MIMO-OFDM System in Wireless Communication: A Survey of Peak to Average Power Ratio Minimization and Research Direction

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Abstract— ***A combination of Multiple Input and Multiple Output (MIMO) and Orthogonal Frequency Division Multiplexing (OFDM) results to a wireless communication system called MIMO-OFDM system. This paper has presented a review of peak to average power ratio (PAPR) reduction in MIMO-OFDM system. Since MIMO-OFDM is a generalized case of OFDM systems based on space time block code (STBC) for two, three, and four antennas, the focused of the study has been on the reduction of PAPR in OFDM signal. With many challenges associated with the implementation of OFDM, one major drawback is the effect of sum of several sinusoids due to time domain OFDM signal that leads to high PAPR. Several techniques have been proposed to address this problem, with more recent algorithms using optimization scheme or hybrid scheme presented in literature. This paper has examined the various techniques with respect to their merit and demerit in the reduction of PAPR of OFDM signal. It presented a hybrid scheme as a way forward to reducing PAPR in OFDM system.***

Keywords-: *Hybrid technique, MIMO, OFDM, Optimization, PAPR*

I. INTRODUCTION

Data transfer is carried out without employing wire in wireless communication. They were very limited wireless communication technologies at the early stage with minimal transfer of data which made sufficient spectrum available at the time. Wireless communication technology has experienced steady growth over time, with the size of system devices reducing, but with increased power processing capability. Advances in wireless communication technology have brought about increase in the demand for standards with enhanced and promising capabilities. This has brought about the need for available wireless spectrum capacity to be improved. In order to meet the demands of customers, many technologies have been developed. Examples of such technologies are Wi-Fi (IEEE 802.11n) networks, Long Term Evaluation (LTE) networks (4G, 3GPPLTE) and other radio and wireless communication networks (Such as WiMAX and HSPA$^+$) to offer increased link capacity, spectral efficiency, and data rate.

The design of wireless communication system with the capacity to take more than one input and output is evolving at increasing rate. Recently it has become increasingly common to use multiple input and multiple output (MIMO) antennas to enhance data handling capacity of wireless communication system. The use of MIMO in wireless communication system offers many benefits such as higher capacity through spatial multiplexing technique, improved transmission quality through diversity scheme. Also, the need for high data rates transmission at high Quality of Service (QoS) in terms of effective utilization of available limited spectrum, has led to the adoption of Multi Input Multi Output (MIMO) –Orthogonal Frequency Division Multiplexing (OFDM) technology in wireless communication systems [1].

It is expected of a wireless communication system to have very high spectrum efficiency and the ability to overcome channel fading in multi-path channel environment. Multipath is the propagation process in wireless communication that occurs due to the radio signals getting to the receive antenna by two or more paths. Factors like atmospheric ducting, ionosphere reflection and refraction, and reflection from water bodies and terrestrial objects such as mountains and buildings are responsible for multipath.

The resulting effect of multipath includes constructive interference, destructive interference, and phase shifting of the signal. Since the shape of the signal carries the information being transmitted, distortion may take place at the receiver during demodulation. If the delays caused by multipath are high enough, bit errors in the packet will take place. The receiver, in this case, cannot distinguish the symbols and interpret the corresponding bits correctly. This causes an error in the symbol decoding. Meeting these requirements using the MIMO or the OFDM modulation technique separately is not easy. However, an integration of MIMO and OFDM (MIMO-OFDM) system can match these requirements.

With MIMO system employing several antennas at both transmit and the receive ends, the OFDM provide digital modulation which divides the signal into a number of narrow band channels to achieve spectral efficiency. On the other hand, the LTE technologies (with 4G as an extension), have some features that support multimedia, video streaming, internet and other broadband service.

MIMO technologies exploit the benefit of multiple signals to enhance the quality and reliability of transmitted signal as the conveyed signal information is mainly affected by multipath fading. Multipath brings about duplicates of the transmitted information at the receiver with certain delays. The introduction of OFDM corrects the multipath effect by efficiently using the spectrum in overlapping the sub-carriers. This therefore provides increase data rate, reduce Inter Symbol Interference (ISI) and then utilizes the spectrum efficiently that is needed for video transmission and other multimedia messages.

It should be noted that despite the advantages offer by MIMO-OFDM technology, it still suffers from the high fluctuations of the transmitted signal called the peak-to-average power ratio (PAPR). In order to address this problem, quite a lot of techniques such as precoding, clipping and Filtering, coding, tone injection, peak windowing, selected mapping, and partial transmit sequence (PTS), and companding have been developed to lessen the high PAPR of OFDM signals.

This paper mainly focuses on review of literature on MIMO-OFDM technology in wireless communication with respect to PAPR of OFDM signal.

II. MULTIPLE ANTENNA TECHNIQUES

Multiple antenna techniques [2] take advantage of spatial dimension to increase data rate capacity and system reliability through spatial diversity. Using multiple antenna at the transmit end has the capacity to increase the transmission of distinctive data streams which can be separated at the receive end. There are basically four antenna architectural models in wireless communication which are: a) Single Input-Single Output (SISO) where both the transmitting end and the receiving end have one antenna each, b) the Single Input-Multiple Output (SIMO) in which case the transmitter has one antenna while the receiver has more than one antenna, c) Multiple Input-Single Output (MISO) this configuration has more than one antenna at the transmitter with only one antenna at the receiver, and finally d) Multiple Input-Multiple Output (MIMO) here multiple antennas are employed at both transmitter and receiver. Figure 1 basic antenna configurations in wireless system.

