PAPR REDUCTION IN MIMO SC-FDMA- A SURVEY

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ABSTRACT
To meet the requirements of high data rate, third generation partnership project (3GPP) has come across the development of long term evolution (LTE). High data rate can be achieved with the help of an advanced modulation method. Orthogonal Frequency Division Multiple Access (OFDMA) was considered as a modulation method especially in the downlink of the communication systems. It gives many advantages like frequency diversity, increased capacity and robustness against impulse noise. Besides these advantages, a major drawback of OFDMA is its high peak-to-average power ratio (PAPR). High PAPR affects the system by lowering the power amplifier efficiency, increased complexity as well as shorter battery life. In case of uplink communication, where better peak power characteristics benefit the mobile terminals with respect to power efficiency, OFDMA is not a possible solution. To handle such situations, 3GPP has introduced a modified form of OFDMA which is known as Single-Carrier Frequency Division Multiple Access (SC-FDMA). It provides same advantages as OFDMA along with low PAPR. To further improve the bit error rate (BER) performance of the system and power amplifier efficiency Multiple-Input Multiple-Output (MIMO) can be extended to SC-FDMA system. This paper surveys causes, effects and possible solutions of high PAPR in a communication system.

Keywords – PAPR, OFDMA, SC-FDMA MIMO SC-FDMA, BER

Introduction

In conventional wireless communications, a single antenna is used at the source, and another single antenna is used at the destination. In some cases, this gives rise to problems with multipath effects. When an electromagnetic field (EM field) is met with obstructions such as hills, buildings etc the wave fronts are scattered and thus they take many paths to reach the destination. The late arrival of scattered portions of the signal causes problems such as fading. In digital communication systems such as wireless internet, it can cause a reduction in data speed and an increase in the number of errors. The use of two or more antennas, along with the transmission of multiple signals one for each antenna at the source and the destination eliminates the trouble caused by multipath wave propagation[1].

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Multiple Input Multiple Output (MIMO) technology has acquired interest because of its possible applications in digital television, wireless local area networks (WLANs), metropolitan area networks (MANs) and mobile communications.
Multiple Input Multiple Output (MIMO) is an antenna technology for wireless communications in which multiple antennas are used at both the transmitter and the receiver. The antennas at each end of the communications circuit are combined to minimize errors and optimize data speed. MIMO transmission can be used for both uplink and downlink. For wideband channels, orthogonal frequency division multiplexing (OFDM) has to be used with MIMO techniques for ISI mitigation and capacity improvement. Single-carrier FDMA (SC-FDMA) is a frequency division multiple access scheme that deal with the assignment of multiple users to a shared communication resource. MIMO SC-FDMA employs spatial multiplexing and dynamic bandwidth assignment [4]. Spatial multiplexing provides additional data capacity by making use of different paths which carries additional traffic. In other words it increases the data throughput capability. To achieve a better cellular coverage and power amplifier efficiency

it is required to make use of MIMO SC-FDMA with low Peak to Average Power Ratio (PAPR).

The remainder of this paper is organized as: Section II gives an overview of OFDMA, SC-FDMA and MIMO SC-FDMA. Section III discusses the causes and effects of high PAPR. Section IV gives possible solutions for PAPR problem. Section V concludes the paper.

OVERVIEW OF OFDMA AND SC-FDMA

A.OFDMA

One of the key elements of LTE is the use of Orthogonal Frequency Division Multiple Access (OFDMA). OFDMA is a multiple access scheme that multiplexes the data on multiple carriers and transmits them in parallel. The assignment of subcarriers to individual users allows simultaneous low data rate transmission from several users. The basic idea of OFDMA is the division of a high speed digital signal into various slower signals and transmission of each slower signal in a separate frequency band. The slow signals are frequency multiplexed to create one waveform in such a way that the symbol duration in each one is long enough to eliminate inter-symbol interference (ISI). One of the key parameters associated with the use of OFDMA within LTE is the use of a wider transmission bandwidth which causes the problem of ISI. Since the bandwidth is divided into several narrower subchannels, each subchannel requires a longer symbol period. Therefore, OFDMA systems can overcome the intersymbol interference (ISI) problem. The other main advantages of OFDMA [1] include:

a). For a particular channel delay spread, the receiver complexity is much lower than that of a single carrier system.

b). Spectral efficiency is high since it uses overlapping orthogonal subcarriers.

c). Capacity can be increased by adapting the data rate per subcarrier according to the signal-to-noise ratio (SNR) of the individual subcarrier.

