CHAPTER 2

REVIEW OF LITERATURE

The issue of the OFDM system is high PAPR of transmitted signal at the transmitter side which degrades the performance of the system when a non-linear HPA is to be used. So, it is necessary to use an appropriate PAPR reduction technique at the transmitter side. In this chapter, the detailed analysis of PAPR, the PAPR reduction techniques and low complexity schemes are discussed. In the following sections, techniques for PAPR reduction in OFDM, complexity reduction for OFDM, weighted schemes and SLM schemes that are available in the literature has been discussed.

2.1 PAPR reduction in OFDM

Liu and Li (2005) inherited the conventional OFDM which includes several attractive properties from the FFT, such as partially overlapping but still orthogonal subcarriers, cyclic convolution property due to the CP, which can diagonalize the channel matrix to achieve single-tap equalization and relatively low implementation complexity.

Jiang and Wu (2008) addressed several PAPR reduction techniques. These distinctive different techniques provide different degrees of effectiveness and present various sets of tradeoffs that may include increased system complexity, reduced spectral efficiency and performance for improved linearity.
Baig et al. (2010) implied that the direct and inverse transforms are identical. Both the functions can be carried out using the same process. When Hartley transform is a real trigonometric transform, the Fourier transform always implies a complex processing and the phase carry fundamental information.

I. Baig and V. Jeoti (2010) analyzed DHT precoded OFDM system using M-QAM. The computer simulation results of DHT precoded OFDM system with Discrete Fourier Transform (DFT) precoded OFDM system, WHT precoded OFDM system, SLM based OFDM system and conventional OFDM were compared. Simulation results has been shown that the PAPR of DHT precoded OFDM system is lower than WHT precoded OFDM system, SLM-OFDM system and OFDM conventional.

Y. Rahmatallah and S. Mohan (2013) addressed PAPR problem in OFDM systems and generated taxonomy of the available solutions to mitigate the problem. The survey described the most commonly encountered impediment of OFDM systems, the PAPR problem and consequent impact on PAs leading to nonlinear distortion. The analysis clearly defined the metrics based on which the performance of PAPR reduction schemes could be evaluated. Taxonomy of PAPR reduction schemes classified them into signal distortion, multiple signalling and probabilistic, and coding techniques with further classification within each category. The complexity analysis has been provided for a few PAPR reduction methods to demonstrate the differences in complexity requirements between different methods. Moreover, the paper provided insights into the transmitted power constraint by showing the possibility of satisfying the constraint without added complexity by the use of companding transforms with suitably chosen companding parameters. The rapid growth in multimedia-based applications has been triggered an insatiable thirst for high data rates and hence increased demand in OFDM-
based wireless systems that can support high data rates and high mobility. As the data rates and mobility supported by the OFDM system increase, the number of subcarriers also increases which in turn leads to high PAPR.

J. Zhou and Y. Qiao (2015) proposed a DHT-spread technique PAPR reduction in a DHT-based Asymmetrically Clipped Optical Orthogonal Frequency Division Multiplexing (ACO-OFDM) system. At the CCDF of $10^{-3}$, the PAPR values of the proposed scheme are about 9.7 and 6.2 dB lower than those of conventional DHT-based ACO-OFDM without DHT-spread technique for 2-Pulse Amplitude Modulation (2-PAM) and 4-PAM, respectively. The transmission experiment over a 100-km standard single mode fiber (SSMF) had been realized to verify the feasibility of the proposed scheme. When the overall link rate was about 10 Gb/s, the proposed scheme had an approximately 7-dB improvement of received sensitivity at forwarding error correction limit compared with the conventional scheme.

W. Wang et al. (2016) proposed a low-complexity TI scheme based on distortion signals. A proper subcarrier perturbation sequence from candidate subcarrier sets according to the mutual information between the peak sample, and the distortion signals were selected. With the chosen subcarrier perturbation sequence, the original problem has been decomposed into the sequential search problem, which provides a dramatic complexity reduction.

M.A. Khan and R.K. Rao (2016) proposed biased subcarriers for PAPR reduction in OFDM. A known time-domain reference sample is used to bias the subcarriers at the transmitter, and the same bias is used at the receiver to recover the sequence of original subcarrier samples. A closed-form analytical expression for CCDF of PAPR has been derived and illustrated as a function of the introduced bias. The effectiveness of the proposed technique was evaluated both analytically and numerically. Analytical and simulation results confirmed that significant reduction in PAPR could be achieved as it
showed that nearly 9.45 dB reduction in 0.1% PAPR could be attained for a
16-QAM OFDM system with 1024 subcarriers. Numerical result has been
shown that the average BER performance of the proposed system has not
been degraded. It has been found that the proposed technique had the lowest
complexity among the various available techniques for PAPR reduction.