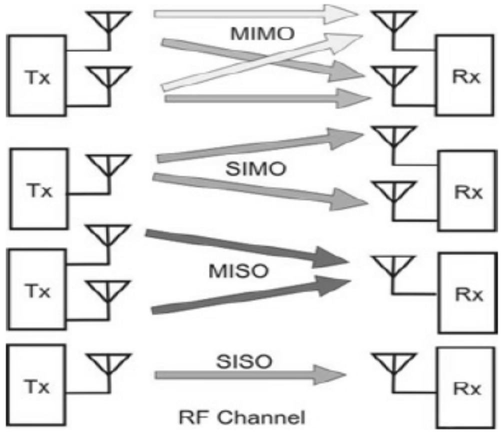

Fig. 1 Basic antenna configurations [3]

A. *Single Inpput-Single Output Technique*

Single Input-Single Output Technique (SISO) is the conventional and most popular antenna configuration employed in wireless communication. In this scheme, the transmitting end and the receiving end wireless communication network are assigned one antenna each. It is used in radio broadcast, television (TV) broadcast and Wi-Fi, Bluetooth technology [4].

B. Single Input Multiple Output/Multiple Input Single Output Techniques

Single Input Multiple Output (SIMO) technology in wireless communication involves the use of one antenna at the transmitter and more than one antenna at the receiver. The merit of SIMO scheme over SISO is that it offers receiver diversity, which receives the strongest signal from several transmitting antennas. It is usually employed in uplink scenarios [5]. Multi Input Single Output (MISO), more than one antenna are employed at the transmitter while one antenna is used at the receiver. It offers transmit diversity as a result of the multiple antennas at a transmitter. The MISO technology is applied in WLAN, MAN and digital television (DTV). It is mainly use in downlink scenarios [5].

C. Multiple Input Multiple Output Technique

Multiple Input Multiple Output (MIMO) technology is wireless communication technology that uses more than one antenna for transmitting and receiving operations. It has become famous antenna configuration in several latest technologies in recent time. MIMO is used in Wi-Fi, Long Term Evolution (LTE) and various other radio and wireless technologies to give increased link capacity, spectral efficiency and improved data rate. Many wireless routers using MIMO technique are currently in the market and thereby making it more widespread and popular. MIMO is effectively a radio antenna technology [6]. Using multiple antennas for transmit and receive operations, the technology enables a variety of signal paths between the source and the destination. The multiple paths available are occasioned by the number of objects that appear to the side or even in the path directly linking the transmitter and the receiver. Before now, these multiple paths are known to only cause interference. However, with the emergence of MIMO technology and subsequent deployment into wireless communication, these additional paths can be employed to enhance link capacity. In order to take advantage of this in MIMO wireless system, transmitted data should be encoded using the space-time code. Space-time code allows the receiver to extract the original transmitted data from the received signals. The space-time code optimizes the Signal to Noise Ratio (SNR), and the codes used define the performance gain that can be realized. Generally, the more the gain achieved the more processing power that is required. The various types of MIMO techniques are presented.

1) Spatial Multiplexing**:** Spatial multiplexing using N transmitting and M receiving antennas allows MIMO system to grow linearly with the minimum of N or M without using extract bandwidth or transmit power. The working principle of MIMO is just like an integration of SIMO and MISO otherwise referred to as receive diversity and transmit diversity respectively, where signals from multiple paths were integrated together to yield a stronger signal with higher SNR. However, in the case of MIMO, the resulting effect is a signal with higher SNR gain than either of SIMO or MISO. This is achieved in MIMO system by sharing entire SNR between its various data streams such that each of them has a lower power level.

   The process of spatial multiplexing is especially significant in a high SNR situation where the system is degree-of-freedom (DOF) limited rather than power limited. Foschini et al [7] stated that the capacity of a channel with N transmits and M receives antennas with separate and very similar distributed Rayleigh faded gains between each pair of antenna is expressed as in [3]:

$$C(SNR) = \min\{N, M\} \log SNR + \delta \tag{1}$$

   where C = channel capacity, SNR = signal to noise ratio. Considering Eq. (1), it can be seen that the degree of freedom is the minimum of N and M and the channel capacity increases directly with N and M.

   There are basically three components of MIMO system, primarily transmitter, channel and receiver. Multiple data are sent out by the transmitter in the form expressed as $X_1, X_2, X_3, ..., X_N$ from different base station antennas and are received by different receive antennas in the form $R_1, R_2, R_3, ..., R_M$ simultaneously. The mathematical expression between transmit and receive data is given by [8]:

$$\begin{aligned} R_1 &= H_{11} X_1 + H_{12} X_2 + ...H_{1M} X_N \\ R_2 &= H_{21} X_1 + H_{22} X_2 + ...H_{2M} X_N \\ &......... \\ R_M &= H_{N1} X_1 + H_{N2} X_2 + ...H_{NM} X_N \end{aligned} \tag{2}$$

   where, X is transmitted signal vector, R is received signal vector, H is channel matrix, N = number of transmitting antenna, M is number of receiving antenna. Figure 2 shows the MIMO transceiver system.

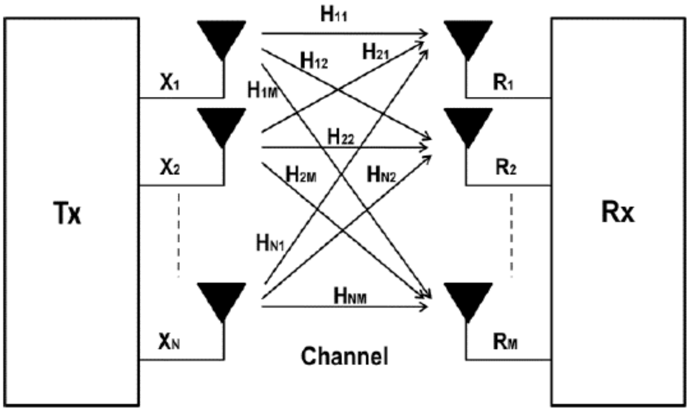

Fig. 2 MIMO Transceiver Block Diagram [8]

2) Spatial Diversity**:** Spatial diversity simply means the ability to employ different "channels" to carry the same data stream from the antenna at the transmit end to the antenna at the receive end when the different channels fade in such way that is not statistically dependent such that information may be retrieved from the channel or channels with the highest SNR. There are two types of spatial diversity: a) transmit diversity, wherein more than one transmit antenna is employed for sending coded information to a receive antenna, and b) receive diversity in which case a transmit antenna sends coded information to more than one receive antennas.