Besides these advantages, the main drawback of OFDMA is the high peak-to-average power ratio (PAPR). Since the transmitted signal is the sum of many modulated subcarriers, at certain point of time the sum may be larger than the average value and at other times it may be smaller which points to the fact that the peak value is larger than the average value [7]. The result of high PAPR is low power efficiency, increase in the complexity of analog-to-digital and digital-to-analog converter, degradation in BER performance of the system etc. To overcome these problems, Third Generation Partnership Project (3GPP) has introduced a modified form of OFDMA known as Single Carrier Frequency Division Multiple Access (SC-FDMA). OFDMA transmits a multi-carrier signal whereas SC-FDMA transmits a single carrier signal. Because of this, SC-FDMA has a lower peak-to-average power ratio (PAPR) than OFDMA.

B. SC-FDMA

Single Carrier Frequency Division Multiple Access (SC-FDMA) is a technique used for high data rate uplink transmission. SC-FDMA is a modified form of OFDMA with similar throughput performance and complexity. It can be considered as DFT-coded OFDM where discrete Fourier transform (DFT) block in the transmitter side which is absent in OFDMA converts the time domain signal to frequency domain signal. This is illustrated in figure 1 [1].

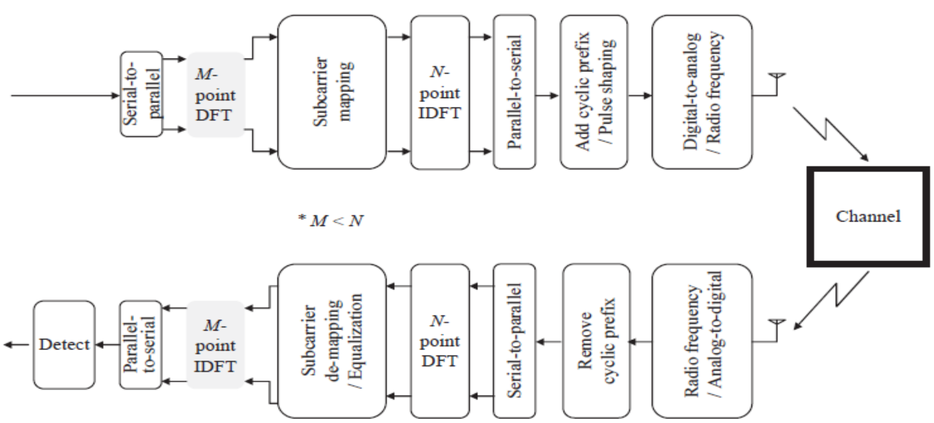

Figure 1: Block diagram of SC-FDMA [1]

Similarly, in the receiver IDFT block present helps in the transformation of frequency domain symbols back to time domain. SC-FDMA has the same advantage as OFDMA like its robustness against multipath signal propagation. An additional advantage of SC-FDMA is its low peak-to-average power ratio (PAPR) compared to OFDMA making it suitable for uplink transmission by user-terminals.

C. MIMO SC-FDMA

Single Carrier Frequency Division Multiple Access (SC-FDMA) can be extended to a Multiple-Input Multiple-Output (MIMO) SC-FDMA scheme in order to improve the bit error rate (BER) performance of the system, provide high throughput by spatial multiplexing and reduce the interference from other users. Figure 2 and 3 **[6]** shows the transmitter and receiver structure of MIMO SC-FDMA. There are u users with $N_T^{(u)}$ transmit antennas and N_R receive antennas. The transmitted signal after spatial multiplexing undergoes a transformation from time domain to frequency domain using DFT block of length $N_{DFT}^{(u)}$. The transformed symbols undergoes subcarrier mapping which may be Distributed mapping (DFDMA) or Localised mapping (LFDMA). Afterwards the symbols are fed to IFFT block of length $N_{IFFT}^{(u)}$to transform back to time domain. The addition of cyclic prefix to overcome the problem of ISI is done next and symbols are transmitted simultaneously from antennas.

