carrier

In the end, we may conclude that ISI has been removed from the k^{th} sub-carrier using CYCLIC PREFIX [1-3].

Properties of CP:

1. Minimum length of CP required is (L-1) i.e $\text{CP} \geq L$ to avoid inter OFDM symbol interference.
2. CP should be greater than the Delay Spread of channel.

3. Addition of long CP results in loss of system throughput
4. Loss in efficiency = CP/ Total OFDM symbol length

$$= (L-1)/(N+L-1)$$

$$= \lim_{n\to\infty} \frac{L-1}{N+L-1}$$

$$= 0$$

2.6 OFDM applications

The previous section detailed OFDM and Cyclic Prefix in OFDM, it should be noted that depending on the application and medium different design issues take precedence. This section identifies some of the current and future applications of OFDM. OFDM takes its place in the next generation of communication systems because of its high data rates and low complexity.

2.6.1 COFDM

Coded OFDM (COFDM) is a practical form of OFDM where redundant bits are inserted into the bit stream at the transmitter. These specially chosen bits allow powerful error correction codes in the receiver to reduce the BER. The more bits used for error correction the better the error correction properties, however the useful data rate is decreased. Types of error correction codes used for example DAB-OFDM are Trellis Coded Modulation (TCM) combined with frequency and time interleaving. In practice all the following technologies use some form of COFDM.

2.6.2 Digital video broadcasting (DVB)

Digital Video Broadcasting (DVB) [7-8] is also using OFDM as the carrier modulation scheme. DVB promises to deliver full multimedia in digital form in a broadcast format. DVB adapts the baseband TV signal from the output of the MPEG- 2 [9] transport multiplexer to the terrestrial channel characteristics. Maximum spectral efficiency within the VHF and UHF bands is achieved by utilizing Single Frequency Network (SFN) operation. There are two modes defined in DVB: **1/** 2K mode, and **2/** 8K mode.

The 2K mode is used for single transmitters and small SFN’s where the distance for transmission is limited. The 8K mode encompasses the 2K mode as well as larger SFN’s. One of the many advantages of OFDM is that different mapping types can be used on different sub-carriers, this aspect is taken advantage of in DVB so that the data rate on a channel mirrors its quality. Table 2.1 shows the system parameters for DVB in 2K mode [8]. Fig. 2.9 shows the block diagram of a DVB-T system.

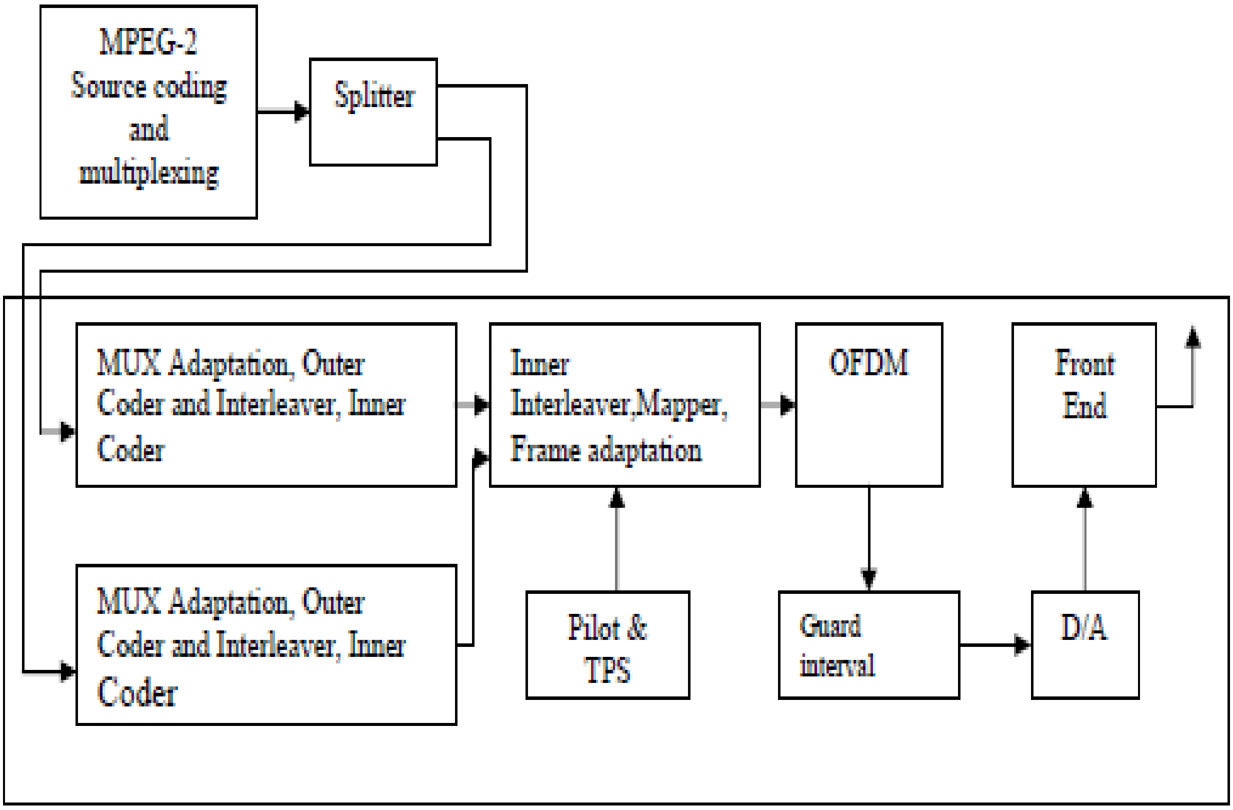


Fig. 2.9 Terrestrial Digital Video Broadcasting

Table 2.1 DVB system parameters

PARAMETERS	VALUE
Information data rate	5-30 Mbps
Modulation	QPSK, 16 QAM, 64 QAM
FEC code	Reed Solomon outer code Convolutional inner code
Code Rates	½ , 2/3, ¾
Total number of subcarriers	1705
OFDM symbol duration	303microseconds
Guard Interval	75.9 microseconds
Signal Bandwidth	5.62MHz

2.6.3 Digital audio broadcasting (DAB)

Digital Audio Broadcasting (DAB) using OFDM has been standardized in Europe [10] and is the next step in evolution beyond FM radio broadcasting providing interference free transmission. The standard for DAB is known as Eureka-147 [11] and is a multi-service digital broadcasting method transmitting at around 1.5Mbps in the 1.536MHz band. In DAB between 192 and 1536 carriers are used with Differential Quadrature Phase Shift Keying (DQPSK), which allows the system to avoid channel estimation techniques. The very long symbol time means that large echo's can be tolerated and that the redundancy due to the CP is not that great. Large echoes are expected as the broadcasting is over large distances so that long delay paths will be present. The PAPR is a problem but as DAB only uses DQPSK modulation it is more impervious to noise generated through saturation of the amplifier. The DAB data payload contains audio, data associated with audio, and other optional data services. Table 2.2 displays system parameters for DAB.

Table 2.2 DAB Parameters

Parameters	Mode		
	I	II	III
Application	SFN	Terrestrial	Satellite
Modulation	DQPSK	DQPSK	DQPSK
Total no. of sub-carriers	1536	384	192
OFDM symbol duration	1246microsecs	312microsecs	156microsecs
Guard Interval	246microsecs	62microsecs	31microsecs
Frequency range	≤375MHz	≤1.5GHz	≤3GHz

2.6.4 HiperLan2/802.11a

Wireless networking standards such as HIPERLAN2 and 802.11a use OFDM as the physical layer modulation scheme and operate in the unlicensed 5GHz frequency band. Hiperlan2 promises to deliver raw data rates of up to 56Mbps which puts them in the ballpark of wired LANs which have data rates of up to 100Mbps. Wireless LANs applications are for home and office networking over short distances (<50 metres) as well as community spaces such as Starbucks which operates the 802.11b wireless standard free of charge for customers and provides data rates up to 11Mbps [12]. Tables 2.3 and 2.4 list Hiperlan2/802.11a specifications and data rates respectively.

Table 2.3 HIPERLAN2 Parameters

Parameters	Values
Sampling rate	20MHz
Useful symbol part duration	64 x T 3.2 microseconds
CP duration	16 x T 0.8 microseconds
Symbol interval	80 x T

	4.0 microseconds
Number of data sub-carriers	48
Total no. of subcarriers	52
Spacing between carriers	0.3125MHz

Table 2.4 Data rates for HIPERLAN2

Modulation	**Coding rate R**	**Nominal bit rate(Mbps)**
BPSK	½	6
BPSK	¾	9
QPSK	½	12
QPSK	¾	18
16 QAM	9/16	27
16 QAM	¾	36
64 QAM	¾	54

2.6.5 Asynchronous Digital Subscriber Line (ADSL)

Asynchronous Digital Subscriber Lines (ADSL) utilizes OFDM over wired links [13]. Data rates for ADSL standard [14] are 1.54Mbps to 6.1Mbps in the downlink and 9.6 to 192Kbps in the uplink over several kilometers of ordinary twisted pair telephone line, while still supporting the standard telephone. The unbalanced data rates make ADSL particularly applicable to internet type applications where the downlink rate is typically much larger than the uplink rate. Stationary channels like wireless links do not change over time, therefore a technique called bit loading is used. Bit loading assigns a mapping type to sub-carriers depending on its quality, using the available bandwidth efficiently. Bit loading used in conjunction with OFDM over wired links is usually called Discrete Multi Tone (DMT).

2.6.6 MIMO-OFDM

Multiple In Multiple Out (MIMO) [15] OFDM combines OFDM with multiple antennas at the transmitter and receiver. This structure allows greater diversity when techniques such as Singular Value Decomposition (SVD) are used. This process, called spatial multiplexing, proportionally boosts the data-transmission speed by a factor equal to the number of transmitting antennas. In addition, since all data is transmitted both in the same frequency band and with separate spatial signatures, this technique utilizes spectrum very efficiently.

2.7 Advantages and disadvantages of OFDM

Some of the advantages and disadvantages linked with OFDM are discussed here :

2.7.1 Advantages of OFDM

2.7.1.1 Combating ISI and ICI

When signal passes through a time-dispersive channel, the orthogonality of the signal can be jeopardized. CP helps to maintain orthogonality between the sub-carriers. Before CP was invented, guard interval was proposed as the solution. Guard interval was defined by an empty space between two OFDM symbols, which serves as a buffer for the multipath reflection. The interval must be chosen as larger than the expected maximum delay spread, such that multipath reflection from one symbol would not interfere with another. In practice, the empty guard time introduces ICI, which is crosstalk between different subcarriers, meaning they are no longer orthogonal to each other [2]. A better solution was later found, that is, cyclic extension of OFDM symbol or CP, which is a copy of the last part of OFDM symbol, appended in front of the transmitted OFDM symbol [16].

CP still occupies the same time interval as guard period, but it ensures that the delayed replicas of the OFDM symbols will always have a complete symbol within the FFT interval (often referred as FFT window); this makes the transmitted signal periodic. This periodicity plays a very significant role as this helps maintaining the orthogonality.

The concept of being able to do this, and what it means, comes from the nature of IFFT/FFT process. When the IFFT is taken for a symbol period during OFDM modulation, the resulting time sample process is technically periodic. In a Fourier transform, all the resultant components of the original signal are orthogonal to each other. So, in short, by providing periodicity to the OFDM source signal, CP makes sure that subsequent subcarriers are orthogonal to each other. At the receiver side, CP is removed before any processing starts. As long as the length of CP interval is larger than maximum expected delay spread $\tau_{\max}$, all reflections of previous symbols are removed and orthogonality is restored. The orthogonality is lost when the delay spread is larger than the length of CP interval. Inserting CP has its own cost, indeed we loose a part of signal energy since it carries no information. The loss is measured as

$$SNR_{loss\_CP} = -10\log_{10}\left(1 - \frac{T_{cp}}{T_{sym}}\right) \qquad (2.23)$$

Here, *TCP* is the interval length of CP and T_{sym} is the OFDM symbol duration. It is understood that although we loose part of signal energy, the fact that we get zero ICI and ISI situation pay off the loss. To conclude, CP gives twofold advantages, first occupying the guard interval, it removes the effect of ISI and by maintaining orthogonality it completely removes the ICI. The cost in terms of signal energy loss is not too significant.

2.7.1.2 Spectral efficiency

When orthogonality is maintained between different sub channels during transmission, then it is possible to separate the signals very easily at the receiver side. Classical FDM ensures this by inserting guard bands between sub channels. These guard bands keep the sub channels far enough so that separation of different sub channels is possible. Naturally inserting guard bands results in inefficient use of spectral resources.