   More attention is given to transmit diversity in this paper as result of its commonly wide application in LTE cellular network and the paper is majorly considering MIMO-OFDM review with respect to PAPR reduction techniques which is a transmit end problem.

3) Transmit Diversity: One of the limitations to the growth of the 3G technology is improving downlink capacity because of the increasing demand for data service usage and multimedia services mainly in downlink. Thus one of the benefits provided by MIMO technology for addressing this challenge in 3G Wideband Coded Division Multiple Access (WCDMA) and Coded Division Multiple Access 2000 (CDMA2000) is the transmit diversity While transmit diversity offer diversity gain, channel state feedback can be included to provide antenna gain in that case there can be either an open loop transmit diversity (without feedback) or closed loop transmit diversity (with feedback) [9].

   One of the most terrible types of channel conditions is slow changing flat fading channels. This channel condition can cause the received signal level to be lower than that of background noise and as such making communication unreliable. However, the effect of flat fading channel can be overcome by transmit diversity through improving the performance of the signal at the receiver. Transmit diversity does this by providing numerous independent copies of the signal at the receive end, such that the possibility of all copies of the signals being in a fade at the same time is very small [10]. The use of large antenna spacing of the order of several carrier wavelength between the transmit antennas enables the realization of transmit diversity this resulting to uncorrelated fading of the transmit signals. The benefit of transmit diversity is that more than one antenna as well as the complex coding are realized the transmit end –base station that has a sufficient amount of space and structure to contain them instead of the receive end –mobile station [3]. Therefore the use of transmit diversity is at the downlink of 3G WCDMA) systems [11].

4) Space Time Codes: Space Time Coding (STC) enables considerable gains to be achieved by making use of both spatial and diversity techniques. That is STC is a coding technique that brings combines various methods for achieving spatial multiplexing gains and diversity gains for a communication link. STC involves multiple copies of data transmission. This aids to compensate for problems such as fading and thermal noise common in channel. Many techniques are grouped under STC that are employed to obtain spatial multiplexing and diversity gains. STC can be classified into Space Time Block Code (STBC) and Space Time Trellis Code (STTC) [3]. When using STBC, data stream is encoded in blocks before transmission. One of the uses of the STBC is Space Time Transmit Diversity (STTD). STTD is mandatorily employed in Universal Mobile Telecommunications System (UMTS) 3G cellular systems for the receiver (mobile station) but optional for the transmitter (base station). The SNR improvement offered by STTD is used for cell edge performance by mobile station [12]. Conversely, the STTC works by incorporating modulation and trellis coding to transmit information over multiple transmit antennas and MIMO channels.

5) Spatial Multiplexing/Spatial Diversity: When compared together considering where there is high signal scattering environment and relatively high SNR such as near the base station, spatial multiplexing does better than spatial diversity. However when the SNR is weak such as at cell edge, spatial diversity does better than spatial multiplexing for the reason that spatial diversity will improve SNR and facilitated the increased data rate [13]. Therefore, an ideal wireless mobile telecommunication system will include spatial multiplexing and spatial diversity with the system evaluating the finest crossover point between the two in a manner that the system dynamically changes over between the two to provide the necessary coverage, provided by spatial diversity or capacity gain, provided spatial multiplexing based on channel condition [2].

III. ORTHOGONAL FREQUENCY DIVISION MULTIPLEXING

The Information data technique is divided into many parallel sub-channels of narrow bandwidth by multicarrier modulation. Each of the sub-channel data rate is to a large extent less than the entirety of data rate. Each one of the sub-channels can be designed to have a bandwidth that is less than the channel coherence bandwidth. Thus by assumption, each sub-channel can said to experience flat fading and then it is possible to implement the demodulator with no equalizer.

In conventional parallel-data system, the signal frequency band taken as a whole is divided into a number of N non-overlapping frequency sub-channels. A separate symbol is used to modulate each one of the sub-channels, and afterward the N sub-channels are frequency multiplexed. As good as this may see in terms of avoidance of spectral overlap of channels to get rid of inter-channel interference (ICI), the process results to inefficient utilization of available spectrum. Hence Orthogonal Frequency Division Multiplex (OFDM) system is examined.

OFDM system uses a multicarrier advance modulation technique to transmit a single data stream over a number of lower rate orthogonal subcarriers. The term “orthogonal” shows that a specific mathematical correlation exists between the frequencies of the multicarrier in the system. The fundamental principle of OFDM is to divide a high-data-rate sequence into several low-rate sequences that are sent out from the transmit end at the same time over a number of subcarriers. For low rate parallel subcarriers, the duration of the symbol is increased and as such the relative amount of dispersion occasioned by multi-path delay spread is reduced. In order to avoid Inter-symbol interference (ISI) caused by multi-path, guard interval is introduced to separate successive OFDM symbols. In the guard interval, to avoid multi-path components interfering between successive symbols that is, Inter-carrier interference (ICI), the guard interval is cyclically extended and this is known as cyclic prefix. As a result, a transformation of highly frequency selective channel into a large set of flat fading, narrowband channels, and non-frequency selective takes place. An implementation of Inverse Fast Fourier Transform (IFFT) or Discrete Fourier Transform (DFT) by an integrated circuit (IC) eliminates the requirement for the complete collection of separate transmitters and receivers. The Fast Fourier Transform (FFT) technique is used to remove collections of sinusoidal generators and coherent demodulation needed in parallel data systems and ensures cost effective implementation of the technology. A block diagram of an OFDM system is shown in Fig. 3.

