

# Bit Error Rate Improvement of Orthogonal Frequency and Code Division Multiplexing by Symbols Peak Power Reduction



## Engineering

KEYWORDS : OFCDM, PAPR, CCDF, PTS, Interleaving

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### ABSTRACT

As we know, that every technology has some advantages and limitations. OFCDM, which is very promising modulation technique for 4G standard like LTE (Long Term Evolution) and WIMAX (Worldwide Inter-operability for Microwave Access) also has some limitations like frequency offset, high peak power as compared to average power and Orthogonal code allotment etc. In this paper, peak power to average power issue has been raised, that limits the performance of OFCDM or other multi-carrier system, if not handled properly. Due to increase of symbols peak power as compared to their average power non-linear distortion occurs, which causes orthogonality of OFCDM sub-carriers get lost, so Inter Carrier Interference (ICI) and Inter Symbol Interference (ISI) both arises. So it is necessary to reduce peak power. Several Peak power reduction techniques have been proposed in literature. These techniques are divided into two groups (i) signal scrambling techniques and (ii) signal distortion techniques. But both have some types of disadvantages. Here is a proposed technique known as sub-carrier processing (SCP) technique, that is used to reduce peak power by more than 5 dB and remove rigorous requirement for power amplifier and digital to analogue converter. Due to reduction in peak power as compared to average power, Inter carrier interference (ICI) and Inter symbol interference (ISI) both can be reduces considerably, so bit error rate (BER) performance of the system get improved.

### I Introduction

Orthogonal frequency and code division multiplexing (OFCDM), is a multi carrier modulation technique for 4G mobile communication. It is combination of orthogonal frequency division multiplexing (OFDM) & 2D spreading. The well known disadvantage of single carrier CDMA (SC-CDMA) is multipath interference (MPI) [1], so it is not suitable for broad-band wireless access. On the other hand, multicarrier technique like multicarrier CDMA (MC-CDMA), OFDM consist of large number of orthogonal sub-carriers to transmit symbols in parallel, so the symbol duration is increased substantially and the system can combat multi path interference (MPI). But OFDM suffers from adjacent cell interference (ACI) unless the same sub-carriers are not used among adjacent cells. To avoid adjacent cell interference (ACI) spreading has been introduced. Thus combining OFDM and 2D spreading (time and frequency domain) Orthogonal Frequency and Code Division Multiplexing has been proposed [2]. Thus it accumulates the properties of OFDM and 2D spreading. Due to which it possess many advantages as compared to other existing techniques OFDM & MC-CDMA which is as follows,

- 1.It has minimum bit error rate (BER) for same signal tonoise ratio (SNR) as compared to other two.
- 2.Its capacity is approximately 1.5 times as compared to orthogonal frequency division multiplexing (OFDM) & multicarrier code division multiplexing (MC-CDMA) if spreadingfactor N is greater than 1
- 3.Orthogonal frequency and code division multiplexing (OFCDM) can operate at broadband channel with approximately 100 MHz and support the data rate ranging from 100Mb/s to 5Gb/s.
- 4.OFCDM supports again serious multipath interference so it achieve higher spectrum utilization than OFDM and MC-CDMA. So it is very suitable for next generation mobile communication system. The OFCDM signal is represented as follows, [3]

$$V_{ofcdm} = \sum_{k=1}^K C_{T,i}^k C_{F,i}^k d_{m,n,k}^i e^{j2\pi f(t-mT)}$$

Where  $C_T$  and  $C_F$  are time and frequency domain spreading code, k indicate kth channel code, K is total number of channels,  $d^i$  is lth data stream, m is mth time index, n mean nth subcarrier. Remaining part of paper is organized as follows, In part II system model of OFCDM is explained. Part III describe the peak power problem and it's reduction method. Proposed sub carrier process (SCP) method is discussed in part IV. Bit error rate (BER) performance of OFCDM and SCP is compared in part V.

Simulation has been performed in part VI and conclusion has been explained in part VII.