Orthogonality makes it possible in OFDM to arrange the subcarriers in such a way that the sidebands of the individual carriers overlap and still the signals are received at the receiver without being interfered by ICI. The receiver acts as a bank of demodulators, translating each subcarrier down to DC, with the resulting signal integrated over a symbol period to recover raw data. If the other subcarriers are all down-converted to the frequencies that, in the time domain, have a whole number of cycles in a symbol period T_{sym}, then the integration process results in zero contribution from all other carriers. Thus, the subcarriers are linearly independent (i.e., orthogonal) if the carrier spacing is a multiple of $1 / T_{sym}$ [17].

2.7.1.3 Other benefits of OFDM

- OFDM transmitters are low cost because it can implement the bits on orthogonal sub-carriers using the IFFT [18].
- OFDM receiver collects signal energy in frequency domain, protects energy loss.
- OFDM is more resistant to frequency-selective fading than single-carrier systems.
- The orthogonality preservation procedures in OFDM are much simpler compared toother techniques even in very severe multipath conditions.
- OFDM can be used for high-speed multimedia applications with low service cost.
- OFDM can support dynamic packet access.

2.7.2 Disadvantages of OFDM

2.7.2.1 Synchronization

OFDM is highly sensitive to time and frequency synchronization errors, and especially at frequency synchronization errors, everything can go wrong [19]. Indeed, demodulation of an OFDM signal with an offset in the frequency can lead to a high bit error rate. The source of frequency synchronization errors is two: first one being the difference between local oscillator frequencies in transmitter and receiver, second being relative motion between the transmitter and receiver that gives Doppler spread. Local oscillator frequencies at both transmitter and receiver must match as closely as they can. For higher number of sub channels, the matching should be even better. Motion of transmitter and receiver causes the other frequency error. So, OFDM may show significant performance degradation at high-speed moving vehicles [20]. To optimize the performance of an OFDM link, accurate synchronization is of prime importance. Synchronization needs to be done in three factors: symbol, carrier frequency, and sampling frequency synchronization. A good description of synchronization procedures is given in [21].

2.7.2.2 Peak to average power ratio (PAPR)

Peak-to-average power ratio (PAPR) is proportional to the number of subcarriers used for OFDM systems. An OFDM system with large number of subcarriers will thus have a very large PAPR when the subcarriers add up coherently. Large PAPR of a system makes the implementation of digital-to-analog converter (DAC) and analog-to-digital converter (ADC) extremely difficult. The design of RF amplifier also becomes increasingly difficult as the PAPR increases.

The clipping and windowing technique reduces PAPR by non-linear distortion of the OFDM signal. It thus introduces self-interference as the maximum amplitude level is limited to a fixed level. It also increases the out-of-band radiation, but this is the simplest method to reduce the PAPR. To reduce the error rate, additional forward error correcting codes can be used in conjunction with the clipping and windowing method.

2.7.2.3 Co- channel interference in cellular OFDM

In cellular communication systems, CCI is combated by combining adaptive antenna techniques, such as sectorization, directive antenna, antenna arrays. Using OFDM in cellular systems will give rise to CCI. Similarly with the traditional techniques, with the aid of beam steering, it is possible to focus the base station’s antenna beam on the served user, while attenuating the co-channel interferers.

2.7.2.4 Inter carrier interference (ICI)

OFDM divides the available bandwidth amongst a set of orthogonal overlapping sub-carriers . Hence, presence of a carrier offset can introduce severe distortion in an

OFDM system as it results in the loss of orthogonality amongst sub-carriers. With the loss of orthogonality , OFDM would loose its principle which helps it in achieving high data rates because of parallel data streams being transmitted onto different sub-carriers. Fig. 2.10 shows the carrier frequency offset among the sub-carriers which further results in ICI.

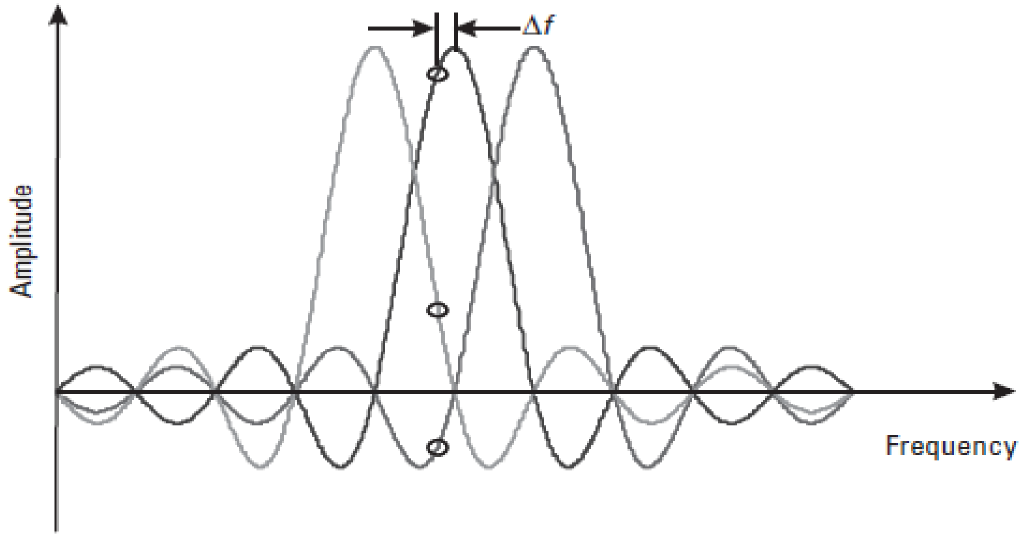


Fig. 2.10 Loss of orthogonality due to carrier frequency offset

2.8 OFDM design issues

System design always needs a complete and comprehensive understanding and consideration of critical parameters. OFDM system design is of no exception, as it deals with some critical, and often conflicting parameters. Basic OFDM philosophy is to decrease data rate at the subcarriers, so that the symbol duration increases, thus the multipaths are effectively removed. This poses a challenging problem, as higher value for CP interval will give better result, but it will increase the loss of energy due to insertion of CP. Thus, a trade-off must be obtained for a reasonable design.

2.8.1 OFDM System design requirements

There are four main system requirements on which OFDM system design depends:

- **Available bandwidth**: Bandwidth is always the scarce resource, so the mother of the system design should be the available bandwidth for operation. The amount of bandwidth will play a significant role in determining number of subcarriers, because with a large bandwidth, we can easily fit in a large number of subcarriers with reasonable guard space.
- **Bit rate:** The overall system should be able to support the data rate required by the users. For example, to support broadband wireless multimedia communication, the system should operate at more than 10 Mbps at least.
- **Delay spread:** Tolerable delay spread will depend on the user environment. Measurements show that indoor environment experiences maximum delay spread of few hundreds of ns at most, whereas outdoor environment can experience up to 10 ms. So the length of CP should be determined according to the tolerable delay spread.
- **Doppler shifts:** Users on a high-speed vehicle will experience higher Doppler shift, whereas pedestrians will experience smaller Doppler shift. These considerations must be taken into account.

2.8.2 OFDM System design parameters

The design parameters are derived according to the system requirements. Following are the design parameters for an OFDM system [22]:

- **Number of sub-carriers:** Increasing number of subcarriers will reduce the data rate via each subcarrier, which will make sure that the relative amount of dispersion in time caused by multipath delay will be decreased . But when there are large numbers of subcarriers, the synchronization at the receiver side will be extremely difficult.
- **Guard time and symbol duration:** A good ratio between the CP interval and symbol duration should be found, so that all multi-paths are resolved and not significant amount of energy is lost due to CP. As a thumb rule, the CP interval must be two to four times larger than the root mean square (RMS) delay spread. Symbol duration should be much larger than the guard time to minimize the loss

of SNR, but within reasonable amount. It cannot be arbitrarily large, because larger symbol time means that more subcarriers can fit within the symbol time. More subcarriers increase the signal processing load at both the transmitter and receiver, increasing the cost and complexity of the resulting device [23].

- **Sub-carrier spacing:** Subcarrier spacing must be kept at a level so that synchronization is achievable. This parameter will largely depend on available bandwidth and the required number of sub channels**.**
- **Modulation type:** This is trivial, because different modulation schemes will give different performances. Adaptive modulation and bit loading may be needed depending on the performance requirement. It is interesting to note that the performance of OFDM systems with differential modulation compares quite well with systems using non-differential and coherent demodulation [24]. Furthermore, the computation complexity in the demodulation process is quite low for differential modulations.

2.9 Conclusion

In this chapter, we discussed about the history of OFDM scheme, its important properties, we also discussed about how OFDM is different from other schemes like FDM and multi carrier modulation. We saw the schematic of OFDM systems with and without the addition of CP, its effects. Some applications of OFDM are then discussed in brief with some tables of parameters along with their values are also mentioned. In the end we concluded with some advantages and disadvantages of the OFDM systems.

CHAPTER 3

PEAK TO AVERAGE POWER RATIO (PAPR)

The peak to average power ratio (PAPR) is a very important attribute for any communication system. Peak power may be defined as the power of a sine wave having amplitude equal to the maximum envelope value of the signal [2]. A low PAPR allows the High Power Amplifier (HPA) to operate efficiently in its linear region of operation, whereas a high PAPR forces the transmit power amplifier to cross the dynamic range and jump in to the saturation or non-linear region of operation which is quite sensitive to random signal variations.

3.1 Definition of PAPR

3.1.1 Baseband PAPR

Baseband PAPR can be characterized into 2 categories as follows:

3.1.1.1 Continuous PAPR

In general, the PAPR of OFDM signals is defined as the ratio between the maximum instantaneous power and its average power

$$PAPR\left[x(t)\right] = \frac{\max\limits_{0 \le t \le NT}\left[x(t)^2\right]}{P_{av}} \tag{3.1}$$

where P_{av} is the average power of $x(t)$ and it can be computed in the frequency domain because Inverse Fast Fourier Transform (IFFT) is a (scaled) unitary transformation.

3.1.1.2 Discrete PAPR

The PAPR of the discrete time sequences typically determines the complexity of the digital circuitry in terms of the number of bits necessary to achieve a desired signal to quantization noise for both the digital operation and the DAC. However, we are often more concerned with reducing the PAPR of the continuous-time signals in practice, since the cost and power dissipation of the analog components often dominate.

To better approximate the PAPR of continuous-time OFDM signals, the OFDM signals samples are obtained by *L* times oversampling. *L*-times oversampled time-domain samples are *LN*-point IFFT of the data block with *(L-1)N* zero-padding. Therefore, the oversampled IFFT output can be expressed as

$$x[n] = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} X_k e^{j\frac{2\pi nk}{LN}} \quad , \; 0 \le n \le LN-1 \qquad (3.2)$$

Fig. 3.1 shows the distribution of the PAPR of the OFDM signals with *N*=256 and *L*=1,2,4,16. As shown in Fig. 3.1 largest PAPR increase happens from *L*=1 to *L*=2. However, the PAPR does not increase significantly after *L*=4. So, we may conclude that $L \ge 4$ is sufficient to get accurate PAPR results [13].

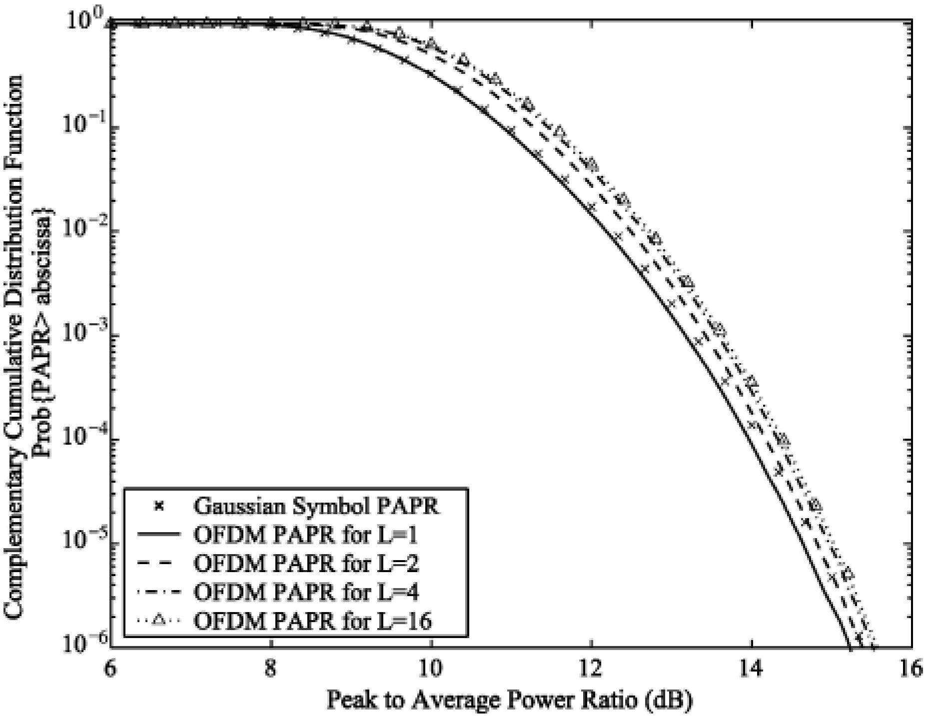


Fig. 3.1 Distribution of PAPR of OFDM signal samples oversampled by different L.