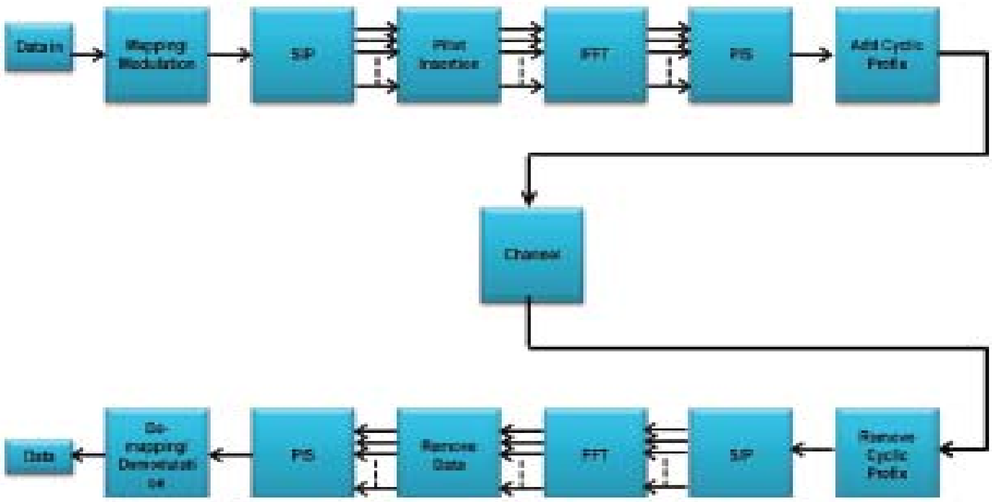

Fig. 3 Simple block diagram of an OFDM system [8]

A. Application of OFDM

The demand for increased data rate multimedia based services and increased spectral efficiency has grown formidably and has become the reason for the continued technology growth in prospective wireless communications. Several advanced technology in recent past have been included with 3G wireless communication systems to enhance data rate and the performance of the system. For example in 3G WCDMA systems, Speed Downlink Packet Access (HSDPA) has been incorporated while in 3G CDMA2000 systems, 1x evolution-data and voice (1xEV-DV) has been integrated. Increasing wireless multimedia application and services like video teleconferencing, network gaming, and audio/video streaming of high quality comes with very high data rate. It is apparent that 3G wireless systems with its finest capacity will not be able to sustain the ever growing demand for wideband wireless services. It is expected that the next generation wireless communication systems namely, 4G, LTE, and 5G will carry much higher data rate services in comparison with growing 3G systems –up to 100Mbit/s in external environments and up to 1Gbit/s in internal environments). Advance LTE (LTE-A) is thought to carry up to 1Gbit/s data rate and gigabit wireless communication for millimetre wave communication called 5G is anticipated to carry data rate of above 1Gbit/s. Achieving this high data rate, the main technical problems to overcome include achieving high spectral efficiency, high frequency-selectivity management as a result of broad bandwidth, high PAPR management as extra number of subcarriers are being added, and selecting an efficient signaling method for high data rate. Thus, it has become important to integrate the latest technical advances in the physical layer into the future wireless systems.

Wireless Local Area Network (WLAN) and Worldwide interoperability for Microwave Access (WiMAX) are presently well-known for data communication technique. These technologies should offer higher data rate and wide bandwidth to users for data and multimedia communication as number of users and demand for higher data rate increases. In these circumstances OFDM became a viable option. OFDM has been adopted by a number of wired and wireless standards. For instance, in asymmetric digital subscriber line (ADSL), digital audio broadcasting (DAB), and Digital Video Broadcasting (DVB), OFDM is the basis for the global standard [14]-[16]. OFDM has been adopted as modulation standard for IEEE 802.11a/ n/ ac and HiperLAN/2. The same goes for new generation cellular telecommunications standard LTE / LTE-A. Furthermore, it is being considered as the standard modulation for 5G communication [17] and Internet of Things (IOT) [18][19].

It offers numerous advantages such selective fading immunity, resilience to inference, efficient utilization of available spectrum, resilient to inter-symbol and inter-frame interference (ISI), resilient to narrow-band effects, and reduction in equalization complexity. However, some drawbacks are associated with the use of OFDM and these include: carrier offset and drift sensitivity, high peak to average power ratio (PAPR), receiver complexity, and demand for complex computation scheme. This has prompted the need for PAPR reduction in OFDM system. The next sub-section considers PAPR reduction techniques.

B. Advantages of OFDM

The numerous benefits provided by OFDM have made it a popular technology used in many high data rate wireless communication systems. Some of these benefits are highlighted as follows.

1) It offers resistance to selective to fading: Comparing OFDM with single carrier systems reveals that it is more immune to frequency selective fading for the reason that it divides the overall channel into multiple narrow-band channels.
2) It is resilient to interference: Interference coming into a channel may perhaps be bandwidth limited and thus (it) does not have an effect on all the sub-channel. This eases the channel fluctuation.
3) It provides efficient utilization of spectrum: Using overlapping orthogonal subcarriers that are closely-spaced facilitates the transmission of data with low bandwidth channels and therefore resulting to efficient use of the available frequency band (or spectrum).
4) It is resilient to Inter-symbol interference (ISI): OFDM shows high resilient to ISI. This is due to the fact that each sub-channel carries low data rate data stream.
5) It is resilient to narrow-band effects: Employing sufficient channel coding and interleaving helps in the recovering of symbols lost on account of the frequency selectivity of the channel and narrow bad interference.
6) Application of simpler channel equalization: Usually digital communication and spread spectrum communication channel equalization has to be used across the entire bandwidth of the channel. Consequently leading to increase in channel equalization complexity. On the contrarily, for OFDM channel equalization, just a single tap equalizer is needed since it uses multiple sub-channels. Thus, equalization complexity in OFDM is reduced.

C. Disadvantages of OFDM

Even as OFDM has been largely employed, some disadvantages still prevail and are required to be addressed when its use is being considered.