S. Mazahir and S.A. Sheikh (2016) proposed two schemes that modify
the companding operation to accommodate the randomness of symbol power.
Probabilistic analysis of symbol's average power, in the relationship with the
amplitude of its constituent samples, has been carried out. In this yield the
theoretical framework employed in the design of the proposed low-
complexity solutions. The proposed schemes essentially made the
companding operation itself nondeterministic the adaptive, i.e.; it adjusts to
comply with the changing symbol amplitude distribution during application
runtime.

M. Chen et al. (2016) demonstrated an IFFT/FFT size efficient DFT-
spread OFDM based on complex-valued IFFT/FFT operations without
Hermitian symmetry constraint at the input, for short-reach, intensity-
modulated and directly-detected optical fiber transmission systems. The only
complex-valued IFFT-based OFDM has the similar PAPR and BER
performance, but with only half of the IFFT/FFT size as the conventional real
IFFT-based OFDM. The complex IFFT-based OFDM combined with the
DFT-spread technique was proposed and applied to reduce PAPR and
IFFT/FFT size, and improve BER performance at the same time. The
experimental results were shown that, with the help of PAPR reduction
enabled by DFT-spread, more than 2-dB improvement in receiver sensitivity
had been achieved after 20.62 km of single mode fiber transmission at a BER
of $3.8 \times 10^{-3}$ (7% hard-decision forward error correction threshold). Also
addition, by using the DFT-spread technique, the BER performance
comparison between complex IFFT-based OFDM and real IFFT-based OFDM was also performed. The results showed that the BER performance of the former is slightly worse than the latter, but has lower hardware complexity and less power consumption due to the reduced IFFT/FFT size.

2.2 Complexity Reduction in OFDM

Ahmed et al. (2010) introduced a new multicarrier system using a low computational complexity transform that combines the WHT and the DFT into a single fast orthonormal unitary transform. The proposed transform has been analyzed in a T-transform based OFDM called T-OFDM, for significant improvement in BER and a reasonable reduction in the PAPR.

C.K. Jao et al. (2010) investigated a Multi-Carrier Modulation (MCM) transceiver based on DHT. The diagonalization of the channel matrix is an important feature for the DFT-OFDM system. However, the conventional DHT-OFDM system could not directly diagonalize the multipath fading channel so that, the Inter carrier Coupling (ICC) effects will occur. A new DHT-based OFDM architecture has been proposed to deal with this problem, that can perfectly diagonalize the channel matrix by using the complemental property of DHT matrix. Also, two-dimensional complex signalling, such as QAM, can also be applied to the proposed structure for bandwidth efficient transmission. The compatibility of DFT-OFDM and DHT-OFDM systems has been considered.

M.S. Ahmed et al. (2011) introduced a new multicarrier OFDM system using a low computational complexity transform that combines the WHT and the DFT into a single fast orthonormal unitary transform. The proposed transform was implemented in a new OFDM called T-OFDM system, leading to a significant improvement BER and reasonable reduction in the PAPR. It has been found that the proposed transform with OFDM attains high
frequency diversity gain by combining all data samples resulting in the transmission over many subcarriers. Consequently, the detrimental effect arising from channel fading on the subcarrier power had been minimized. Theoretical analysis of an uncoded T-OFDM performance over AWGN, flat fading, quasi-static FS fading channel models with zero forcing equalizer (ZFE) and minimum mean square error (MMSE) equalizer was presented in this work. Moreover, the low superposition of the subcarriers passing through the T-transforms leads to a reduction in the high peak of the transmitted signal while preserving the average transmitted power and data rate. Simulation results demonstrated that the proposed T-OFDM system achieves lower PAPR and the same BER over AWGN and flat fading channels. Compared to OFDM, T-OFDM was found to have better BER when MMSE equalizer was to be used, but worse when ZFE has been used.