### II System Model of OFCDM

The schematic of OFCDM transmitter and receiver is as Follows

**Transmitter:** At the transmitter, incoming serial data stream is-converted into serial to parallel (S/P) multistream, then parallel multistream data is channel encoded and then modulated,

After that 2D spreading is done. In 2D spreading firstly time domain spreading is done and then replicate the same code in frequency domain. After 2D spreading, all subcarriers data is

Combined and code multiplexed, then IFFT transform is taken

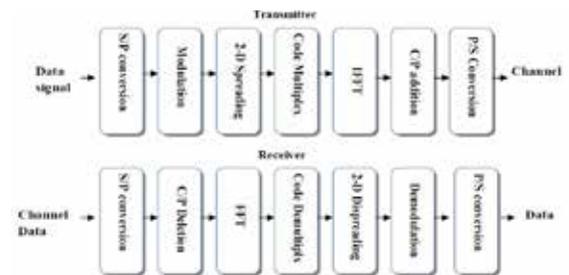


Fig.1 Block diagram of OFCDM transmitter & receiver

which convert high frequency subcarrier and then cyclic prefix block is inserted to avoid the inter symbol interference. Finally OFCDM symbol is transmitted in broadband wireless channel.

**Receiver:** At the receiver, all process is just opposite to the transmitter side, first of all cyclic prefix is removed after that FFT is performed which down convert the sub carrier after that demodulation is done then decoding and lastly parallel to serial (P/S) converted and retrieved original data.

### III Peak power problem

As from the system model of OFCDM, there is IFFT operation at the transmitter side. Due to this IFFT operation peak power problem arises[4]. Peak power is always compared with average power and their ratio is defined as peak to average power ratio (PAPR) of any transmitted signal  $x(t)$ , which is given by equation as,

$$PAPR = \frac{\max(|x(t)|^2)}{\text{mean}(|x(t)|^2)} \quad (2)$$

where  $\max(|x(t)|^2)$  is peak power and  $\text{mean}(|x(t)|^2)$  is average power of  $x(t)$ . PAPR is represented in dB by,

$$PAPR(\text{dB}) = 10 \log_{10} PAPR \quad (3)$$

PAPR is major issue in all multicarrier system. As OFCDM is multicarrier system it also suffer from PAPR. Consider a single carrier system with BPSK modulated symbols  $s(0), s(1), s(2), \dots$  is represented by level  $+a$ , then power in each symbol is  $a^2$  and average power  $E[s^2(k)] = a^2$ . Hence in single carrier system both peak and average power is  $a^2$ . Hence the ratio

$$PAPR = 10 \log \frac{\text{Peak Power}}{\text{Average Power}} \quad (4)$$

is equal to  $10 \log(a^2 / a^2) = 1 = 0\text{dB}$ . Hence there is no significant deviation of peak power from average power level. Now suppose, symbols  $S(0), S(1), S(2), \dots, S(N-1)$  are the IFFT of  $s(0), s(1), s(2), \dots, s(N-1)$ . Then  $k$ th IFFT sample is given by

$$S(k) = \frac{1}{N} \sum_{i=0}^{N-1} s(i) e^{j2\pi \frac{ki}{N}}$$

Then average power,  $E\{S(k)^2\} = \frac{1}{N^2} \sum_{i=0}^{N-1} E\{|S(i)|^2\} E\{|e^{j2\pi \frac{ki}{N}}|\}$

Because  $E\{e^{j2\pi \frac{ki}{N}}\} = 1$ ,  $E\{S(k)^2\} = \frac{1}{N^2} \sum_{i=0}^{N-1} E\{|S(i)|^2\}$

$$E\{S(k)^2\} = \frac{1}{N^2} \sum_{i=0}^{N-1} a^2$$

$$E\{S(k)^2\} = \frac{a^2}{N}$$

Hence average power =  $a^2/N$ . For peak power suppose a symbol

$$S(0) = \frac{1}{N} \sum_{i=0}^{N-1} s(i) e^{j2\pi \frac{0i}{N}}$$

$$S(0) = \frac{1}{N} \sum_{i=0}^{N-1} s(i)$$

Now let  $s(0) = s(1) = s(2) = \dots = s(N-1) = +a$ . Then

$$S(0) = \frac{1}{N} \sum_{i=0}^{N-1} s(i) = \frac{1}{N} \cdot aN = a$$

So peak power =  $a^2$ . Then peak to average power ratio =

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

So there is significant swing of peak power from average power, as number of subcarrier  $N$  increases. Which can be shown in table?