1) It is sensitive to carrier offset and drift: OFDM shows more sensitivity to carrier frequency offset and drift compared to single carrier system.
2) It exhibits high peak to average power ratio (PAPR): Being characterized by noise such as amplitude variation in time domain and having relatively large range of dynamic, OFDM signals cause high PAPR. This affects the RF amplifier efficiency since it is required that the amplifiers be linear and contain the high amplitude swings and what these factors mean is that the amplifier cannot operate with a higher efficiency level.
3) It brings about receiver complexity: OFDM receiver complexity increases with higher number of sub-channels.
4) It requires complex computation: Associated with OFDM system is computational complexity and this increases both at the transmitter and receiver with increasing subcarrier.

D. Research Direction in OFDM System

As a result of the few obvious disadvantages in OFDM systems, many research studies have focused on addressing these problems. The technology of OFDM transmission is an efficient realization of a multicarrier modulation principle such that a high-speed serial data stream is divided into multiple parallel low-streams, every one of them modulating a different subcarrier. This principle adjusts the frequency selective wideband channel to a large number of flat narrowband channels. In addition, this allows the channel to be robust against multi-path propagation.

It is also easy to combine OFDM with multiple antenna systems thereby resulting to MIMO-OFDM. As a result of the exceptional performance, high flexibility, and easy implementation, OFDM has been the basis of many modern communication standards. Mostly, because the network's interference has become a motivating factor for system performance, for this reason, it has attracted high level research interest.

Some of the captivating research interests in OFDM system and its ancillary are highlighted as follows:

1) Reduction of PAPR: High PAPR in OFDM systems occurs due to the use of a large number of subcarriers. The presence of high PAPR limits transmitter power amplifier operation and thereby causes receiver amplifier saturation.
2) Channel estimation: Eliminating interference is the prime challenge in any communication receiver. Channel estimation in OFDM system is an important factor towards easing interference.
3) Frequency offset and drift: At the receive end of wireless communication system, OFDM signals are affected by frequency offset and drift as a result of the relative motion between transmitter and receiver (Doppler effect). In the process of detection, the receiver should mitigate the effects arising from frequency offset and drift.
4) Integration of OFDM to MIMO systems: Despite the fact that OFDM provides high speed data communication yet its capacity is not increased. Conversely, the capability of MIMO to achieve diversity gain can be taken to achieve high capacity. Thus combining OFDM with MIMO will lead to high speed high capacity communication system.
5) Long Term Evolution (LTE): The LTE project is evolving. The primary objective is to enhance the capacity and network speed by digital signal processing techniques. A small number of areas in which research is being conducted are the iterative channel estimation, traffic scheduling [20].
6) Communication between devices: This technology called device to device (D2D) communication. Here, two machines of the same type communicate with each other by means of wired network or wireless network [21].
7) Cancellation of Inter Carrier interference (ICI): Orthogonality loss among subcarriers results to ICI. Few of the schemes used for cancellation of ICI include parallel interference cancellation, successive interference cancellation, ICI self-cancellation, and windowing [20].
8) Very large scale integration (VLSI) and Digital signal processor (DSP) realization of OFDM: Recently, the implementation of different algorithms using VLSI and DSP with low demand for OFDM is a challenging area of research [22][23].

E. Techniques for Peak to Average Power Ratio Reduction

Many techniques for reducing peak to average power ratio have been proposed and implemented in literature. These methods are split into groups as shown Fig. 4