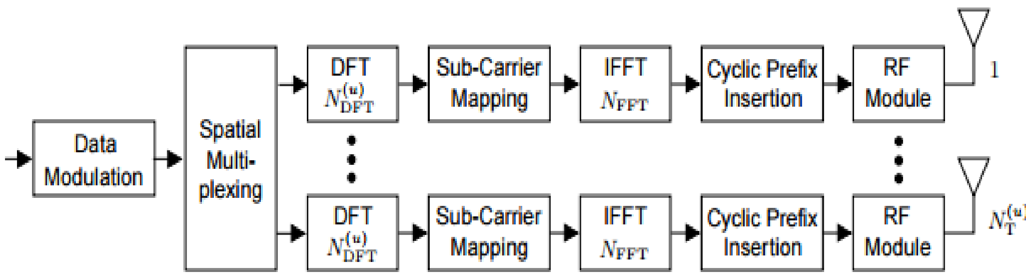

Figure 2:MIMO SC-FDMA Transmitter [6]

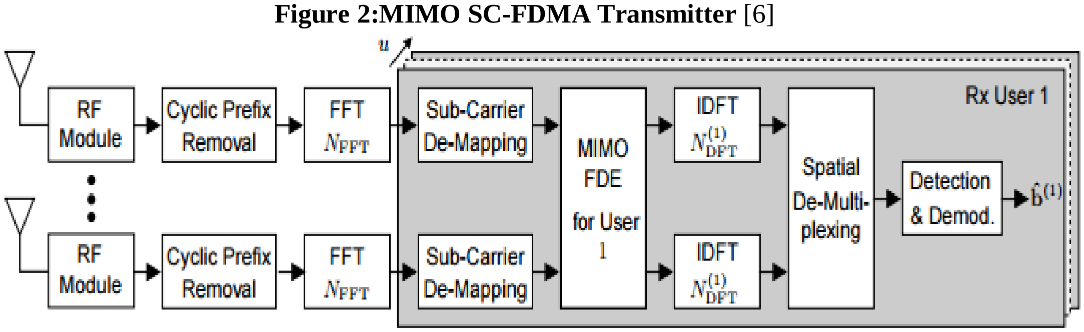

Figure 3: MIMO SC-FDMA Receiver [6]

The receiver structure performs the reverse operation of the transmitter structure. In addition to that separate frequency domain equalisation is done for each user. Equalization is used because it helps to reduce the ISI in the signal. Time domain equalizers are very complex in high ISI channel and difficult to implement [7] and hence frequency domain equalizers are preferred. In addition to that equalizers makes the SC transmission more easily with less complexity.

CAUSES AND EFFECTS OF HIGH PAPR

The main requirements of a mobile user includes low bit error rate (BER), high data rate, high spectral efficiency, low peak-to-average power ratio (PAPR), high power efficiency and low computational complexity [7]. Among these requirements, PAPR is an important factor to be considered. But in some situations, the system performance may degrade due to high PAPR. Hence it is essential to reduce the PAPR. The problem of high PAPR arises in multicarrier communication system whereas it is low for single carrier communication system because of its single-carrier structure.

A). Causes of high PAPR

The peak-to-average power ratio (PAPR) is defined as the ratio of peak power to average power of the transmitted signal in a given transmission block. PAPR occurs during the summation of carriers together. Multicarrier signals like OFDM signals have modulated subcarriers with different amplitude and phase. These subcarriers are all transmitted at the same time. When these subcarriers get added up, sometimes the peak power becomes greater than the average power and results in high PAPR. Due to high PAPR in OFDMA signals, the signals will be clipped when passed through nonlinear power amplifier resulting in signal distortion. The intermodulation distortion caused due to signal distortion can be avoided by using highly linear power amplifiers operating with a large backoff **[11]**. But the result is low power efficiency.

B). Effects of high PAPR

For signals with high PAPR, if the input power is not decreased it may cause signal distortion which inturn produce intermodulation distortion. To avoid this distortion, the signals need highly linear power amplifiers that operates with large backoff. This leads to poor power efficiency of amplifiers and small battery life [3].