S. Bouguezel et al. (2011) proposed a new reciprocal orthogonal parametric DFT by appropriately replacing some specific twiddle factors in the kernel of the classical DFT by independent parameters that can be chosen arbitrarily from the complex plane. A new class of parametric unitary transforms could be obtained from the proposed transform by selecting all its independent parameters from the unit circle. One of the special cases of this class has been exploited for developing a new one-parameter involuntary DHT. The proposed parametric DFT and DHT can be computed using the existing fast algorithms of the DFT and DHT, respectively, with computational complexities similar to those of the latter. Indeed, for some special cases, the proposed transforms required less number of operations. The transforms of small sizes were used in some image and video compression techniques and employed as building blocks for larger size transform algorithms. The proposed parametric DFT and DHT, given the introduction of the independent parameters, offered more flexibility in achieving better performance compared to the classical DFT and DHT.
Imran Ali et al. (2011) presented a new receiver processing mechanism where the T-transform was replaced by two equivalent transforms and the equalization was carried out in between them. The new approach diagonalized the channel matrix, and single tap equalization was possible without any compromise in the performance. Thus, detailed computational complexity of the proposed approach has been presented and compared with some other schemes.

M.S. Moreolo (2011) demonstrated that Optical OFDM (O-OFDM) based on DHT with large-size constellations, furnishing alternative simplified schemes suitable for Intensity-Modulated Direct-Detection (IM/DD) systems. Both DC-biased Optical OFDM (DCO-OFDM) and power-efficient ACO-OFDM solutions were analyzed for real constellations from Binary Phase Shift Keying (BPSK) to 32-PAM. The performance was compared to standard O-OFDM based on FFT using constellations from 4-QAM to 1024-QAM, showing perfect agreement.

X. Ouyang et al. (2012) proposed DHT precoded OFDM system to counteract the peak power problem. By utilizing an intrinsic relationship between DHT and DFT, the transmitter can be simplified to generate the precoded signals by only linear combination instead IDFT and DHT, and the transceiver complexity can be reduced to simplify the system design. Simulations had confirmed that the PAPR of DHT precoded OFDM systems is substantially lower than that of both the DCT and the Walsh transform precoded OFDM system.

Ji and Ren (2013) introduced conversion vectors obtained by using IFFT of the phase rotation vectors in place of the conventional IFFT operations. It was shown that the computational complexity of the conventional SLM scheme could be substantially reduced.
J. Zhou et al. (2014) proposed a cost-effective and efficient modulation scheme for IM/DD-OOFDM systems by combining Complex-to-Real Transform (C2RT) and Fast Hartley Transform (FHT), named as Fast FFT. The proposed scheme can modulate the complex constellation by the real-valued operations. Compared with the FFT method, the same OFDM signal can also be generated by Fast-FFT, but the computational complexity nearly halved. Meanwhile, compared with the FHT scheme, Fast-FFT modulated the complex constellations by adding a simple C2RT module for a wide applicable range. The transmission experiment of over 50-km Standard Single-Mode Fiber (SSMF) had been implemented to verify the feasibility of fast-FFT-based IM/DD O-OFDM systems, including ACO-OFDM and DCO-OFDM systems.

K.J. Kim et al. (2014) proposed a low-complexity near-optimal DFT-based channel estimator with leakage nulling for OFDM systems using virtual subcarriers. The proposed estimator was composed of a time-domain index set estimation considering the leakage effect followed by a low-complexity time domain post-processing to suppress the leakage. The performance and complexity of the proposed channel estimator were analyzed and verified by computer simulation. Simulation results were shown that the proposed estimator outperforms conventional estimators and provides near-optimal performance while keeping the low complexity comparable to the simple DFT-based channel estimator.

K.J. Ahmed and J.R. Zeidle (2015) developed a novel receiver structure for Constant Envelope OFDM based on the Taylor series expansion, alleviating the need for angle demodulation at the receiver. This results in immunity from phase cycle slip due to phase wrapping and the threshold effect which would otherwise cause performance degradation. These receivers allowed for a simpler implementation without the need to compute the
arctangent at the receiver. The performance of these new receivers was studied when error correction coding was employed, and it showed that they not only provided excellent performance but also significantly outperformed the conventional arctangent based receiver for coded Constant Envelope OFDM performance.

S.H. Wang et al. (2015) proposed a novel precoding scheme for further reducing the computational complexity and PAPR of T-OFDM. In the suggested scheme, the precoding matrix was combined with an Inverse DFT (IDFT) to construct a new transform matrix at the transmitter. Notably, the transform matrix is both unitary and circulant, with each column being a perfect Gaussian integer sequence containing just four non-zero elements of \{±1,±j\}. A low-complexity receiver is to be additionally constructed for the proposed precoding scheme. A closed-form expression has been derived for the BER in T-OFDM and the proposed precoding scheme under FS fading channels. The simulation results for the BER were shown to be in good agreement with the mathematical derivations. Also, it is demonstrated that T-OFDM and the proposed scheme have an equivalent BER performance when their precoding matrices are to be designed in such a way as to obtain full frequency diversity.