3.1.2 Passband PAPR

If N is large, an OFDM system usually does not employ pulse shaping, since the power spectral density of the band-limited OFDM signal is approximately rectangular. Thus, the amplitude of OFDM RF signals can be expressed as

$$\begin{aligned} x_{PB}(t) &= \Re\{x(t)e^{j2\pi f_c t}\} \\ &= \Re\{x(t)\cos(2\pi f_c t)\} - \Im\{x(t)\sin(2\pi f_c t)\} \qquad (3.3) \end{aligned}$$

Where f_c is the carrier frequency and $f_c >> \Delta f$ where Δf is the subcarrier spacing of the signal . Therefore, the peak of RF signals is equivalent to that of the complex baseband signals.

The average power of the pass band signal is

$$\begin{aligned} E\left[x_{PB}(t)^2\right] &= E\left[\Re\{x(t)e^{j2\pi f_c t}\}^2\right] \\ &= E\left[\{x_I(t)\}\cos(2\pi f_c t) - \{x_Q(t)\}\sin(2\pi f_c t)\right]^2 \\ &= \frac{1}{2} E\left[x(t)^2\right] \qquad (3.4) \end{aligned}$$

Therefore, the pass band PAPR is approximately twice the baseband PAPR, i. E

$$PAPR\{x_{PB}(t)\} \approx 2PAPR\{x(t)\} \qquad (3.5)$$

We are concerned with the PAPR of the baseband OFDM signal.

3.2 Complimentary cumulative distribution function (CCDF)

The cumulative distribution function (CDF) of the PAPR is one of the most frequently used performance measures for PAPR reduction techniques. In the literature, the complementary CDF (CCDF) is commonly used instead of the CDF itself. The CCDF of the PAPR denotes the probability that the PAPR of a data block exceeds a given threshold. In [22] a simple approximate expression is derived for the CCDF of the

PAPR of a multicarrier signal with Nyquist rate sampling. From the central limit theorem, the real and imaginary parts of the time domain signal samples follow Gaussian distributions, each with a mean of zero and a variance of 0.5 for a multicarrier signal with a large number of subcarriers. Hence, the amplitude of a multicarrier signal has a Rayleigh distribution, while the power distribution becomes a central chi-square distribution with two degrees of freedom. The CDF of the amplitude of a signal sample is given by

$$F(z) = 1 - \exp(z) \tag{3.10}$$

What we want to derive is the CCDF of the PAPR of a data block. The CCDF of the PAPR of a data block with Nyquist rate sampling is derived as

$$\begin{aligned} \Pr(PAPR > z) &= 1 - \Pr(PAPR \le z) \\ &= 1 - \left(1 - \exp(-z)\right)^N \end{aligned} \tag{3.11}$$

This expression assumes that the N time domain signal samples are mutually independent and uncorrelated. This is not true, however, when oversampling is applied. Also, this expression is not accurate for a small number of subcarriers since a Gaussian assumption does not hold in this case. Therefore, there have been many attempts to derive more accurate distribution of PAPR.

The CCDFs are usually compared in a graph such as Fig. 3.2, which shows the CCDFs of the PAPR of an OFDM signal with 256 and 1024 subcarriers (N = 256,1024) for quaternary phase shift keying (QPSK) modulation and oversampling factor 4 (L = 4). The CCDFs of the PAPR after applying one of the PAPR reduction techniques (i.e., the selected mapping, SLM, technique with 16 candidates) are also shown in Fig. 3.2.

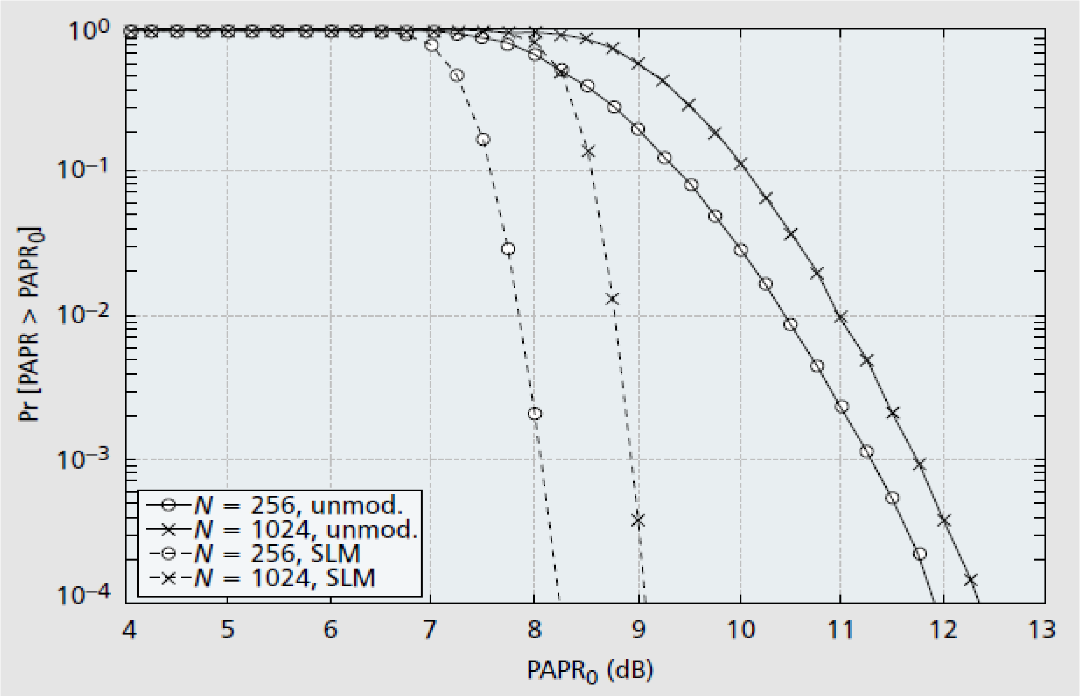


Fig. 3.2 CCDFs of PAPR of an OFDM signal with 256 and 1024 subcarriers for QPSK modulation and oversampling factor 4 (L = 4).

3.3 Distribution of PAPR in OFDM systems

It is known that the CCDF of PAPR can be used to estimate the bounds for the minimum number of redundancy bits required to identify the PAPR sequences and evaluate the performance of any PAPR reduction scheme. We can also determine a proper output back-off of HPA to minimize the total degradation according to CCDF. Moreover, we can directly apply distribution of PAPR to calculate the BER and estimate achievable information rates. In practice, we usually adjust these design parameters jointly according to simulation results. Therefore, if we can use an analytical expression to accurately calculate the PAPR distribution for OFDM systems, it can greatly simplify the system design process. Therefore, it is of great importance to accurately identify PAPR distribution in OFDM systems. Recently, some upper and lower bounds of the PAPR, which is based on the Rayleigh distribution and Nyquist sampling rate, have been derived. In the OFDM system with M-Phase-Shift- Keying (MPSK) modulation, signal constellation has the same amplitude level, and thus the power of each subcarrier is constant. Therefore, the PAPR of an MPSK-OFDM signal can be expressed as [25]

$$PAPR[x(n)] \le N \tag{3.6}$$

However, for the OFDM system with square M-Quadrature Amplitude Modulation (MQAM), signal constellation has varying signal power levels over different constellation points. When all the subcarriers have the same phase, the maximum of PAPR occurs. Therefore, according to the conclusion of [26], the upper bound of PAPR in MQAM-OFDM systems can be derived out

$$\frac{3N}{M-1} \le PAPR_{\max}[x(n)] \le \frac{3N\left(\sqrt{M}-1\right)^2}{M-1} \tag{3.7}$$

For a relatively large N , the lower and upper bounds of the distribution of the PAPR have been proposed in [27], which were developed based on the previous works in conjunction with some approximations and parameters obtained through simulations. In [28], some bounds analysis has also been developed for both independent and dependent subcarriers in OFDM systems. For independent subcarriers, a generic path for bounding practical constellations was used and discussed. For dependent subcarriers, some theoretical bounds of distributions of the PAPR have been obtained in terms of the Euclidian distance distributions, in which the focus was mainly on binary codes, such as Bose-Chaudhuri-Hocquenghem (BCH) codes. However, the lower and upper bounds can offer little help in characterizing the distribution of the PAPR in practical OFDM systems. In fact, the accurate statistical distribution of the PAPR for generic OFDM system is what we want.

When the number of the subcarriers is relatively small, the CCDF expression of the PAPR of OFDM signals can be written as [29]

$$\Pr\{PAPR > \gamma\} = 1 - \left(1 - e^{-\gamma}\right)^N \tag{3.8}$$

However, (3.8) does not fit well in OFDM systems with a very large N [27]. In [30], an empirical approximation expression of the CCDF of the PAPR in OFDM systems has been given as

$$\Pr\{PAPR > \gamma\} = 1 - \left(1 - e^{-\gamma}\right)^{2.8N} \tag{3.9}$$

It should be noted that (3.9) lacks theoretical justification and also yields some discrepancies with the simulation results for large N, which has been proved in [31].

3.4 PAPR in single carrier systems

Now, the question that can strike one's mind is that PAPR occurs in OFDM or multi carrier schemes or is it associated with single carrier schemes also? To get the answer to this question we will consider a non-OFDM or single carrier system with BPSK modulated symbols.

Let the symbols be $x(0)$ $x(1)$ $x(2)$ $x(3)$ .... $x(N-1)$

And the amplitude of each symbol is $\pm a$

Then,

$$\text{Power in each symbol} = a^2$$

This may be called as the Peak power of this signal.

$$\textit{Average power} = E\left\{|x(k)|^2\right\}$$

$$= a^2$$

Hence, in this single carrier system , both , peak and average power = a^2

Peak to Average Power associated with this signal can be given as

$$PAPR = \text{Peak Power / Average Power}$$

$$= 1$$

PAPR has no unit because it is a ratio of power to power. In terms of decibels, this PAPR for single carrier scheme will be given as

$$\text{PAPR (dB)} = 10\log_{10} PAPR$$

$$= 0 \text{ dB}$$

This means there is no signal deviation from the mean power level.

So, we conclude that PAPR is associated with multi carrier transmission schemes only and not with single carrier modulation schemes.

3.5 PAPR in OFDM systems

The information symbols $x(0)$ $x(1)$ $x(2)$ $x(3)$ .... $x(N-1)$ are loaded onto the different orthogonal sub-carriers as shown in Fig. 3.3.

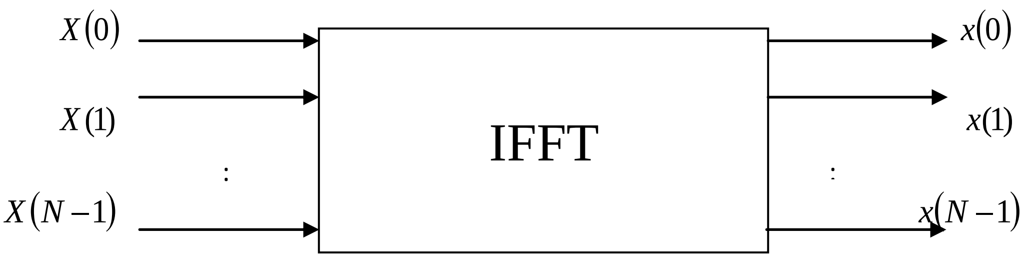


Fig. 3.3 IFFT operation done on the information symbols

Hence, the transmitted samples are $x(0)$ $x(1)$ $x(2)$ $x(3)$ .... $x(N-1)$ which are the IFFT samples of the information symbols $X(0)$ $X(1)$ .... $X(N-1)$.

We transmit the IFFT samples of the information symbols and not the information symbols exactly.

So, let $x(k)$ represents the k^{th} sample

Then,

$$x(k) = \frac{1}{N}\sum_{i=0}^{N-1} X(i) e^{j2\pi k\, i/N} \qquad (3.1)$$

Where *X(i)* represents the i^{th} information symbol and *N* represents the number of sub-carriers.

$$\text{Average Power} = E\left\{|x(k)|^2\right\}$$

$$= \frac{1}{N^2}\sum_{i=0}^{N-1} E\left\{|X(i)|^2\right\} E\left\{\left|e^{j2\pi k\, i/N}\right|^2\right\}$$

$$= \frac{1}{N^2}\sum_{i=0}^{N-1} E\left\{|X(i)|^2\right\}$$

$$= \frac{1}{N^2}\sum_{i=0}^{N-1} a^2$$

$$= \frac{a^2 N}{N^2}$$

$$= \frac{a^2}{N} \qquad (3.2)$$

Hence, the average power of transmission is $\frac{a^2}{N}$.