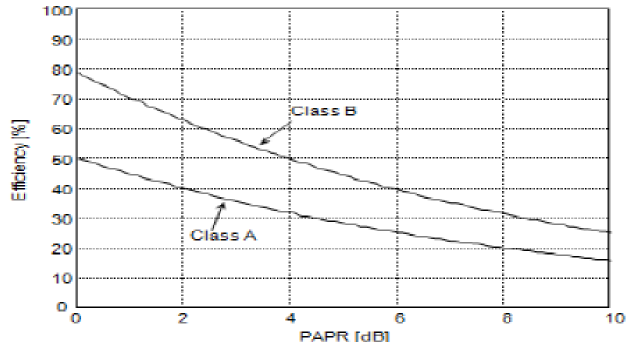

Figure 4:A theoretical relationship between PAPR and transmit power efficiency for ideal High power amplifier [3]

Another effect of high PAPR is the increased complexity of analog-to-digital converter and digital-to-analog converter due to an increase in quantization error. Other than high PAPR, in some cases bit error rate (BER) degradation may be only negligible [4].

POSSIBLE SOLUTIONS FOR PAPR PROBLEM

PAPR is an important factor to be considered in the design of mobile terminals especially in the uplink of the communication system. High PAPR may cause poor amplifier power efficiency, increased complexity of the system, shorter battery life etc. Thus it is essential to reduce PAPR inorder to achieve a better performance for the system.

Different PAPR reduction methods have been developed for MIMO SC-FDMA systems. One method to decrease PAPR is to increase the roll-off factors of the pulse shaping filters. Ref [9] gives such a method. The commonly used subcarrier mapping methods are Interleaved Frequency Division Multiple Access (IFDMA) and Localized Frequency Division Multiple Access (LFDMA). Among the two, IFDMA has less PAPR because the data symbols are distributed in an evenly spaced manner to the system bandwidth.

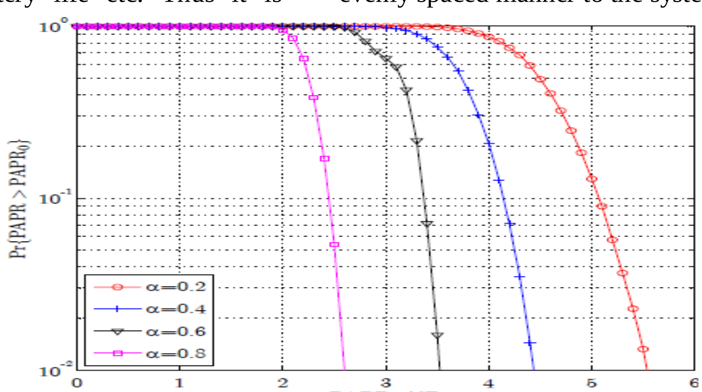

Figure 5: PAPR for different pulse shaping roll-off factors using IFDMA [9]

Other than this, two codes used for PAPR reduction are Space-Frequency Block Code (SFBC) and Space-Time Block Code (STBC). The use of conventional SFBC as such is not preferred because it may change the spectral components of the transmited signals and hence destroy the low PAPR property [10]. Ref [5] shows a better PAPR reduction using an innovative mapping method with SFBC. For this, two schemes developed are orthogonal single-carrier SFBC and quasi-orthogonal single-carrier SFBC. In the first scheme, a matrix corresponding to Alamouti based SFBC scheme is obtained in a way that PAPR of obtained signal ia same as PAPR of original signal. In the second scheme, QO code is obtained such that it preserves the SC like nature of the signal along with low PAPR. Hence the use of innovative mapping methods helps to provide a good PAPR performance and preserve the single-carrier nature of SC-FDMA signal. But a limitation is performance degradation due to non-adjacent subcarriers.