### 2.3 Weighted OFDM Schemes

I.A. Tasadduq and R.K. Rao (2001) investigated the potential of some of the well-known linear block codes in reducing the PAPR. A method of biasing the code words was presented to minimize the PAPR. The influence of combined weighting and block coding on the PAPR had been investigated. A class of block codes capable of both error correction and PAPR reduction together with several weighting functions were considered. The interplay of various weighting functions with block codes was investigated for PAPR reduction.
T. Giannopoulos et al. (2006) derived a new set of weighting factors which improve the performance of the PTS algorithm while the computational complexity remains the same. Furthermore, this paper examined the complexity of Very Large Scale Integration (VLSI) implementation of PTS versus the power savings in the analog part due to the PAPR reduction. It has been shown that with the new set of weighting factors the power consumption of PA was reduced by 21.1% in comparison to OFDM without PAPR reduction.

O. Muta and Y. Akaiwa (2008) proposed a Weighting Factor (WF) estimation method for Peak Power Reduction (PPR) based on adaptive flipping of parity carriers in a turbo-coded OFDM system. In this PPR scheme, the PAPR of a turbo-coded OFDM signal is reduced with adaptive flipping of the phase of a parity carriers corresponding to the WFs. At the receiver, the WFs were estimated at a turbo decoder by exploiting the redundancy of an error-correcting code using no extra SI. When the proposed WF estimation method is used for the system using a turbo code with constraint length $K = 4$ and a code rate of $R = 1/2$, the instantaneous power of the OFDM signal at the CCDF of $10^{-4}$ can be reduced by about 2.1 dB through the application of the PPR scheme. When the BER performance was evaluated as a function of the peak signal-to-noise power ratio (PSNR), the proposed method achieved better BER performance than the case without the PPR in an attenuated 12-path Rayleigh fading condition. The improvements in BER performance as a function of PSNR are about 1.1, 2.0, and 2.1 dB at $BER = 10^{-4}$ for turbo-coded OFDM signals using QPSK, 16-state QAM, and 64-state QAM schemes, respectively.

Shin et al. (2013) proposed a PAPR reduction scheme based on a weighted OFDM signal to reduce the PAPR. In the proposed scheme, a weight has been imposed on each discrete OFDM signal via a certain kind of
a band limited signal and an OFDM signal formed with the weighted discrete data; this can be considered before an HPA so that the original signal can be recovered completely at the receiver side.

D. Roque and C. Siclet (2013) described low-complexity equalization techniques for Weighted Cyclic Prefix (WCP)-OFDM. This modulation technique refers to Filter Bank Based Multicarrier (FBMC) transmission system provided with short filters. It allows the use of non-rectangular waveforms to mitigate interference caused by time-frequency selective channels while preserving an efficient implementation.

H. Kim (2013) proposed a new PAPR reduction technique for SLM-based OFDM. The proposed SLM technique uses a phase rotation as well as a sliding amplitude weighting factor in the frequency domain to generate statistically independent OFDM symbols group. Some subcarrier with high frequency produces many peak points in the time domain so that it causes high PAPR. Thus, the basic principle of the proposed scheme is that some subcarrier with low frequency is given to a high amplitude weighting factor moreover, some subcarrier with high frequency is given to a low amplitude weighting factor.

Y. Hui et al. (2015) developed optimal order selecting scheme for 4-weighted fractional Fourier transform (4-WFRFT) over doubly selective channels. First, the expression for a Carrier-to-Interference Ratio (CIR) was deduced and then through maximizing the CIR, optimal order factor will be obtained. Through selecting the optimal order factor of 4-WFRFT, this system can match the doubly selective channel characteristics through switching between OFDM and SC systems according to obtained channel state information. The simulation results showed that the optimal order 4-WFRFT scheme could improve the performance over doubly selective channels on the traditional SC or OFDM.
2.4 SLM Based OFDM Schemes

S. W. Kim et al. (2006) proposed a novel PAPR reduction method using WHT to lower the high PAPR of OFDM system. The merit of this proposed method is an efficient PAPR reduction performance as well as no loss of bandwidth efficiency. Furthermore, the PAPR reduction process can be made in the real time although there may be a little bit increment of calculation complexity. In this literature, two PAPR reduction methods will be presented that combines the SLM and DSI with a WHT. From simulation results, it had been shown that the PAPR reduction method using a WHT could get about 1dB better PAPR reduction performance than already-existing SLM and DSI methods. Also, it can be expected that the more robust data transmission is available in nonlinear HPA and multi-path fading channel by PAPR reduction function and frequency diversity effect.