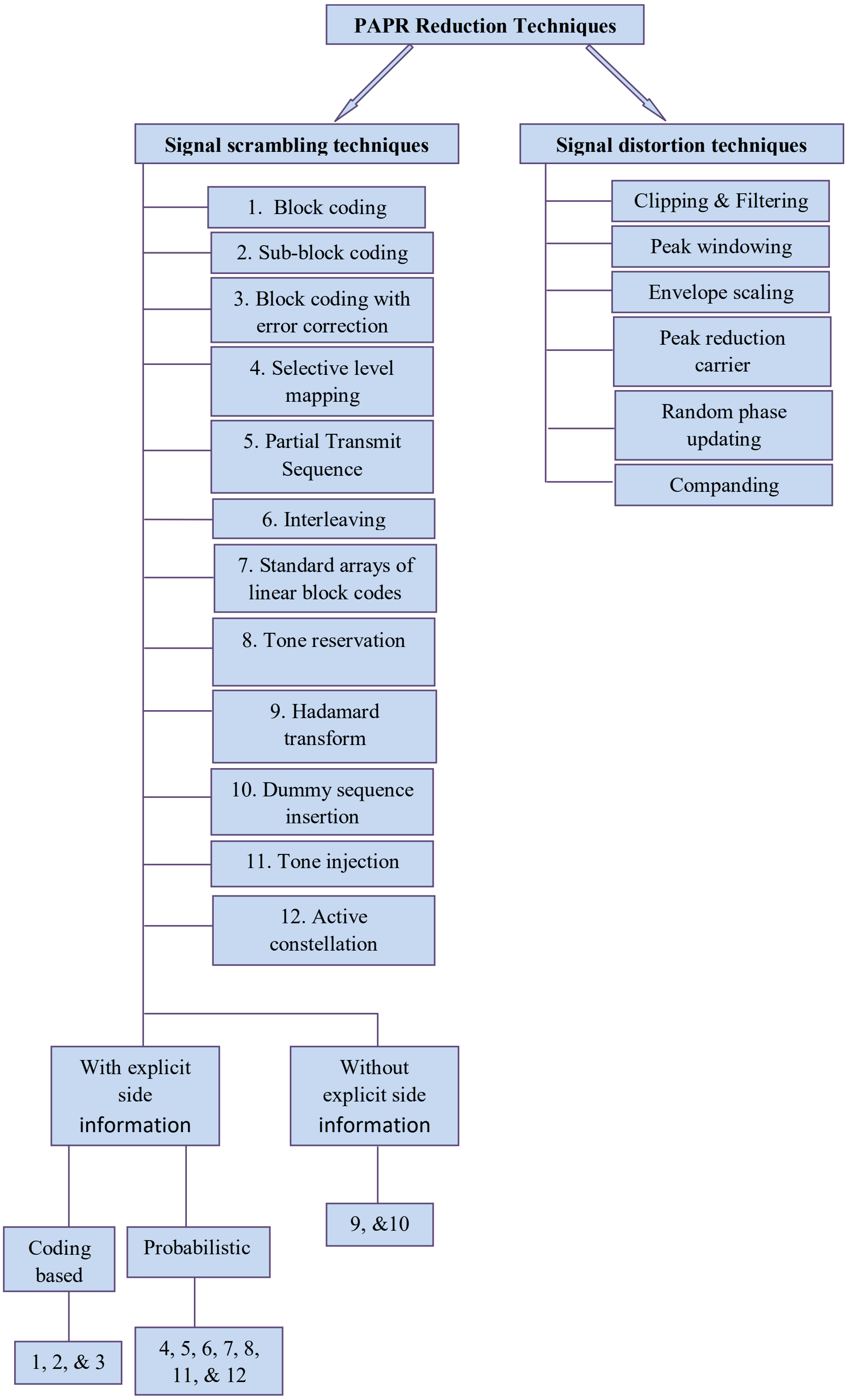

Fig. 4 Block diagram of techniques for PAPR reduction

1) Signal Scrambling Techniques

- Block Coding Technique: The concept behind the scheme is the possibility of reducing PAPR by block coding the data in a way that set of permissible code words does not include the ones that result in excessive peak envelope powers (PEPs) [24]. Coding techniques are applicable to signal scrambling, M sequences, Golay complementary sequences, Shapiro-Rudin sequences. Block coding was originally proposed by Wilkinson and Jones in 1995 for minimizing the peak to mean envelope power ratio of multicarrier communication system [25]. The main objective of the study was to minimize PAPR by block coding the data. There are three stages for developing block coding scheme. The first stage involves the collection of suitable sets of code words for any number of carriers, any M-ary phase modulation technique, and any code rate. The next stage involves the selection of the set of code words which facilitate proficient implementation of the encoding/decoding. Then the last stage provides error deduction and correction potential.

A number of methods are available for the collection of sets of code words. The most insignificant method is sequential searching of the PEP for all possible code words for certain length of given number of carriers [24]. This is a simple and correct approach for short codes because it requires extensive computation. When considering collection of longer code words, more sophisticated searching techniques such as natural algorithms can be used. A look up table or combinatorial logic taking advantage of the mathematical structure of the codes can be employed for the selection of code words selected from searches for encoding/decoding.

- Sub-block Coding Technique: The development of sub-block coding (SBC) is anchored on the observation that all 75% rate systematically coded block codes with an odd parity checking bit as the last bit showing lowest PEP. The SBC scheme is referred to as systematic odd parity checking coding (SOPC) [24]. It is observed that sub-block coding and block coding techniques are not efficient in reducing PAPR at what time the frame size is large. There is the possibility of obtaining large reduction of PAPR if the long information sequence is divided into different sub-blocks, and all sub-blocks encoded with system on a programmable chip. There are several possible locations where the odd parity checking bits can be placed in each frame to reduce PAPR. In order to further minimize PAPR, redundant bit location optimization sub-block coding (RBLO-SBC) optimizes these locations. The combination of the coded sub-blocks, where two coding techniques rather than one is employed to encode the same source of information is optimized by combination optimized sub-block coding scheme (COSBC).
- Block Coding Technique with Error Correction: The block coding technique with error correction was proposed by Ahn et al. [26] as a new coding based scheme for the reduction of PAPR of an OFDM signal. This coding based technique has error correction capability. The technique involve in the block coding is such that the OFDM symbol can be reduced by opting for only those code words that has lower PAPR. The main objective of this coding scheme is to properly design block codes that will not just only reduce PAPR but provide error correction capability. For instance, at the system transmitter, a k bit data block, assuming k equal to 4-bit data, is encoded by a (n, k) block code with a generator matrix, G and then by the phase rotator vector, b to give the encoded output x = a.G + b (mod 2).

  In order to obtain proper G and b that ensures the minimum PAPR for the OFDM system, check all the 2n codes and select only 2k codes that gives the minimum PAPR. Subsequently, the generator matrix, G and the phase rotator vector, b are produced and then used to provide mapping between these symbols combination and input data vector, a. An execution of the converse function of the transmitter is carried out in the receiver system. The generator matrix, G is used to obtain the parity check matrix, H provided the effect of the phase rotator, b is solved before calculations of the syndromes [24]. This scheme provides improvement in the overall system performance and capability in error correction.
- Selected Mapping: The approach to PAPR reduction using selected mapping (SLM) was proposed by Bauml et al. [27]. The process involves the multiplication of the parallel OFDM signal by several phase sequences that are generated offline and stored in a matrix. A replica of the OFDM signal is multiplied by a random vector of phase sequence matrix. Inverse Fast Fourier Transform (IFFT) or Discrete Fourier Transform (DFT) of each sub-block is performed and PAPR value is calculated for each sub-block to determine the one with minimum value. That is, the idea is to generate a complete set of candidate signal representing the same information, and after which the most favorable signal having minimum PAPR is selected and then transmitted. The selected signal index is called side information index (SI index) [28]. In order to enable the receiver to recover the original data, the side information index is also transmitted alongside. As a probabilistic technique, SLM is easy to implement, causes no distortion in the transmitted signal, and capable of offering substantial PAPR reduction. However, the complexity of the system due to the use of large number of sub-blocks required to send side information is a disadvantage to the use of SLM technique.
- Partial Transmit Sequence: Partial transmit sequence (PTS) is a technique proposed by Muller and Hubber [29]. The main concept behind the PTS scheme is division of data block into non-overlapping sub-blocks such that each sub-block is phase-shifted by means of statistically independent rotation factor to reduce PAPR. This scheme is flexible and efficient for PAPR reduction in OFDM system. PTS is probabilistic based scheme for PAPR reduction. It is said to be a case of modified SLM scheme. PTS outperforms the SLM counterpart. The core benefit of this method over SLM is that the need for sending any side information to the receiver at what time differential modulation is used in all sub-blocks does not arise. However, PTS also causes complexity in OFDM system since it also requires several sub-blocks.