The power of any i^{th} symbol where the amplitude of every symbol is given as $\pm a$ is represented as

$$\text{Peak power} = a^2 \qquad (3.3)$$

Peak to average power will be given as the ratio of peak power to the average power calculated in (3.2 & 3.3)

$$\text{PAPR} = \frac{a^2}{a^2 / N}$$

$$= N \qquad (3.4)$$

Hence, PAPR in an OFDM system can be significantly high depending upon the number of sub-carriers used.

So, PAPR increases as number of sub-carriers increase [1-3].

3.6 Characteristics of PAPR

- High PAPR in an OFDM system essentially arises because of the IFFT operation.
- Data symbols across sub-carriers can add up to produce a high peak value.
- In an OFDM system with 512 sub-carriers and BPSK modulation , the PAPR at the output can be as high as 10dB (i.e 10 times peak power compared to average power).
- PAPR of an OFDM system is characterized using Complimentary Cumulative Distribution Function (CCDF).

3.7 Motivation for PAPR reduction

PAPR in multi-carrier modulation schemes must be reduced for the following reasons :

3.7.1 Non-linear characteristics of high power amplifier (HPA)

Most radio systems employ the HPA in the transmitter to obtain sufficient transmission power. For the purpose of achieving the maximum output power efficiency, the HPA is usually operated at or near the saturation region. Moreover, the nonlinear characteristic of the HPA is very sensitive to the variation in signal amplitudes**.**

However, the variation of OFDM signal amplitudes is very wide with high PAPR. Therefore, HPA will introduce inter-modulation between the different subcarriers and introduce additional interference into the systems due to high PAPR of OFDM signals.

This additional interference leads to an increase in BER. In order to lessen the signal distortion and keep a low BER, it requires a linear work in its linear amplifier region with a large dynamic range. However, this linear amplifier has poor efficiency and is so expensive. Power efficiency is very necessary in wireless communication as it provides adequate area coverage, saves power consumption and allows small size terminals etc. It is therefore important to aim at a power efficient operation of the non-linear HPA with low back-off values and try to provide possible solutions to the interference problem brought about. Hence, a better solution is to try to prevent the occurrence of such interference by reducing the PAPR of the transmitted signal with some manipulations of the OFDM signal itself. The characteristic of a typical HPA is shown in Fig. 3.4.

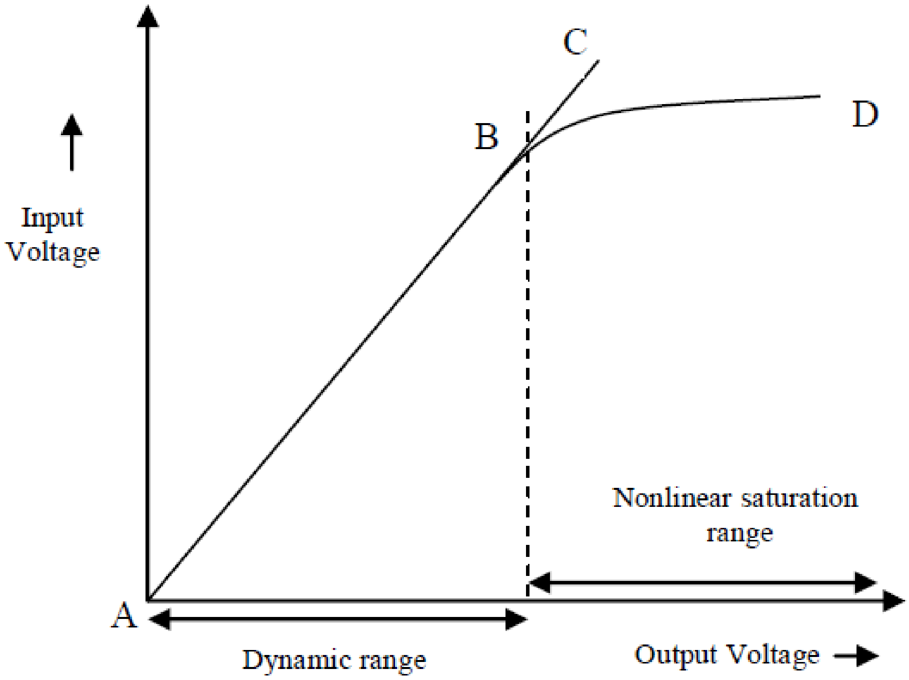


Fig. 3.4 High power amplifier characteristics

In Fig. 3.4 the performance of HPA corresponding to the different regions of operation is shown. When the peak deviation about the average is significantly high, the signal level moves outside the dynamic range i.e A to B. High PAPR results in amplifier saturation thus leading to nonlinearity and hence loss of orthogonality among the subcarriers i.e the amplifier's region of operation moves towards D which is quite undesirable [32].

3.7.2 Analog to digital converter (ADC)

Large PAPR also demands the DAC with enough dynamic range to accommodate the large peaks of the OFDM signals. Although, a high precision DAC supports high PAPR with a reasonable amount of quantization noise, but it might be very expensive for a given sampling rate of the system. Whereas, a low-precision DAC would be cheaper, but its quantization noise will be significant, and as a result it reduces the signal Signal-to-Noise Ratio (SNR) when the dynamic range of DAC is increased to support high PAPR. Furthermore, OFDM signals show Gaussian distribution for large number of subcarriers, which means the peak signal quite rarely occur and uniform quantization by the ADCs is not desirable. If clipped, it will introduce in band distortion and out-of-band radiation (adjacent channel interference) into the communication systems. Therefore, the best solution is to reduce the PAPR before OFDM signals are transmitted DAC [33].

3.7.3 Power saving

When a HPA have a high dynamic range, it exhibits poor power efficiency. It has been shown by a number of researchers in their work that PAPR reduction can significantly save the power, in which the net power saving is directly proportional to the desired average output power.

3.8 Conclusion

This chapter gave an insight of the PAPR, its performance measure, distribution of PAPR. The main motivation behind reducing this problem of PAPR has also been discussed in this chapter.

CHAPTER 4

PAPR REDUCTION TECHNIQUES

A number of PAPR reduction techniques in OFDM have been proposed in the literature along with their simulation results and performance. In this chapter, we will discuss the existing PAPR reduction techniques, their advantages, drawbacks, design parameters etc.

PAPR reduction techniques are classified into different approaches : Clipping and filtering, windowing , peak cancellation , tone reservation , tone interjection and scrambling techniques like partial transmit sequence (PTS) and selected mapping (SLM).

- The clipping technique employs clipping or nonlinear saturation around the peaks to reduce the PAPR. It is simple to implement, but it may cause in-band and out of-band interferences while destroying the orthogonality among the subcarriers [39].
- To remedy the out-of-band problem of clipping, a different approach is to multiply large signal peaks with a certain nonrectangular window. To minimize the out-of-band interference, ideally the window should be as narrowband as possible. On the other hand, the window should not be too long in the TD because that implies that many signal samples are affected, which increases the BER.
- The methods like tone rejection and tone interjection are based on adding a data-block-dependent time domain signal to the original multicarrier signal to reduce its peaks. This time domain signal can be easily computed at the transmitter and stripped off at the receiver.
- Scrambling techniques scramble the input stream and process them in such a way that the algorithm used reduces the PAPR in time domain so as to get a

better performance out of the OFDM systems. These techniques include PTS, SLM and interleaving [34-39].

4.1 Clipping and windowing

The simplest way to reduce the PAP ratio is to clip the signal, such that the peak amplitude becomes limited to some desired maximum level. Although clipping is definitely the simplest solution, there are a few problems associated with it. First, by distorting the OFDM signal amplitude, a kind of self-interference is introduced that degrades the BER. Second, the nonlinear distortion of the OFDM signal significantly increases the level of the out-of-band radiation. The latter effect can be understood easily by viewing the clipping operation as a multiplication of the OFDM signal by a rectangular window function that equals one if the OFDM amplitude is below a threshold and less than one if the amplitude needs to be clipped. The spectrum of the clipped OFDM signal is found as the input OFDM spectrum convolved with the spectrum of the window function. The out-of-band spectral properties are mainly determined by the wider spectrum of the two, which is the spectrum of the rectangular window function. This spectrum has a very slow roll off that is inversely proportional to the frequency.

Amplitude clipping limits the peak envelope of the input signal to a predetermined value or otherwise passes the input signal through unperturbed [42], that is

$$A(x) = \begin{cases} x, |x| \le B \\ Be^{j\phi(x)}, |x| \le B' \end{cases} \tag{4.1}$$

Where $\phi(x)$ is the phase of *x*. The distortion caused by amplitude clipping can be viewed as another source of noise. The noise caused by amplitude clipping falls both in-band and out of- band. In-band distortion cannot be reduced by filtering and results in an error performance degradation, while out-of-band radiation reduces spectral efficiency. Filtering after clipping can reduce out-of-band radiation but may also cause some peak re-growth so that the signal after clipping and filtering will exceed the clipping level at some points. To reduce overall peak re-growth, a repeated clipping-and-filtering operation can be used. Generally, repeated clipping-and-filtering takes many iterations to reach a desired amplitude level [32-34].

To remedy the out-of-band problem of clipping, a different approach is to multiply large signal peaks with a certain nonrectangular window. Any window can be used, provided it has good spectral properties. To minimize the out-of-band interference, ideally the window should be as narrowband as possible. On the other hand, the window should not be too long in the time domain because that implies that many signal samples are affected, which increases the BER. Examples of suitable window functions are the cosine, Kaiser, and Hamming windows.

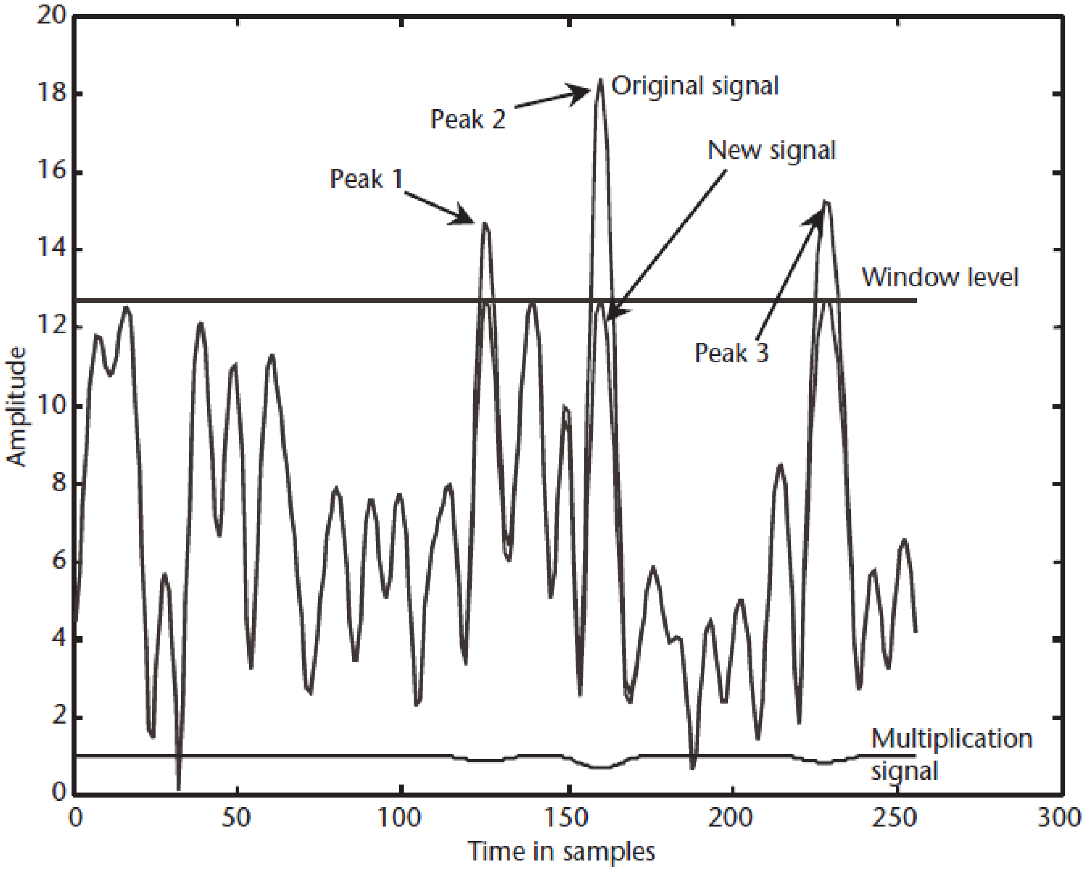


Fig. 4.1 Windowing of an OFDM signal

Fig. 4.1 shows that peak 1 , peak 2 and peak 3 are clipped below the window level and hence, the PAPR of the OFDM signal is reduced up to an extent. Fig. 4.2 shows the performance of clipping and some non-rectangular window performances for a 32 sub-carrier OFDM system.