**TABLE I**  
**PAPR FOR BPSK AND QPSK MODULATION IN (dB)**

N	1	2	4	8	16	32	64	128
BPSK	0	3.01	6.02	9.03	12.04	15.05	18.06	21.07
QPSK	0	3.01	6.02	9.03	12.04	15.05	18.06	21.07

Thus from the table PAPR increases as number of subcarrier  $N$  increases, no matter what modulation scheme is used. Hence high value of PAPR in OFCDM is due to the IFFT operation. Due to this data symbols across the subcarrier can add up to produce high peak value. PAPR is characterized by Complementary Cumulative Distribution Function (CCDF).

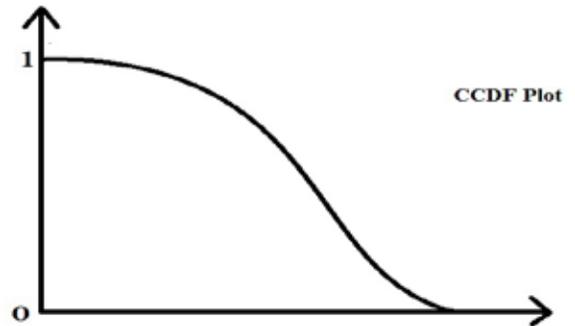
**CCDF**

CCDF stand for complementary cumulative distribution function. CCDF is defined as probability that a random variable  $X$

exceeds a particular value  $x$  means

$$F_x(x) = P(X > x) \text{ or } CCDF = 1 - CDF.$$

CCDF curve start from one and slowly goes to zero, means probability of higher value of random variable decreases. Typical CCDF curve is as follows-



Ideally PAPR curve should be at zero dB line means peak power and average power both are equal. For single carrier system the PAPR curve lie on zero dB line but it vary for

OFCDM system, means there is certain probability that peak power is higher than average power.

**Effect of PAPAR on OFCDM**

Transistor work as an amplifier in linear mode but when peak deviation about average is significantly high then signal level moves into non linear region of amplifier characteristics. So output of amplifier gets distorted. So non linear distortion occurs, due to these nonlinearity OFCDM losses its orthogonality that leads to inter carrier interference (ICI) and Inter Symbol Interference (ISI). So the bit error rate (BER) of system increases and overall performance get decreases. Thus PAPR reduction is very necessary.

**IV Subcarrier processing (SCP) technique**

There have been many new approaches developed during the last few years. Several PAPR reduction techniques have been proposed in the literature. These techniques are divided into

two groups, (I) signal scrambling techniques and (II) signal distortion techniques.

Signal scrambling technique includes method as,

- 1 Selective Mapping (SLM)
- 2 Block Coding Scheme
- 3 Partial Transmit Sequence (PTS)
- 4 Interleaving Scheme
- 5 Tone Reservation (TR) and
- 6 Tone Injection (TI)

Signal Distortion Technique consist of methods as,

- 1 Peak Windowing Technique
- 2 Peak Reduction Carriers
- 3 Clipping and Filtering etc.

Signal scrambling techniques work with side information which minimized the effective throughput since they commence redundancy. Signal distortion techniques introduce band interference and system complexity also. So to avoid these drawbacks SCP technique is proposed. One of the signal distortion methods of PAPR reduction is clipping, in which

when signal level exceeds certain value( clip value), the signal clips. But due to high clipping, power distortion occurs, which is termed as clipping noise, due to which in-band distortion

occurs. Dardari [5], showed that, in-band distortion causes shrinking of signal constellation. The shrinking of signal constellation means reduction in Eb, which results reduction

of overall Eb/N0 of all subcarriers, that causes degradation of Bit Error Rate (BER) of the system. So, clipping beyond certain level max up to 6 dB for any multicarrier system [5] is not permitted. But clipping less than 6 dB is very effective to reduce PAPR, because it is simple and no complexity is added in the system on application of it. In this paper, subcarrier processing (SCP) technique has been proposed, by addition of two methods, single carrier (SC) and clipping, because both techniques are simple and easy to implement. In SCP first PAPR of system is brought back to clipping range 6 dB as mentioned above by use of single carrier (SC) method and then clipping is performed to reduce PAPR considerably. If we convert multicarrier system

into single carrier, then advantages of multi-carrier system like spectral efficiency and high throughput will be lost. On the other hand, if system is purely multicarrier system, then