- Interleaving Technique: Interleaving is a data randomization technique developed by Jayalath and Tellambura [30] for reducing PAPR in OFDM system. The concept is anchored in the fact that if long correlation pattern is broken down, highly correlated data structures having large PAPR can be reduced. An adaptive scheme for complexity minimization was also proposed. The primary concept in adaptive interleaving (AL) is to make provision for early terminating threshold. That is, rather than searching for all interleaved sequences, the search is discontinued as soon as the PAPR goes below the threshold. The AL will be compelled by the minimal threshold to search for all the interleaved sequences. The main significance of this approach is that it is of lesser complexity than the PTS technique but gives a comparable outcome. The method gives no assurance for PAPR reduction and for the worst PAPR scenario of N value. In this case, using AL technique would require the addition of higher order error correction.
- Standard Arrays of Linear Block Codes: In the standard arrays of linear block codes (SALBC) technique, the transmit signal is taken as one that has minimum PAPR from U different signals. The U different signals are generated by scrambling a code word with the suitably selected co-set leaders [24]. Since co-set leaders are employed only for scrambling, there is no requirement for transmitting side information and this enable the syndrome decoding to easily decode the received signal. The basic concept is using the standard array of block codes for PAPR reduction in OFDM system, and not for error correction. The possibility of achieving this is by selecting a vector that produces low PAPR in each co-set as its co-set leaders rather than minimum weight vector. This technique is a modified version of SLM wherein the transmitted signal as the one with low PAPR from differently scrambled signal of the information by several random sequences. This scheme is found to show slight performance improvement in the reduction of PAPR compared to the SLM scheme. With the most crucial aspect of the SALBC being that slight improvement in performance achieved compared to SLM with no side information transmitted.
- Tone Reservation: The key idea of Tone Reservation (TR) technique is to maintain a small set of tones for the reduction of PAPR. This can be formulated as a convex problem and can be addressed appropriately. The number of PAPR reduction relies on certain factors like reserve tones, reserved tone location, level complexity and power allowed on reserved tones. This scheme depicts the additive approach to PAPR minimization in the multicarrier communication system. TR technique demonstrates that keeping a small fraction of tones causes large PAPR reduction using the simple algorithm at the OFDM system transmitter with no additional receiver complexity. With N number of tones being small, the set of tones kept or reserved for the reduction of PAPR may signify a substantial part of the available bandwidth and can cause data rate reduction. The merit of the TR scheme is less complexity, no side information, and no further operation is needed at the receive end of the system. TR technique is anchored in adding a data block dependent time domain signal to the original multicarrier signal to minimize its peaks. This time domain signal can be simply calculated at the transmit end of the system and removed at the receive end.
- Hadamard Transform: Hadamard transform (HT) technique is concerned with the relationship between the OFDM input sequence correlation properties and PAPR probability. This scheme minimizes the rate of high peaks in comparison with the original OFDM system. The used of HT in 16 QAM OFDM system has shown capability to reduce PAPR to about 2dB with no increase in power and side information and small increase in complexity of the system [24]. The notion behind the use of the HT is to minimize the autocorrelation of the input sequence to reduce the problem of PAPR without any requirement for transmitted side information at the receiver.
- Dummy Sequence Insertion: Dummy sequence insertion (DSI) technique is one in which a dummy sequence is incorporated into the input data for the reduction of PAPR prior to IFFT operation. The dummy sequence can be in the form of complementary sequence, correlation sequence, and other particular sequence which does not work like the side information and this is unlike the SLM and PTS schemes. Thus there is no bit to error ratio (BER) degradation as a result of side information error. The method of PAPR threshold is integrated with DSI technique. If lower output is achieved for the PAPR of IFFT than a certain defined PAPR threshold level, then the output data of the IFFT is transmitted. If not, dummy sequence is added to reduce the PAPR. In this technique, dummy variable are included in the transmitted data for PAPR reduction of the OFDM signal. At the receiver, the dummy variables are easily discarded since it contains no information. This is unlike the block code based techniques for the reduction of PAPR which are prone to overhead of large side information to be transmitted to the receiver. In terms of BER performance, the DSI outperforms the conventional PTS and offers more effective transmission capacity for PAPR reduction than the conventional block coding. A better performance than other techniques is obtained using DSI technique with complementary sequence.

- Tone Injection: The method of tone injection (TI) was presented by Muller and Huber [29]. This scheme is based on additive method for the reduction of PAPR. Reduction of PAPR of multicarrier signal is achievable using additive method without any loss in data rate. In order to reduce PAPR using the TI technique, the constellation size is increased so as to enable each of the point in the original constellation to be mapped into a set of corresponding constellation points. This scheme is called tone injection technique for the reason that the points in the original basic constellation are replaced with new points in larger constellation which corresponds to injecting tone of the appropriate phase and frequency in the multicarrier symbol. However, the disadvantages of these technique are requirement for side information for decoding signal at the receive end, and the need for extra IFFT operation that is more complex.
- Active Constellation: Active constellation (AC) extension method works in such a way that some of the outer signal constellation points in the data block are vigorously extended in the direction of the outer side of the original constellation to minimize the PAPR of the data block. The key idea behind the working of this scheme can be understood in the case of a multicarrier signal with QPSK modulation in each subcarrier. There are four possible constellation points in each subcarrier that lie in each quadrant in the complex plane and at equal distant from the real and imaginary axes. Suppose white Gaussian noise (WGN), the highest possibility decision region is the four quadrants bounded by the axes, therefore, a data symbol received is absorbed. With point at more distant from the decision limits than the usual constellation point (appropriate quadrant) will provide better margin that assures lower bit to error ratio (BER). The concept of AC extension can be applied to QAM and MPSK constellations since the data points that lie on the outer margins of the constellation have space for increased boundaries with no error probability degradation for other data symbols. In this method, the BER is slightly reduced at the same time as the peak size of the data block considerably reduces. In addition, no data rate loss and no side information is needed. Nevertheless, the transmitter signal power may increase for the data block due to these modifications. Hence, the use of this technique is limited to a with a large constellation side.