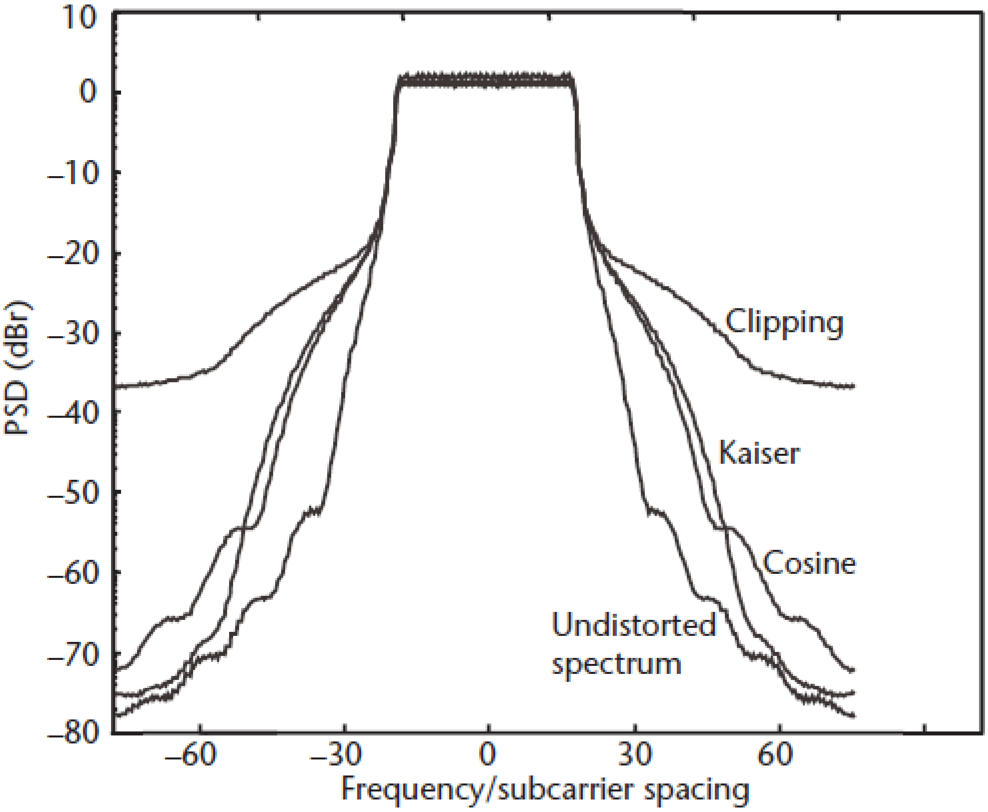


Fig. 4.2 Frequency spectrum of an OFDM signal having 32 sub-carriers with clipping and peak windowing

In Fig. 4.3, MATLAB simulation results with parameters as shown in the table 4.1 are given, which show performance improvement in PAPR of an OFDM system after applying clipping to it. The graph shows that the probability of the PAPR being greater than 6dB is around 0.124 and above 8dB is around 0.0000976. On the other hand, for the simple OFDM signal without applying clipping, the probability of PAPR being greater than 12dB is around 0.00657.

Table 4.1 Simulation parameters for clipping

Parameters	Values
Number of sub-carriers	256
Modulation scheme	16-QAM
Oversampling rate	4
Clipping level	80% of the peak value

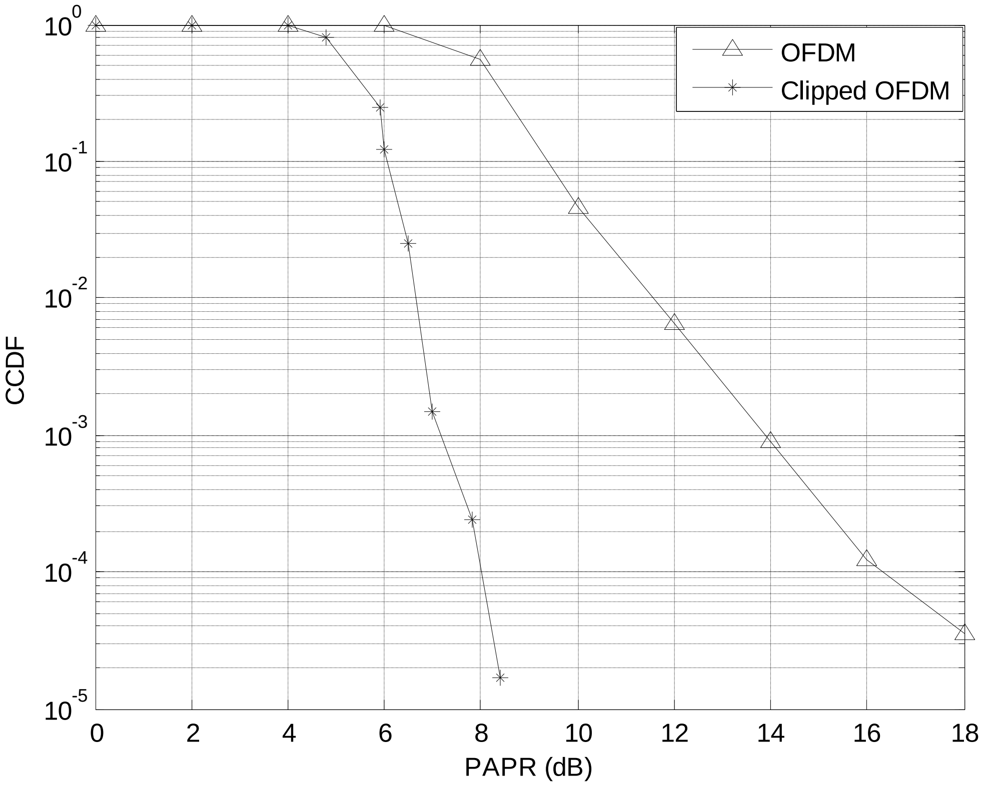


Fig. 4.3 MATLAB graph showing performance improvement using clipping technique.

4.2 Scrambling techniques

Signal scrambling techniques include two main techniques namely partial transmit sequence (PTS) and selected mapping (SLM).

4.2.1 Partial transmit sequence (PTS)

In the PTS technique, an input data block of N symbols is partitioned into disjoint sub-blocks. The subcarriers in each sub-block are weighted by a phase factor for that sub-block. The phase factors are selected such that the PAPR of the combined signal is minimized. Fig. 4.4 shows the block diagram of the PTS technique [37].

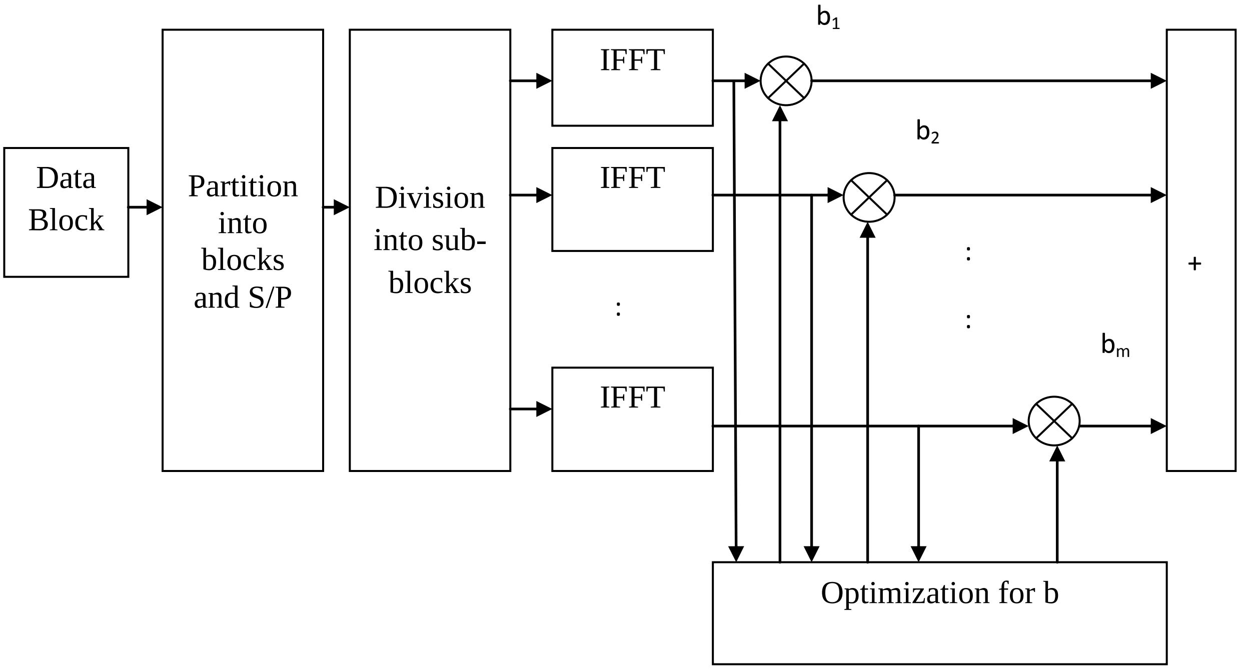


Fig. 4.4 Block diagram for PTS

In PTS , input data block ***X*** is partitioned into M disjoint sub-block

$$X_m = \left[X_{m,0}, X_{m,1} \ldots\ldots\ldots\ldots X_{m,N-1}\right]^T \text{ , } m = 1,2,\ldots\ldots, \text{M} \tag{4.1}$$

Such that ,

$$\sum_{m=1}^{M} X_m = X \tag{4.2}$$

And the sub-blocks are combined to minimize the PAPR in time domain. The *L*-times oversampled time domain signal of X_m, m=1,2,.....,M is denoted as

$$x_m = \left[x_{m,o}, x_{m,1}, \ldots\ldots\ldots\ldots, x_{m,NL-1}\right]^T, m = 1,2,\ldots\ldots., M \tag{4.3}$$

Is obtained by taking the IDFT of length *NL* on X_m concatenated with *(L-1)N* zeros.

These are called the partial transmit sequences.

Complex phase factors, $b_m = e^{j\phi_m}$, m=1,2,......,M are introduced to combine the PTSs. The set of phase vectors is denoted as a vector $b = \left[b_1, b_2, \ldots\ldots\ldots, b_m\right]^T$

The time domain signal after combining is given by

$$x'(b) = \sum_{m=1}^{M} b_m x_m \tag{4.4}$$

Our objective is to find theset of phase factors that minimizes PAPR.

In general, the selection of the phase factors is limited to a set with a finite number of elements to reduce the search complexity. The set of allowed phase factors is written as

$$P = \left\{e^{j2\pi l/W}\right\} l = 0,1,\ldots\ldots, W-1 \tag{4.5}$$

We may choose any values of phase factors that minimizes PAPR [41].

The Fig. 4.5 below shows the performance of PTS with respect to normal OFDM having simulation parameters as shown in table 4.2.

Table 4.2 Simulation parameters for PTS

Parameters	Values
Number of sub-carriers	256
Modulation scheme	16-QAM

Oversampling rate	4
Number of sub-blocks	16
Phase factors	1,-1

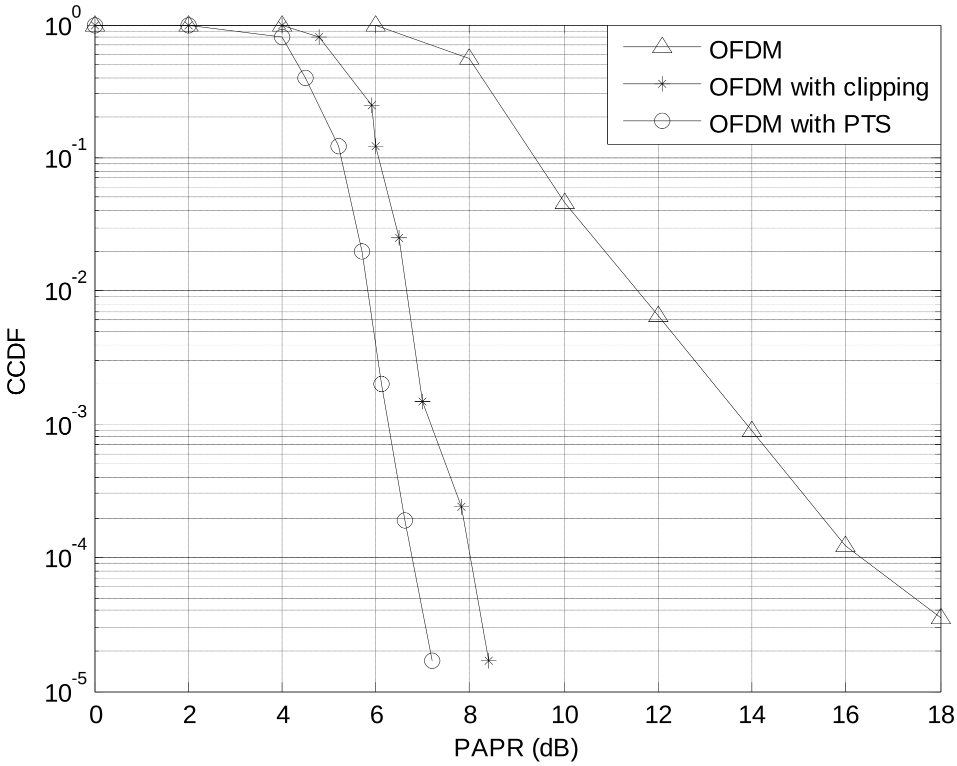


Fig. 4.5 PTS performance with OFDM having 256 SCs and 16-QAM modulation

4.2.2 Selected Mapping

In the SLM technique, the transmitter generates a set of sufficiently different candidate data blocks, all representing the same information as the original data block, and selects the most favourable for transmission [42]. A block diagram of the SLM technique is shown in Fig.4.6. Each data block is multiplied by U different phase sequences, each of length N, $B^{(u)} = [b_{u,0}, b_{u,1}, ..., b_{u,N-1}]^{T}$, $u = 1,2,3,......,U$, resulting in U modified data blocks. We set $B^{(1)}$as all one vector to include the unmodified data block. If we suppose that the modified data block for u^{th} phase sequence be

$X^{(u)} = \left[X_0 b_{u,0}, X_1 b_{u,1}, \ldots.., X_{N-1} b_{u,N-1}\right]^T$, u = 1,2,......,U. For implementation, the SLM technique needs U IDFT operations and the number of required side information if $\log_2 U$ for each data block. This approach is applicable with all types of modulation and any number of sub-carriers. The amount of PAPR reduction for SLM depends on the number of phase sequences U and the design of the phase sequences [38,40].