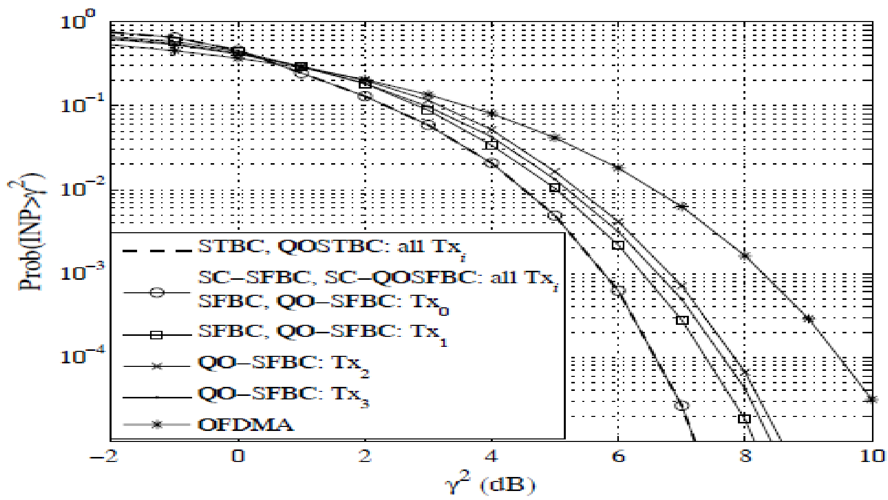

Figure 6: PAPR performance of SC-QOSFBC, SC-SFBC and other schemes [5]

A novel space-frequency block coding also helps to reduce PAPR **[2]**. The mapping of data symbols to subcarriers as the original symbols on DFT output of the transmitter block causes the reduction in PAPR.

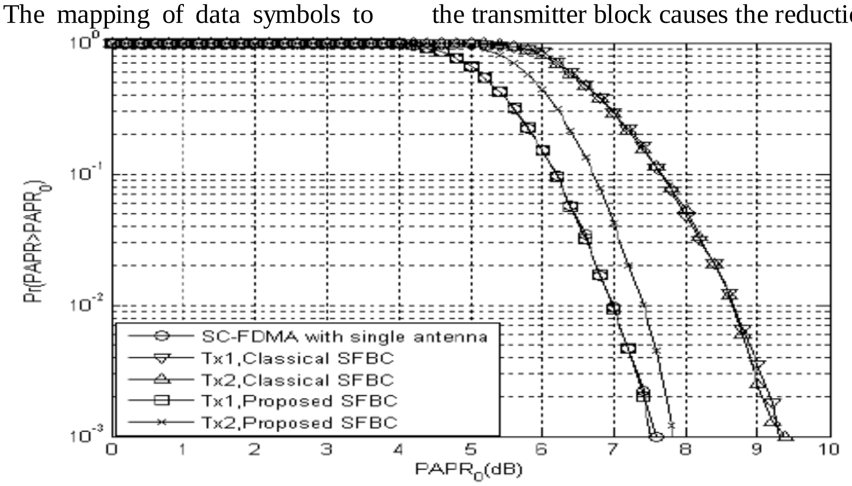

Figure 7: CCDF of PAPR for QPSK [2]

For the proposed SFBC scheme, reduction in PAPR is noticed for first transmit antenna which is same as SC-FDMA with single antenna. Second transmit antenna shows a slightly increased PAPR compared to single antenna transmission. From the graph it is clear that for classical SFBC scheme PAPR increases since the mapping changes the structure of original DFT output symbols. The scheme also brings additional advantages like improvement in power amplifier efficiency and cellular coverage.However its use makes only negligible BER degradation.