Z. Sembiring and M. Syahruddin (2012) introduced an alternative technique to replace a conventional complex DFT-based OFDM system. The proposed technique was simpler and faster than conventional one because it required only real arithmetic computations. The performance of OFDM modulator and demodulator based on DHT was carried out with giving binary random data as the data sources. After processed by IDHT as the modulation function, the signals were then transmitted via the dispersive channel using AWGN as the channel model. The transmitted signals were detected in the receiver part with reverse processes as done in transmitter part. The measurements of parameters were repeated five times to obtain and to calculate the accuracy of the new system. The plotted graph of average BER versus Signal to Noise Ratio (SNR) showed that the BER was decreased when the given value of SNR increased. The analysis of system performance had been evaluated for several numbers of subcarriers used and the results showcased some advantages. The modification of DHT algorithm is expected to reduce the complexity and time consuming for long-length of
Computational on the performing of OFDM modulator and demodulator based on DHT.

K.H. Kim et al. (2013) proposed a new PAPR reduction scheme for OFDM based on the SLM scheme. The proposed SLM scheme generated alternative OFDM signal sequences by cyclically shifting the connections in each subblock at an intermediate stage of IFFT. Compared with the conventional SLM scheme, the proposed SLM scheme achieved similar PAPR reduction performance with much lower computational complexity and no BER degradation. The performance of the proposed SLM scheme was analysed mathematically and verified through numerical analysis. Also, it showed that the proposed SLM scheme had the lowest computational complexity among the existing low-complexity SLM schemes exploiting the signals at an intermediate stage of IFFT.

T. Deepa and R. Kumar (2015) proposed a precise method for the performance of a new Discrete Cosine Transform (DCT) based OFDM system using a low complexity T-transform that combines the WHT and the DCT into a single fast orthonormal unitary transform called T-DCT on AWGN and Rayleigh fading channels. The T-transform was developed through the sparse matrices factorization using tensor product scheme. Theoretical analysis of the T-transform for DCT based OFDM has been presented in this work. Analysis and simulation results demonstrated that the proposed OFDM system achieved lower PAPR and better BER performance over AWGN and Rayleigh fading channels. Compared to T-DFT based OFDM, T-DCT of OFDM was found to have lower PAPR and better BER performance.

N. Binu and C.D. Suriyakala (2015) proposed correct time windowing at the OFDM receiver, which the transmitted multiple carriers that could be demodulated orthogonally. The method has been proposed for a lot of radio systems. It has high spectral efficiency and inherent resistance to dispersion in
the propagation channel. The clipping technique was suggested to clips the OFDM signal to a predefined signal without data distortion in removing weight at the receiver side, by using a band limited signal and each clipping noise sample will be multiplied by a window function. In the proposed scheme, a comparative study was done to ensure that the BER performance and CCDF are compared to the existing clipping and filtering method.

L. Wang and J. Liu (2015) proposed a Partial Phase Weighting SLM (PPW-SLM) for PAPR reduction in OFDM system. In the proposed PPW-SLM, PPW method and the properties of IFFT were employed for simplifying the calculations of IFFTs and obtaining good PAPR reduction performance. Theoretical analysis and simulation results showed that, compared with SLM, the proposed PPW-SLM could obtain a significant computational complexity reduction in similar PAPR reduction performance.

S.H. Wang (2016) proposed a novel PAPR reduction method in which frequency-domain phase rotation, cyclic shifting, complex conjugate, and subcarrier reversal operations are all employed to increase the diversity of the candidate signals. Furthermore, to circumvent the multiple-IFFT problem, all the frequency-domain operations were converted into time-domain equivalents. It was shown that the subcarrier partitioning and reassembling processes are key to realizing Low-complexity time-domain equivalent operations. Moreover, it was shown theoretically and numerically that the computational complexity of the proposed scheme is significantly lower than that of the traditional SLM method and that the PAPR reduction performance is within 0.001 dB of that of SLM.
2.5 Inference from Literature Survey

In this chapter, the various approaches by the researchers to achieve low complexity and PAPR reduction from various techniques are studied. From the literature survey, it is inferred that several techniques have been proposed such as clipping, coding, and peak windowing, and SLM, PTS, TR and TI techniques for PAPR reduction in OFDM system. However, various schemes have been devised to eliminate the deleterious effect of high PAPR in OFDM signals, albeit with the expense of high computational complexity, distortion, data rate loss and BER performance degradation.