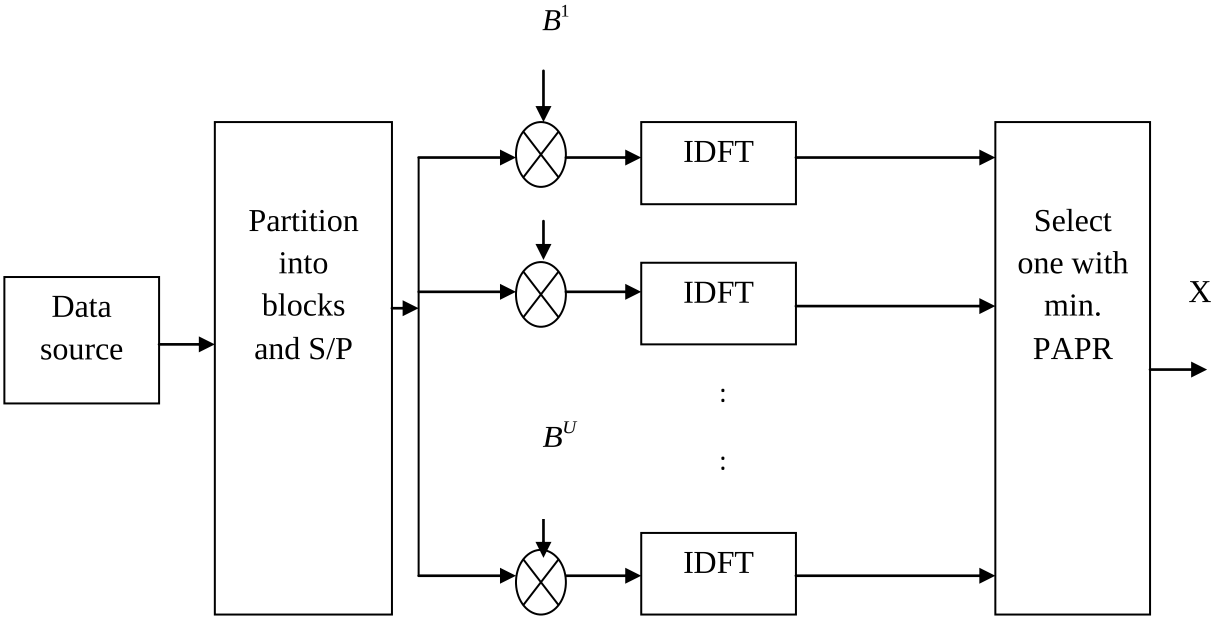


Fig. 4.6 Block diagram for SLM technique

Fig. 4.7 shows the performance of SLM compared to PTS and simple OFDM having parameters as mentioned in table 4.2.

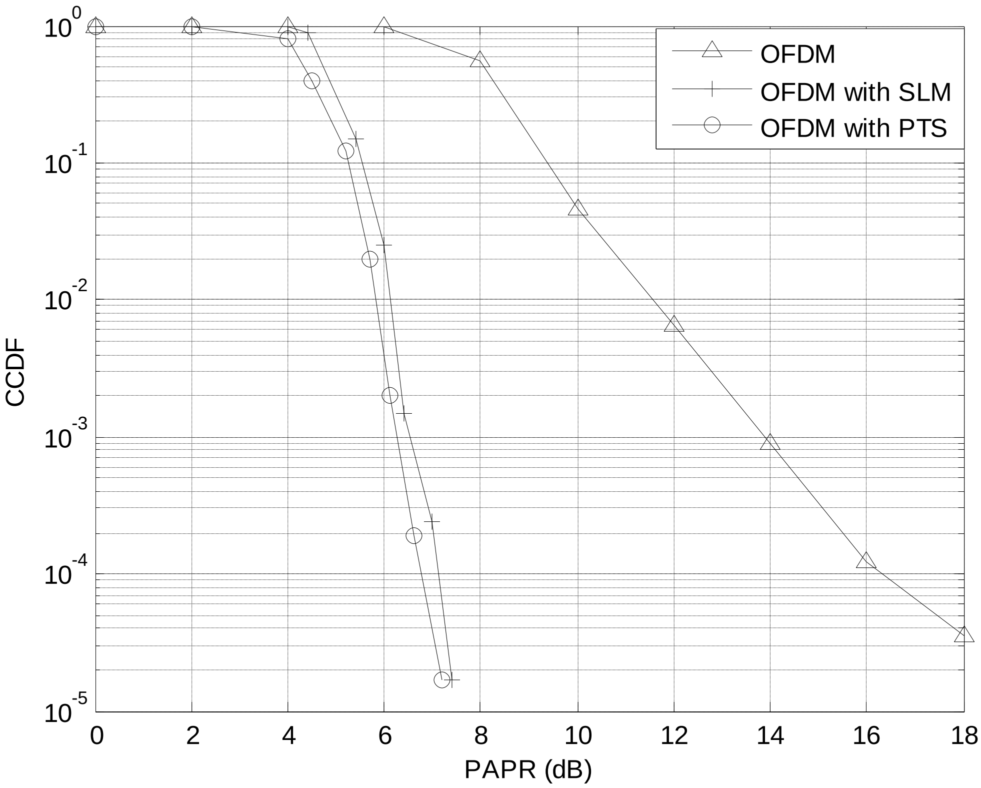


Fig. 4.7 CCDF for SLM compared to PTS and simple OFDM

Fig.4.7 shows that the performance of SLM is quite improved as compared to the simple OFDM but lags a little behind when compared to the PTS technique.

4.2.3 Interleaving

The interleaving technique for PAPR reduction is quite similar to the SLM technique. In this approach, a set of interleavers is used to reduce the PAPR of the multicarrier signal instead of a set of phase sequences. The complexity of this technique is quite less as compared to the other signal scrambling techniques.

4.3 Tone rejection (TR)

Tone reservation (TR) and tone interjection (TI) are two efficient techniques to reduce the PAPR of a multicarrier signal. These methods are based on adding a data-block-dependent time domain signal to the original multicarrier signal to reduce its peaks. This time domain signal can be easily computed at the transmitter and stripped off at the receiver. For the TR technique, the transmitter does not send data on a small subset of subcarriers that are optimized for PAPR reduction [23]. The objective is to find the time domain signal to be added to the original time domain signal **x** such that the PAPR is reduced. If we add a frequency domain vector $C = [C_0, C_1, \ldots\ldots, C_{n-1}]^T$ to X, the new time domain signal can be represented as $x + c$ = IDFT {X + C} ,where **c** is the time domain signal due to *C*. The TR technique restricts the data block X and peak reduction vector *C* to lie in disjoint frequency subspaces. The *L* nonzero positions in *C* are called peak reduction carriers (PRCs). Since the subcarriers are orthogonal, these additional signals cause no distortion on the data bearing subcarriers. To find the value of $C_n, n \in \{i_1, i_2, \ldots.. i_L\}$, we must solve a convex optimization problem that can easily be cast as a linear programming (LP) problem [33]. In the case of DMT for wireline systems, there are typically subcarriers with SNRs too low for sending any information, so these subcarriers must go unused and are available for PAPR reduction. In wireless systems, however, there is typically no fast reliable channel state feedback to dictate whether some subcarriers should not be used. Instead, a set of subcarriers must be reserved regardless of received SNRs, resulting in a bandwidth sacrifice.

4.4 Tone interjection (TI)

The basic idea here is to increase the constellation size so that each of the points in the original basic constellation can be mapped into several equivalent points in the expanded constellation [13,37]. Since each symbol in a data block can be mapped into one of several equivalent constellation points, these extra degrees of freedom can be exploited for PAPR reduction. This method is called tone injection because substituting a point in the basic constellation for a new point in the larger constellation is equivalent to injecting a tone of the appropriate frequency and phase in the multicarrier signal.

Assume that *M*-ary square quadrature amplitude modulation (QAM) is used as a modulation scheme and the minimum distance between constellation points is *d*. Then the real part of X_n ,$R_{n,}$ and imaginary part, I_n , can take values $\{\pm d/2, \pm 3d/2, \ldots\ldots, \pm(\sqrt{M}-1)d/2\}$ where $\sqrt{M}$ is equal to the number of levels per dimension. Assume that $X_n = d/2 + j.3d/2$. Modifying the real and/or imaginary part of X_n could reduce the PAPR of the transmit signal. Since we want the receiver to decode X_n correctly, we must change X_n by an amount that can be estimated at the receiver. A simple case would be to transmit $X_n = X_n + pD + j.qD$, where *p* and *q* are any integer values and *D* should be at least $d\sqrt{M}$ in order not to increase BER at the receiver. The TI technique may be more problematic than the TR technique since the injected signal occupies the same frequency band as the information bearing signal. The TI technique may also result in a power increase in the transmit signal due to the injected signal. The simulation results in Fig 4.8 show the performance of TR technique as compared with clipping and original OFDM.

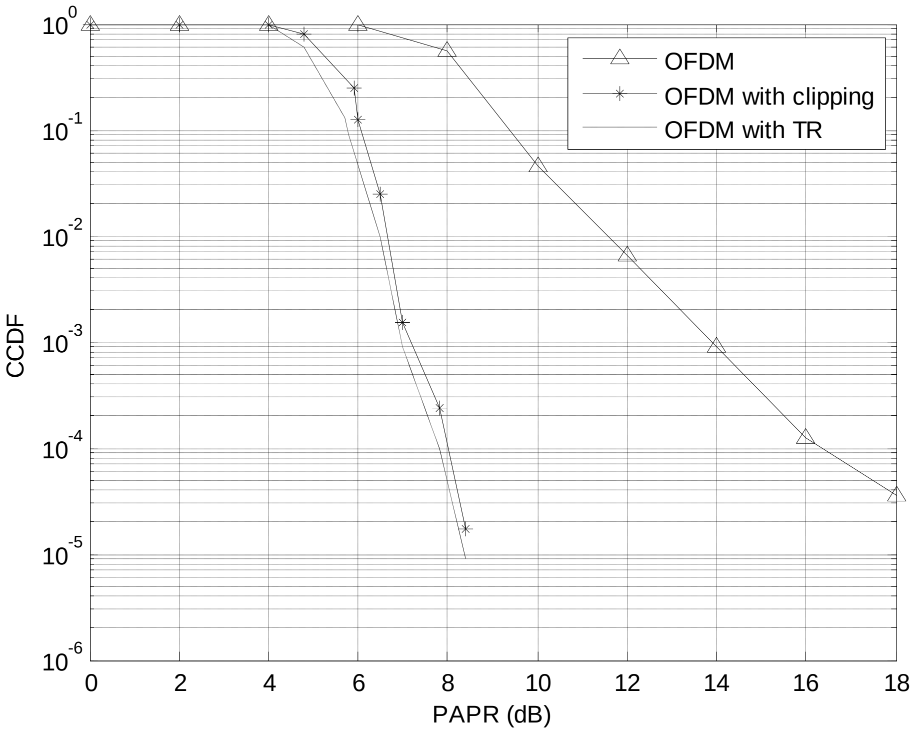


Fig. 4.8 Performance of TR technique with OFDM and OFDM with clipping applied.