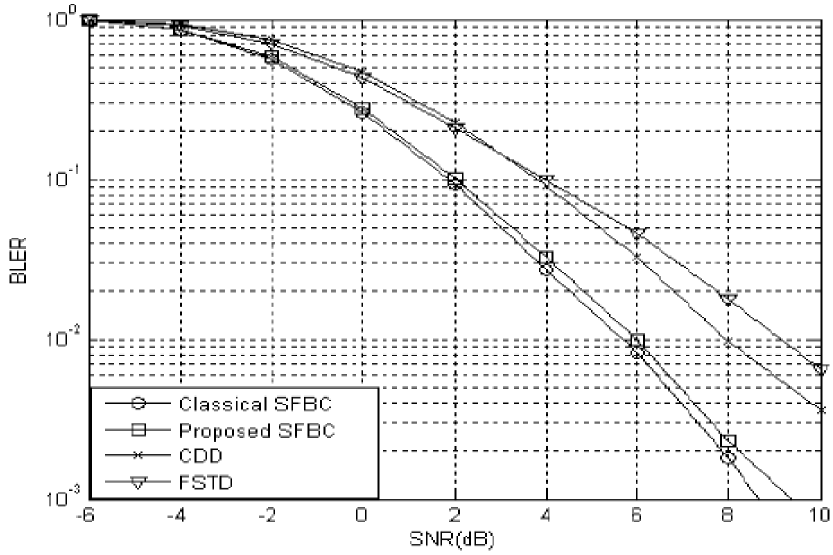

Figure 8: BER performance for QPSK [2]

A good PAPR reduction is also obtained by the use of modified SFBC, modified Quasi-orthogonal SFBC (QOSFBC) and modified SFBC with Frequency Switched Transmit Diversity (FSTD) instead of conventional SFBC, QOSFBC and SFBC with FSTD because the use of conventional schemes destroys the low PAPR property [4]. In the conventional scheme, frequency inversion between subcarriers changes the frequency structure of the transmitted signals thereby destroying the single carrier property of the signal and SC-FDMA loses its low PAPR advantage. In the case of modified schemes, the data symbols are mapped as original symbols on DFT output and therefore provide a good PAPR performance. The schemes have been used for two and four transmit antennas. In case of two transmit antennas, performance of first antenna shows that proposed SFBC has low PAPR same as [2] and better than [10]. Similarly, performance of second antenna concludes that proposed scheme has low PAPR than other methods. Figures 9-12 shows that the proposed modified scheme is better than conventional schemes in terms of PAPR reduction.

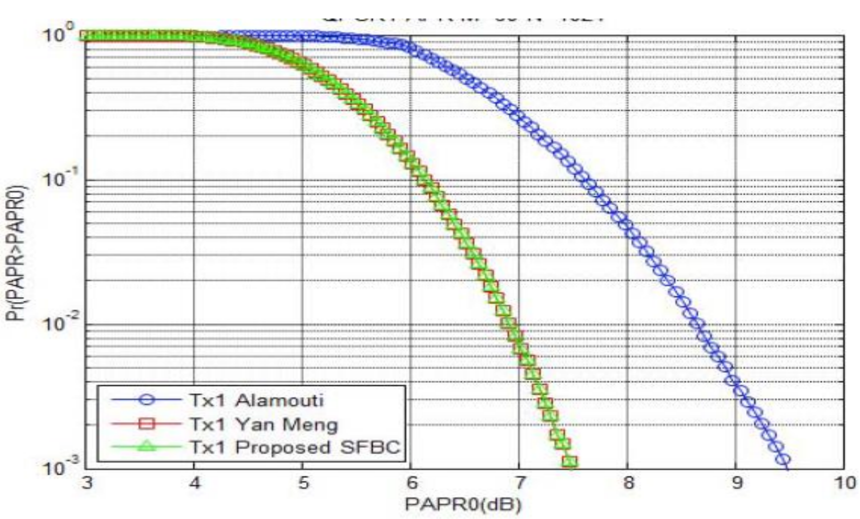

Figure 9: PAPR performance for T_{x1} in two ransmit antennas [4]