PAPR increases. In order to reduce effect of PAPR, it is necessary to convert multicarrier into single carrier upto some level keeping in mind spectral efficiency and throughput of

multicarrier system. The proposed method of sub-carrier processing includes optimize level of conversion from multi-carrier system to single carrier system with small level of clipping maximum up to 6 dB [5].

The basic idea is to group the data symbols to be transmitted into blocks and use smaller size IFFT to map symbols with the same number of subcarriers. So here the system is converted into single carrier system by first taking M-point FFT and then N-point IFFT. If M is equal to N then multicarrier system completely converts into single carrier system, which is not desired because spectral efficiency and throughput of single carrier system is low. So it is desired that M should be less than N, then system will act like multicarrier system. Due to this optimized multicarrier system, again PAPR increases but lesser as compared to purely multicarrier system which can be further removed by small amount of clipping. So, SCP method reduces PAPR considerably and also limits disadvantages of clipping as well as single carrier system. In SCP there is simple modification in transmitter as well as receiver side. At transmitter side the modulated symbol is grouped into M block symbols & then M-point FFT operation is performed which converts these data symbol from time domain to frequency domain. The frequency domain samples are mapped into N subcarriers, typically  $M < N$  & then N-point IFFT operation is performed to convert frequency domain symbols into time domain symbols after that cyclic - prefix is added & parallel data converted to serial one then transmitted.

As in OFCDM each data is carried by individual subcarrier but in this method many subcarrier carry the same data because mapped data is less as compared to number of subcarriers. Proposed SCP transmitter and receiver schematic is given in fig.3.

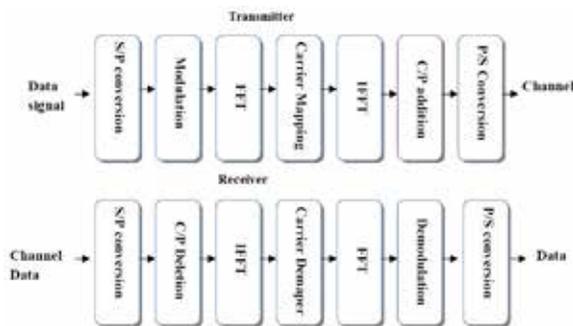


Fig.3 SCP transmitter and Receiver

Thus in SCP method FFT is performed before IFFT at the transmitter side and their values are different, so some types of mapping must be involve matching symbols and subcarriers. Mapping means zeroes are added to subcarriers if they are vacant. Mapping is of two types 1.Distributed Mapping

2. Localized mapping

Distributed Mapping

The distributed mapping is also called interleaving. In this mapping zeros are not added in sequential manner but follow a fixed or variable gap between data. Proper interleaving leads

to significant reduction in PAPR. When zeros are appended in such a manner that no peaks of data overlap to each other then PAPR reduces considerably. Interleaving is shown in fig.4.

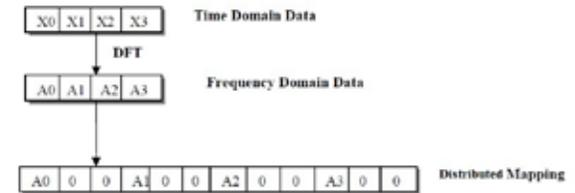


Fig.4 Distributed Mapping

Localized Mapping

In localized mapping the DFT outputs are mapped to subset of subsequent subcarriers, there by restrict them to a fraction of system bandwidth. Localized mapping are not as effective as interleaving. Localized mapping can be shown in fig.5.