4.5 Criteria for selection of PAPR reduction techniques in OFDM systems

There are many factors that should be considered before a specific PAPR reduction technique is chosen. Some of them are discussed here [31-33]:

- **PAPR reduction capability:** The most important factor in choosing a PAPR reduction technique. Careful attention must be paid to the fact that some techniques result in other harmful effects. For example, the amplitude clipping technique clearly removes the time domain signal peaks, but results in in-band distortion and out-of-band radiation**.**
- **Increased transmit power:** Some techniques require a power increase in the transmit signal after using PAPR reduction techniques. For example, TR requires more signal power because some of its power must be used for the PRCs. When the transmit signal power should be equal to or less than that before using a PAPR reduction technique, the transmit signal should be normalized back to the original power level, resulting in BER performance degradation for these techniques.
- **BER increase at the receiver:** This is also an important factor and closely related to the power increase in the transmit signal. Some techniques may have an increase in BER at the receiver if the transmit signal power is fixed or equivalently may require larger transmit signal power to maintain the BER after applying the PAPR reduction technique. For example, the BER after applying ACE will be degraded if the transmit signal power is fixed. In some techniques such as SLM, PTS, and interleaving, the entire data block may be lost if the side information is received in error. This may also increase the BER at the receiver.
- **Loss in data rate:** Some techniques require the data rate to be reduced. As shown in the previous example, the block coding technique requires one out of four information symbols to be dedicated to controlling PAPR. In SLM, PTS, and interleaving, the data rate is reduced due to the side information used to inform the receive of what has been done in the transmitter. In these techniques

the side information may be received in error unless some form of protection such as channel coding is employed. When channel coding is used, the loss in data rate due to side information is increased further.

- **Computational complexity:** Computational complexity is another important consideration in choosing a PAPR reduction technique. Techniques such as PTS find a solution for the PAPR reduced signal by using many iterations. The PAPR reduction capability of the interleaving technique is better for a larger number of interleavers. Generally, more complex techniques have better PAPR reduction capability.
- **Some other considerations:** Many of the PAPR reduction techniques do not consider the effect of the components in the transmitter such as the transmit filter, digital-to-analog (D/A) converter, and transmit power amplifier. In practice, PAPR reduction techniques can be used only after careful performance and cost analyses for realistic environments.

4.6 Conclusion

In this chapter, we have discussed different existing PAPR reduction techniques along with their simulation results and performance comparisons. The advantages and drawbacks of every technique have also been discussed in a brief manner. The comparison of the CCDF curves for various techniques show that PTS performs best when it comes to the reduction of PAPR and it is applicable to every modulation scheme and any number of sub-carriers, making it quite an attractive technique for PAPR reduction.

CHAPTER 5

PROPOSED WORK

In this chapter, a novel signal scrambling technique for PAPR reduction in OFDM systems which works for any modulation scheme and for any number of sub-carriers is explained in detail. This technique involves the employment of a little more IDFT blocks as compared to the other existing PAPR techniques like PTS and SLM but the amount of PAPR reduction is quite significant. The simulation results show the performance improvement as compared to other techniques along with the block diagram of the proposed work.

5.1 Description of the technique

In this technique, we consider an input data block of M bits which is further divided into N number of uncorrelated sub-blocks. Each sub-block is oversampled by L so as to have data length equal to that of the original input data stream. Each sub-block is multiplied by the available set of phase factors vector. IDFT of the available vectors is taken and PAPR is calculated for each. Phase factor vector which gives the least PAPR is chosen and selected for the corresponding sub-block. Adding up all the sub-blocks with optimal phase factor vectors for each correspondingly will give us the signal to be transmitted as shown in the Fig 5.1. The data block X is divided into sub-blocks of equal length such that $X = \sum_{n=1}^{N} X_n$ where n=1, 2, 3 …. N are the sub-blocks which after being optimized with the phase factor vectors and IFFT of which are added to minimize the PAPR in time domain. The phase factor vectors are given by b_m for the simulation purposes we have taken the value of $m = 4$. The length of b_m is equal to the length of the input bit sequence having values from the set $S = \{e^{j2\pi \, l/W} \mid l = 1,2 \ldots W-1\}$ where W is the number of allowed phase factors which we have taken as 4 here. The amount of PAPR reduction using this technique is quite impressive with a little increase in the complexity of the algorithm because of the deployment of IFFT blocks for every sub-

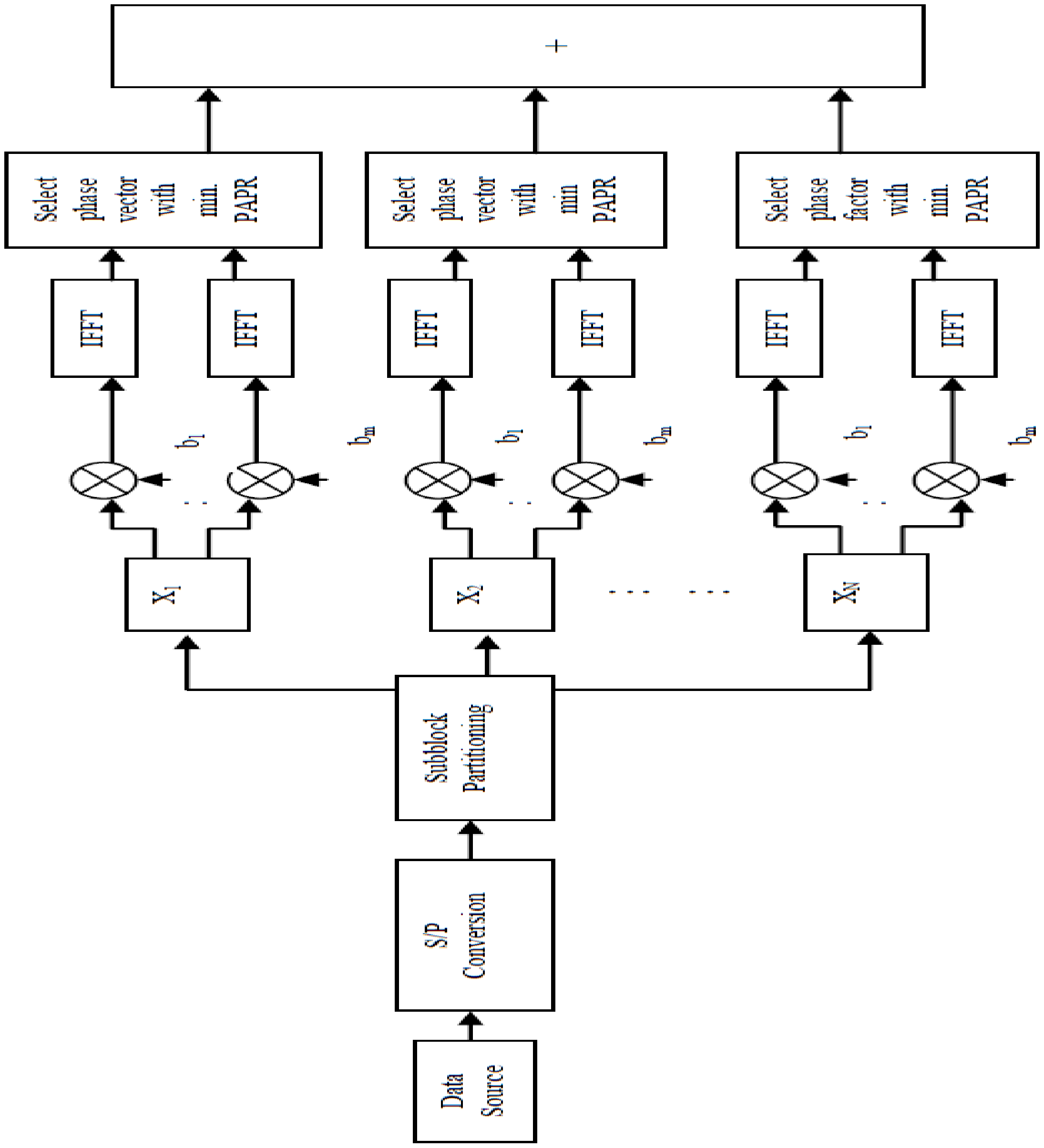


Fig. 5.1 Block diagram of the proposed technique

block optimized with the phase factor vector. Also, the phase factor vectors don't need to have a value assigned to every bit in the vector as we have oversampled the signal by an amount *L*. The elements of the sub-block which have a value assigned from the set of corresponding input sequence are meant to be optimized with the phase factor vector and hence we may control the complexity by reducing the number of phase factor by an amount of $(N-1)/N$. At the receiver, the information of these phase factor vectors is needed to recover the optimized OFDM signal back in its original form for the applications to process it. The proposed technique works for any modulation scheme and any number of subcarriers with an acceptable amount of delay because of the IFFT blocks involved.

5.2 Simulation results

The performance of the technique proposed in the above section has been shown with the help of MATLAB graph (Fig. 5.3) compared with the performance signal scrambling techniques like partial transmit sequence (PTS) and selected mapping (SLM) for the OFDM signal shown in Fig.5.2. These techniques perform quite well when it comes to PAPR reduction in time domain. The simulation parameters for the same have been given in the table 5.1.

Table 5.1 Simulation parameters for the proposed approach compared to PTS and SLM

Parameters	**Value**
Bit sequence length	256
Modulation	QPSK
Sub-block partitioning	Adjacent partitioning
Number of sub-blocks	4
Number of phase factors allowed	4(1, -1, j, -j)
Number of phase factor vectors	4
IFFT length	256

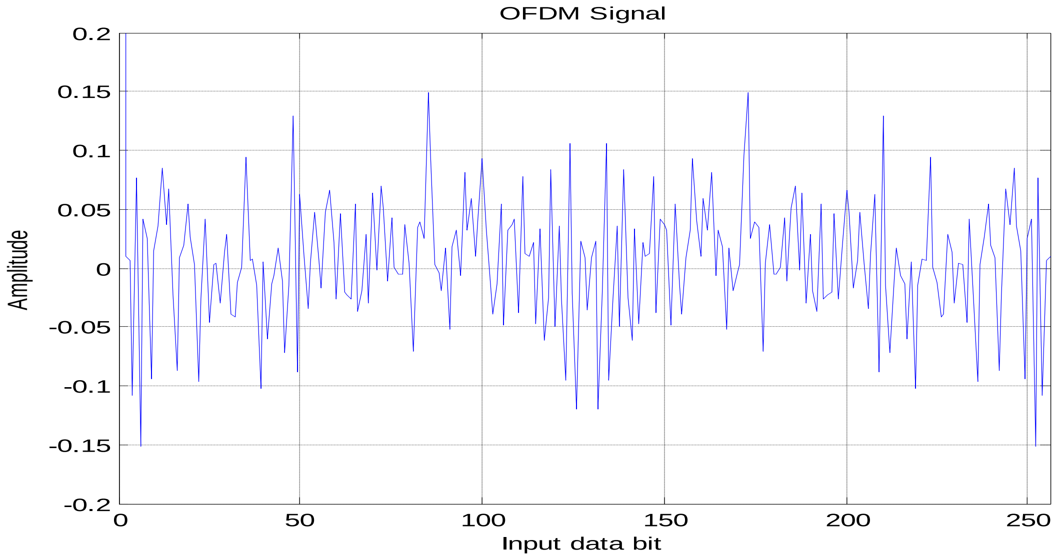


Fig. 5.2 QPSK modulated OFDM signal for 256 bit long sequence

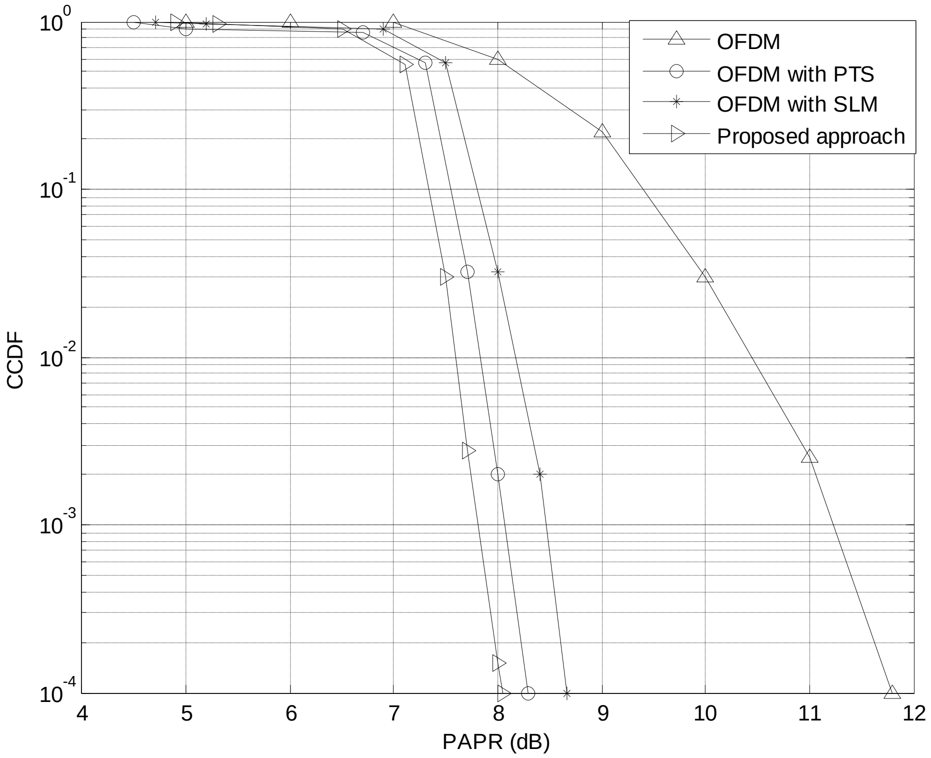


Fig. 5.3 CCDF of proposed approach compared with PS and SLM for 256 sub-carrier

5.3 Conclusion

In the MATLAB graph, it can clearly be seen that the proposed approach gives better results as compared to other techniques with same simulation parameters. The probability of PAPR being greater than 8dB is 0.6, 0.032, 0.002, 0.00015 for the simple OFDM, OFDM with SLM applied, OFDM with PTS applied and OFDM with the proposed approach respectively. As we go on increasing the bit sequence length, the PAPR performance degrades proportionally.