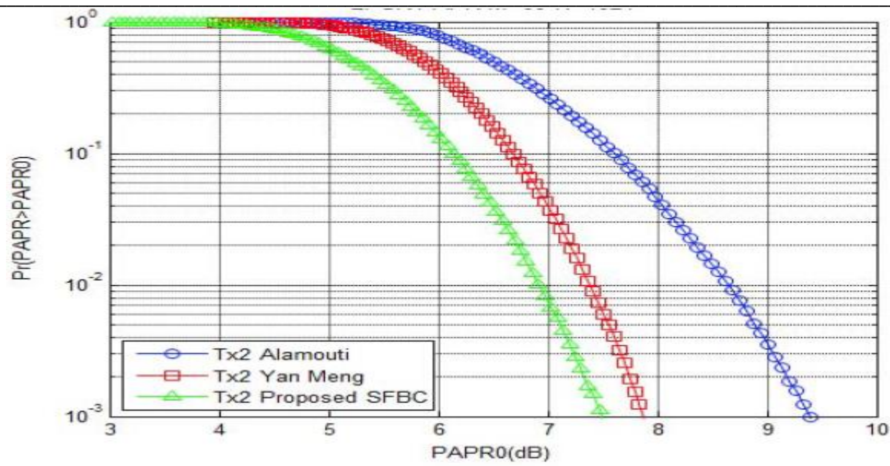

Figure 10: PAPR performance for T_{x2} in two transmit antennas [4]

Similarly, PAPR performance have been obtained for four transmit antennas using QOSFBC and SFBC with FSTD. The PAPR performance for four antennas showed that proposed QOSFBC scheme has the lowest PAPR. Also, proposed SFBC with FSTD has better PAPR reduction than Alamouti-based SFBC with FSTD and SFBC scheme in [2] with FSTD. In Frequency Switched Transmit Diversity (FSTD), different groups of subcarriers are transmitted from different transmit antennas.

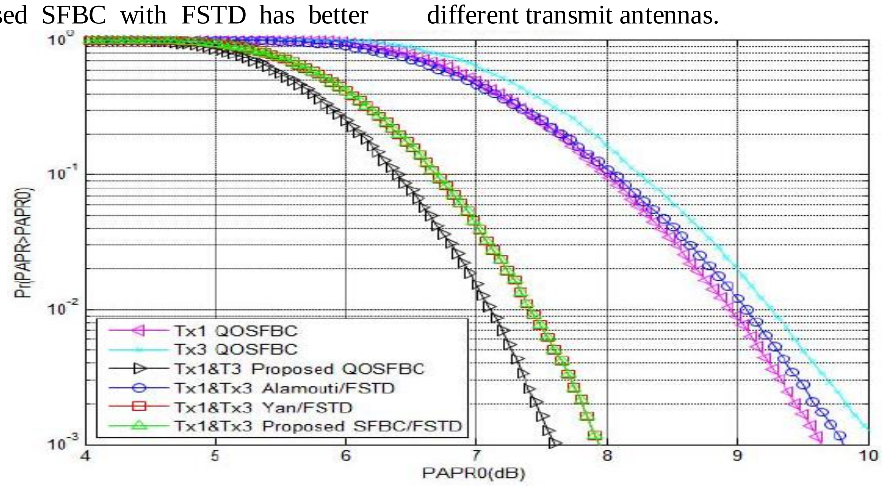

Figure 11: PAPR performance for $T_{x1}$and T_{x3} in four transmit antennas [4]

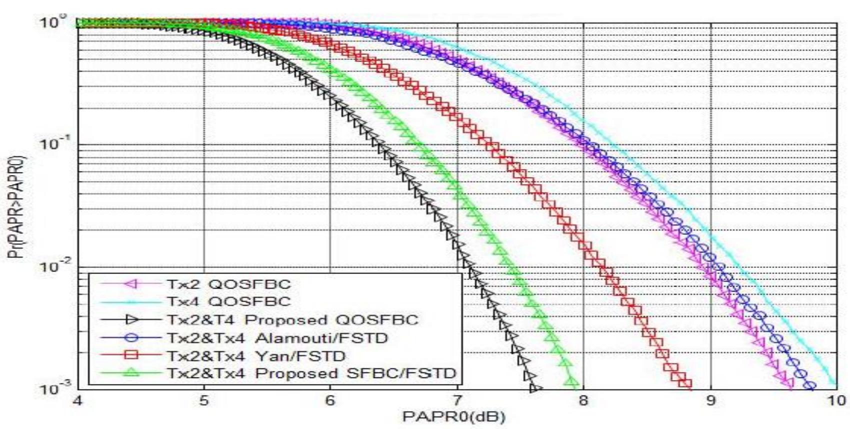

Figure 12: PAPR performance for T_{x2} and T_{x4} in four transmit antennas [4]

But BER degradation is negligible as in figures[13] and [14]. All proposed methods shows only negligible BER degradation in case of both two and four transmit antennas. It is necessary to reduce the BER, which inturn helps to improve the system peformance. Therefore it is essential to look for a modified scheme that reduces BER, at the same time decreasing PAPR.