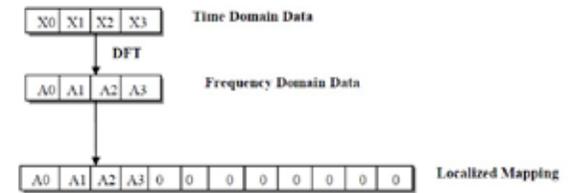


Fig. 5. Localized Mapping

V BER Performance of SCP

As peak-to-average power ratio (PAPR) decreases, the value of peak power decreases, due to reduction in peak power, interference power of subcarrier PICI get reduces, so the Bit

Error Rate (BER), which depends on interference power that can be shown by  $EQ^r$  13, [8]. So, performance of overall system improves.

$$BER_1 = \frac{1}{2} \left( Q \left( \cos \theta [p(-\Delta f) + \sqrt{P_{ici}}] \sqrt{\frac{2E_b}{N_0}} \right) \right) \quad (11)$$

$$BER_2 = \frac{1}{2} \left( Q \left( \cos \theta [p(-\Delta f) - \sqrt{P_{ici}}] \sqrt{\frac{2E_b}{N_0}} \right) \right) \quad (12)$$

$$BER_{symbol} = BER_1 + BER_2 \quad (13)$$

Where  $E_b/N_0$  is the signal-to-noise ratio per bit;  $E_b$  is the energy per bit;  $N_0$  is the double-side power spectral density of the white Gaussian noise;  $\theta$  denotes the carrier phase noise;  $\Delta f$  is the carrier frequency offset; N is the number of sub-carriers;

Q - Is the error function. Thus from  $EQ^r$  -13, it is clear that when the value of  $P_{ici}$  decreases the value of bit error rate (BER) decreases.  $p(f)$  is a sinc function, which is given by following equation

The total bit error rate is given by

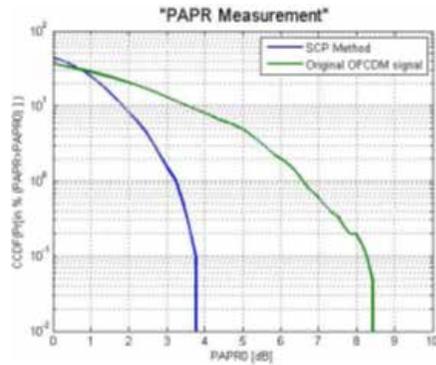
Using above equations, simulation has been performed for BER for SCP.

**VI Simulation**

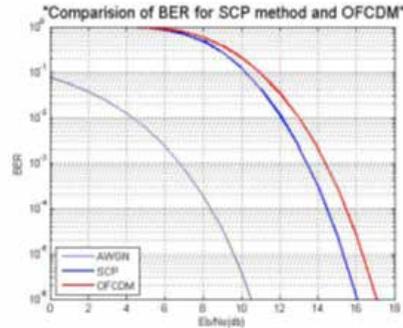
The parameters that have been taken for simulation is shown in table Using above parameters, simulation has been performed for PAPR, using different modulation schemes.

No. of subcarriers	1024
No. of FFT points	64
No. of IFFT points	128
Modulation	BPSK
Mapping	Distributed
No. of times algorithm runs	1000
Maximum power limit	46
SNR	15
Channel	AWGN Channel

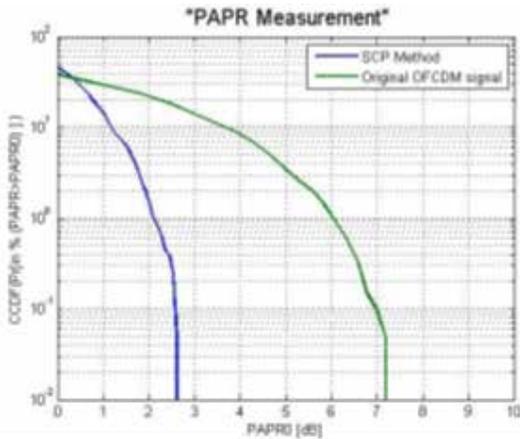
Here PAPR graph is plotted using complementary cumulative distribution function (CCDF) function. when interleaving is performed then PAPR reduces significantly and it reaches up to 7 dB. From the graphs, it is clear that probability of PAPR being greater, in OFCDM is more as compared to SCP, means peak power of OFCDM symbols is greater than SCP symbols. So inter carrier interference power  $P_{ICI}$  is higher in OFCDM system than SCP system. Same is applicable for next two graphs, but due to application of different modulation schemes, amount of PAPR reduction is different. Here simulation is performed using above equations, by taking  $\Theta = 0^\circ$ . Normalized frequency offset = 0.3, Number of sub-carrier N is 52.