CHAPTER 6

CONCLUSION AND FUTURE SCOPE

6.1 Conclusion

This dissertation focussed on an important aspect of communication linked with one of the most popular multi-carrier transmission schemes called Orthogonal Frequency Division Multiplexing (OFDM). PAPR is a problem associated with every multi-carrier transmission scheme and when seen in context with OFDM, it affects the system quite heavily by deteriorating the orthogonality of the scheme which is the backbone of the scheme. Being a motivation behind high data rate applications, problems like PAPR in an OFDM system needs to be handled in an efficient way. A novel technique has been proposed to deal with the PAPR that makes use of IDFT blocks and works effectively for any number of sub-carriers and any modulation scheme. The performance of this technique has been compared with other existing techniques for PAPR reduction on the basis of Complimentary Cumulative Distribution Function (CCDF) which is an effective measure of the PAPR. MATLAB results along with the simulation parameters have also been shown to support the statement. The complexity of this approach is a bit more as it involves more number of IDFT blocks to process the parallel streams of data but this much of complexity is acceptable for the amount of PAPR reduction it offers.

6.2 Future scope

MIMO-OFDM and OFDMA are the multi-carrier transmission schemes which are quite popular among the researchers around the world with the great demand of high data rates efficiently. This approach can be applied to these new world technologies considering different fading environments and channels that a signal passes through.

REFERENCES

[1] D. Tse, P. Viswanath, Fundamentals of wireless communication, Cambridge University Press, 2005.

[2] R.Prasad, OFDM for wireless communication systems, Artech House Publishers, 2004.

[3] A.Goldsmith, Wireless communications, Cambridge University Press, 2005.

[4] S. Weinstein and P. Ebert, "Data transmission by frequency division multiplexing using the discrete fourier transform," *IEEE Transactions on Communication Techniques*, vol. COM-19, pp. 628-634, October 1971.

[5] R. W. Chang, "Synthesis of band limited orthogonal signals for multichannel data transmission," *Bell Syst. Tech. Jo.*, vol. 45, pp. 1,775- 1,796, Dec 1966.

[6] B. R. Saltzberg, "Performance of an efficient parallel data transmission system," *IEEE Trans. on Commun. Technologies",* vol. COM-15, Dec 1967.

[7] J. Stott, "The DVB terrestial (DVB-T) specification and its implementation in a practical modem," *International Broadcasting Convention*, pp. 255-260, 1996.

[8] ETSI, "Digital Video Broadcasting (DVB); framing structure, channel coding, and modulation for digital terrestial television (DVB-T)," European Telecommunications Standard Institute ETSI EN 300 744, Nov 1999.

[9] ISO/IEC, "Information technology - generic coding of moving pictures and associated audio information: Part 2 video," ISO/IEC 13818, 2000.

[10] ETSI, "Radio Broadcast Systems: Digital Audio Broadcasting (DAB) to mobile, portable and fixed receivers," ETSI final draft ETS 300 401, Nov 1994.

[11] P. Shelswell, "The COFDM modulation system: The heart of digital audio broadcasting," *Electronic and Communication Engineering Journal*, vol. 7, pp. 127-135, June 1995.

[12] V. Tarokh and H. Jafarkhani, "An Algorithm for Reducing the Peak to Average Power Ratio in a Multicarrier Communication System," in *IEEE VTC*, Piscataway, NJ, USA, pp. 680-684, June 1999.

[13] J. Tellado-Mourelo, "Peak to Average Power Reduction for Multicarrier Modulation," in Department of Electrical Engineering: Stanford University, 1999.

[14] O. Edfors, Sandell, M., van de Beek, J.J., Landström, D., Sjöberg, "An Introduction to Orthogonal Frequency Division Multiplexing," Division of Signal Processing, Luleå University of Technology, Research Report TULEA 1996:16 1996.

[15] H. Bolckei, D. Gesbert, and A. J. Paulraj, "On the capacity of OFDM-based spatial multiplexing systems," *IEEE Transactions on Communications*,, vol. 50, pp. 225-234, 2002.

[16] D. Matic, OFDM Synchronization and Wideband Power Measurements at 60 GHz for Future Wireless Broadband Multimedia Communications, Ph.D. Thesis, Aalborg University, Denmark, September 2001.

[17] U.S. Jha, Low Complexity Resource Efficient OFDM Based Transceiver Design, Ph.D.Thesis, Aalborg University, Denmark, September 2002.

[18] C.R. Nassar et al., Multi-carrier Technologies for Wireless Communication, Kluwer Academic Publishers, Dordrecht, The Netherlands, 2002.

[19] H. Sari et al., Transmission Techniques for Digital Terrestrial TV Broadcasting, *IEEE Comm. Mag.*, vol. 33, no. 2, pp. 100–109, February 1995.

[20] E.P. Lawrey, Adaptive Techniques for Multiuser OFDM, Ph.D. Thesis, James Cook University, Australia, December 2001.

[21] O.Edfors et al., An Introduction to Orthogonal Frequency-Division Multiplexing, Research Report, no. 1996:16, Division of Signal Processing, Lulea University of Technlogy, Sweden, September 1996.

[22] R.V. Nee and R. Prasad, OFDM for Wireless Multimedia Communications, Artech House Publishers, Norwood, MA, USA, 2000.

[23] T. Pollet et al., BER Sensitivity of OFDM Systems to Carrier Frequency Offset and Wiener Phase Noise, *IEEE Trans. Comm.*, vol. 43, no. 2–4, pp. 191–193, February–April 1995.

[24] H. Rohling and T. May, Comparison of PSK and DPSK Modulation in a Coded OFDM System, Proc. IEEE VTC, pp. 5–7,October 1997.

[25] S. H. Müller and J. B. Huber, “A Comparison of Peak Power Reduction Schemes for OFDM,” *Proc. IEEE GLOBECOM '97*, Phoenix, AZ, pp. 1–5, Nov. 1997.

[26] J. G. Proakis, *Digital Communications*, 4th ed. New York, , USA: McGraw-Hill, 2001.

[27] N. Dinur and D. Wulich, “Peak-to-average power ratio in high-order OFDM,” *IEEE Trans. Communications*, vol. 49, no. 6, pp. 1063–1072, Jun. 2001.

[28] S. Litsyn and G.Wunder, “Generalized bounds on the crest-Factor distribution of OFDM signals with applications to code design,” *IEEE Trans. Information Theory*, vol. 52, no. 3, pp. 992–1006, Mar. 2006.

[29] S. Shepherd, J. Orriss, and S. Barton, “Asymptotic limits in peak envelope power reduction by redundant coding in orthogonal frequency-division multiplex modulation,” *IEEE Trans. Communications*, vol. 46, no. 1, pp. 5–10, Jan. 1998.

[30] R. van Nee and A. deWild, “Reducing the peak to average power ratio of OFDM,” in *Proceedings of the 48th IEEE Semiannual Vehicular Technology Conference*, vol. 3, pp. 2072–2076, May 1998.

[31] H. Ochiai and H. Imai, “On the distribution of the peak-to-average power ratio in OFDM signals,” *IEEE Trans. Communications*, vol. 49, no. 2, pp. 282–289, Feb. 2001.

[32] S.H.Han, J.H.Lee, “An Overview of Peak-to-average power ratio reduction techniques for multicarrier transmission”, *IEEE Wireless Commun.*,Vol 12(2), pp. 60-65, April 2005.

[33] T.Jiang, Y.Wu, ”An Overview: Peak-to-Average Power Ratio Reduction Techniques for OFDM Signals*”, IEEE Trans. on Broadcasting*, vol. 54, no. 2,pp. 257-268, June 2008.

[34] J. Armstrong, “Peak-to-Average Power Reduction for OFDM by Repeated Clipping and Frequency Domain Filtering,” *Elect. Lett.*, vol. 38, no. 8, pp. 246–47 , Feb. 2002.

[35] L.J.Cimini, N.R.Sollenberger,” Peak-to-Average Power Ratio Reduction of an OFDM Signal Using Partial Transmit Sequences”, *IEEE Commun Letters”,* vol. 4, no. 3,pp. 86-88, March 2000.

[36] D. S. Jayalath and C. Tellambura, “Adaptive PTS Approach for Reduction of Peak-to-Average Power Ratio of OFDM Signal”, *Elect. Lett.*, vol. 36, no. 14, pp. 1226-1228, July2000.

[37] S. H. Han and J. H. Lee, “PAPR Reduction of OFDM Signals Using a Reduced Complexity PTS Technique,” *IEEE Sig. Proc. Lett.*, vol. 11, no. 11, pp. 887–890, Nov. 2004.

[38] H. Breiling, S. H. Müller–Weinfurtner, and J. B. Huber,“SLM Peak-Power Reduction without Explicit Side Information,”*IEEE Commun. Lett.*, vol. 5, no. 6, pp. 239–241,June 2001.

[39] H. Saeedi, M. Sharif, and F. Marvasti, “Clipping Noise Cancellation in OFDM Systems Using Oversampled Signal Reconstruction,” *IEEE Commun. Lett.*, vol. 6, no. 2, pp. 73–75, Feb. 2002.

[40] S. S. Yoo, S. Yoon, S. Y. Kim, and I. Song, “A novel PAPR reduction scheme for OFDM systems: Selective mapping of partial tones (SMOPT),” *IEEE Trans. Consumer Electronics*, vol. 52, no. 1, pp. 40–43, Feb. 2006.

[41] L. Yang, R. S. Chen, Y. M. Siu, and K. K. Soo, “PAPR reduction of an OFDM signal by use of PTS with low computational complexity,” *IEEE Trans. Broadcasting*, vol. 52, no. 1, pp. 83–86, Mar. 2006.

[42] D. H. Park and H. K. Song, “A new PAPR reduction technique of OFDM system with nonlinear high power amplifier,” *IEEE Trans. Consumer Electronics*, vol. 53, no. 2, pp. 327–332, May 2007.

RESUME

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Objective

To develop my knowledge and skills and deliver the results as per the expectations of the Institution.

Education

2012 to 2014	M.Tech. (Electronics & Communication Engineering) (Pursuing)(With Teaching Assistance) Jaypee University of Information Technology, Solan, HP Current CGPA - 7.0
2005 to 2009	B.Tech. (Electronics & Communication Engineering) Babu Banarsi Das Institute of Technology, Ghaziabad, UP Percentage - 69.98
2004 to 2005	Intermediate D.D.P.S , Bijnor (CBSE) Percentage - 69.40
2002 to 2003	High School D.D.P.S , Bijnor (CBSE) Percentage - 83.40

Key Skills

Computer skills : Microsoft office (Word, Power Point, Excel).

Operating System : Windows.

Simulation Tools : Matlab, Labview,LAN Trainer, PSpice, Xilinx ISE.

Summer Training

Six Weeks of vocational training at C-DOT , MBM Telephone Exchange Bijnor(UP).

Projects

- PAPR Reduction in MIMO OFDM using Partial Transmit Sequence (Academic
- RF Based Prepaid Energy Meter (Final year project in UG).

Achievements & Responsibilities

- Qualified GATE-2011 and got Teaching Assistance in Post Graduate.
- Played (under 16) Badminton at U.P State Level representing my district
- Was the Head of Discipline Committee in Undergraduate College.
- Captain of college football team.
- Awarded as “Best Sportsperson” in college.
- Qualified P.A.B.T for Indian Air Force.

The undersigned hereby certifies that all information given in this document is true, complete and correct.

Prashant
Singh