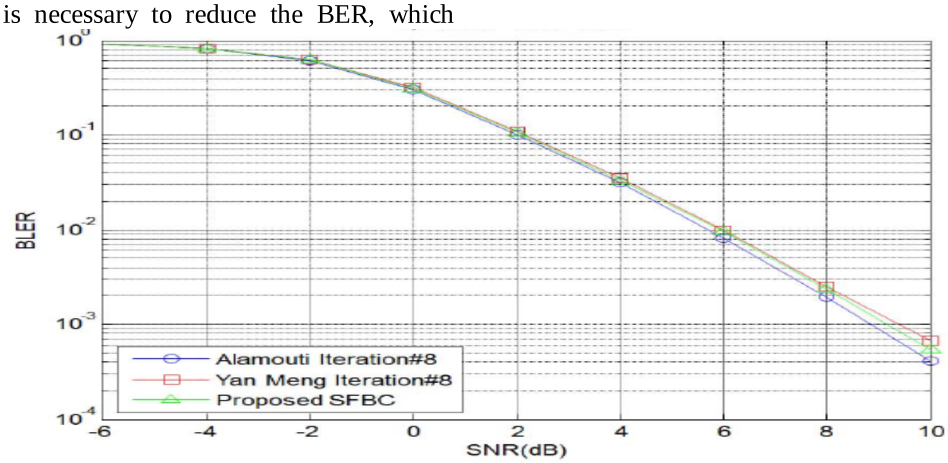

Figure 13: BLER performance for two transmit antennas [4]

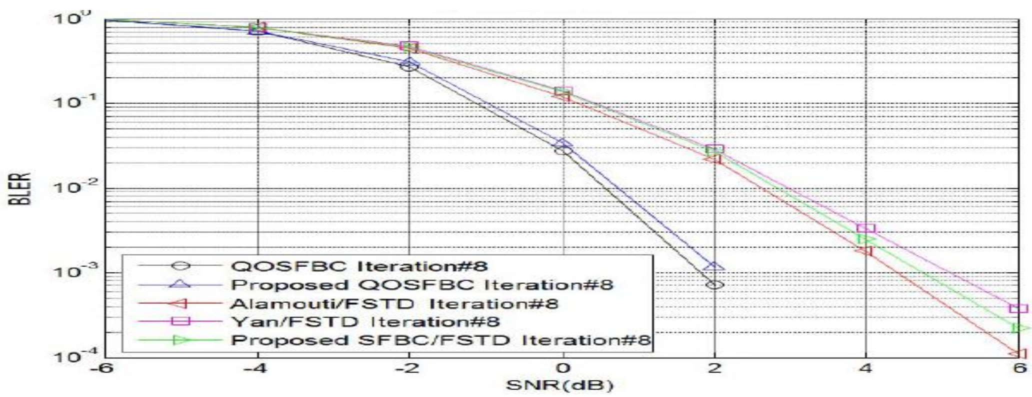

Figure 14: BLER performance for four transmit antennas [4]

Since BER is influenced by coding and modulation techniques, a good degradation along with low PAPR can be obtained by changing the coding and modulation techniques. Lower order modulation techniques like BPSK, QPSK etc and coding schemes like space-time block codes (STBC) are preferred.

CONCLUSION

In this paper we have done a survey on the works done by various researches for PAPR reduction. It is essential for the uplink of the communication system to achieve a low PAPR property. Many works pointed out the ways to obtain low PAPR along with improved power amplifier efficiency and high throughput. The frequency inversion of signals must be avoided as they changes the spectral components of the transmitted signal thereby causing destruction of single-carrier property and low PAPR. It is also necessary to reduce BER degradation along with PAPR reduction. Through this paper, we are recommending various solutions for PAPR problem amd BER degardation. Other than the proposed methods another solution is the use of lower order modulation techniques like BPSK or QPSK and coding schemes like space-time block codes (STBC) which is believed to give a better performance than the existing methods.

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