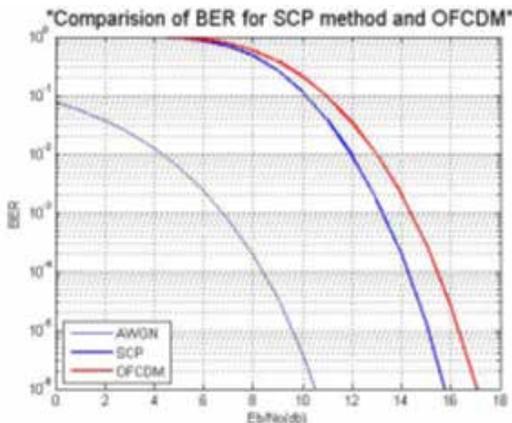
**Fig.7 Result using QPSK Modulation**



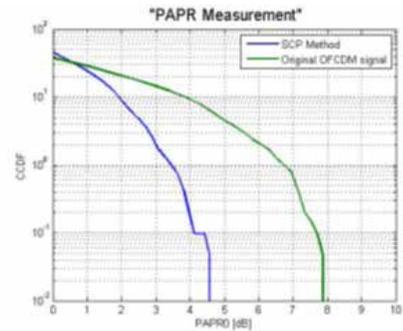
**Fig.10 BER Simulation result for PAPR Reduction using QPSK modulation**



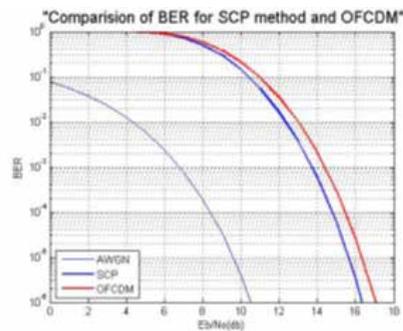
**Fig. 6. Result using BPSK Modulation**



**Fig.9 BER simulation result for PAPR Reduction using BPSK modulation**



**Fig.8. Result using QAM-16 Modulation**



**Fig.11 BER Simulation result for PAPR Reduction using QAM-16 modulation**

**VII Result Analysis and Discussion**

Simulation results can be analyze in better way by following table,

Modulation schemes	PAPR Reduction	BER Improvement of SCP Over OFCDM
BPSK	4.5 dB	0.000099
QPSK	4.3 dB	0.000009
QAM16	3 dB	0.000006

Thus we can see from the table that PAPR reduced 4.5 dB when BPSK modulation technique has been use, 4.3 dB for QPSK and 3 dB for QAM-16. Because symbols are more closer in QAM-16 as compared to BPSK and QPSK So interference occurs more in QAM-16 as compared to QPSK and BPSK. So PAPR reduction is lesser in QAM-16 as compared to QPSK and BPSK. Thus when PAPR reduced then according to Eqn-13 BER of system get reduced. So the SCP technique offer improved BER. As from the table, it can be seen that BER improvement is maximum when BPSK modulation technique is used and minimum in case of QAM-16.

### VIII Conclusion

In this paper, simulation has been performed for PAPR as well as bit error rate(BER). From the results, it is clear that, the proposed SCP technique gives lesser PAPR as compared to present in original OFCDM system. Reduction in PAPR means reduction in peak power, due to which, interference power of subcarrier decreases. When inter carrier interference power decreases, then bit error rate (BER) decreases and then throughput of the system increases, which is desired for any communication system.

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