2) Signal Distortion Techniques

- Clipping and Filtering: A common challenge in OFDM system is high PAPR. The high effect of PAPR results in effects such as increased complexity of the analogue to digital converter (ADC) and digital to analogue converter (DAC) and reduced radio frequency (RF) power amplifier efficiency. In order to address the setback occasioned by high PAPR in OFDM, one technique that seems simple and effective is clipping. In this technique, the components of the OFDM signal that go beyond clip level are cancelled. Nevertheless, clipping produces distortion power that is called clipping noise, and increase the spectrum of the transmitted signal which causes interference [31]. As a nonlinear process, clipping causes in-band noise distortion, which decreases BER and out-of-band noise performance with reduced spectral efficiency [32].

Since clipping causes spectrum expansion, there is need for introducing a scheme to address this effect. Clipping and filtering is a technique that is effective in eliminating the components of the expanded spectrum. The introduction of filtering can ensure decrease in spectrum growth, and following clipping process with filtering can cause reduction in out-of-band radiation. However, the use of filtering after clipping can cause certain peak re-growth in which the peak signal goes beyond the clip level [33]. Iterative (or repeated) clipping and filtering usually called RCF technique, minimizes the PAPR with no spectrum growth. Nonetheless, iterative process is time consuming and thereby resulting in OFDM transmitter computational complexity.

It is proper to perform interpolation prior to clipping otherwise out-of-band effect will occur. In order to overcome out-of-band effect, interpolation should be done before clipping of signal. Usually, in OFDM system application, serial to parallel block converts serial input data which has different frequency components which are base band modulated symbols and apply interpolation to these symbols by zero padding in the middle of input data. After which clipping is carried out to remove high peak amplitudes and frequency domain filtering is employed for the reduction of out-of-band signal, but result in peak re-growth [33].

The clipping and frequency domain filtering scheme is carried out repeatedly until the amplitude is set to the threshold value level to prevent peak out-of-band and peak re-growth. The good thing about this technique is that it be employed for any number of subcarriers and requires no redundancy. The reduction of PAPR is achieved at the expense of slight increase in the overall in band distortion.

- Peak Windowing: The method of peak windowing was proposed by Van Nee and Wild [34]. This scheme suggests that it is possible to eliminate large peaks at the expense of a small amount of self interference when there is occasional occurrence of large peaks. In this scheme, the reduction of PAPR is achieved at the expense of increasing BER and out-of-band radiation. Compared to clipping, peak windowing offers improved PAPR reduction with superior spectral properties. In peak windowing technique, large signal peak is multiplied with a given window such as Gaussian shaped window, cosine, Kaiser and Hamming window. Given that the OFDM signal is multiplied with many of these windows, the spectrum that is produced is a convolution of the original OFDM spectrum with the spectrum of the applied window. Hence, it is expected of the window to be as narrow band as possible, equally the window should not be too long in the time domain because many signal samples are affected which results to increase in BER. The widowing scheme can be used to reduce PAPR down to about 4dB regardless of the number of subcarriers. The loss in signal-to-noise (SNR) occasioned by signal distortion is limited to about 0.3dB.
- Envelope Scaling: Envelope scaling technique was proposed by Foomooljareon and Fernando [35]. The technique was developed to reduce PAPR by scaling the input envelope for a number of subcarriers prior to sending them to IFFT. The final input that provides the lowest PAPR will be sent to the system. The input sequence has the same phase information as the original one though with different envelopes. Thus the receiver can decode the received sequence without any side information. The basic idea in this scheme is that the envelope of the input in some subcarriers is scaled to get a reduced PAPR value at the IFFT output. The technique seems only appropriate for PSK modulation schemes, where all envelope of all subcarriers input are equal. In a situation where QAM modulation scheme is implemented by an OFDM system, the carrier envelope scaling will result in serious degradation of BER at the receiver. In order to limit BER degradation, the amount of side information would also be too much when there is large number of subcarriers.
- Peak Reduction Carrier: The use of peak reduction carrier (PRC) for reducing PAPR in OFDM system was proposed by Tan and Wassell [36]. This technique involves using higher order modulation method to characterize a lower order modulation symbol. This allows the amplitude and phase of the PRC to be situated within the constellation region representing the data symbol to be transmitted. For instance, to employ a PRC that uses a 16 PSK constellation to carry QPSK data symbol, the 16 phases of the 16 PSK constellations are split into four regions representing the four different values of the QPSK symbol. PRC scheme is suitable to PSK modulation where the envelopes of all subcarriers are equal. Since PRC technique uses higher order modulation schemes to represent the data of lower order modulation scheme, this will result to the effect of an increased probability of error and as such worsen the general performance BER. Thus a tradeoff exists between reduction of PAPR and BER performance when choosing the PRC constellation.
- Companding: The use of companding scheme for PAPR reduction in OFDM system was proposed by Wang et al. This can view from the fact that OFDM signal can be taken as Gaussian distributed, and the large OFDM signal takes place occasionally. Thus the companding technique can be employed for improving the performance of OFDM transmission. In the use of companding technique, the OFDM signal is companded first before it is converted into analogue signal. The OFDM signal after undergoing the IFFT process is companded and quantized. After digital to analogue (D/A) conversion, the signal is transmitted through the channel. At the receive end, the received signal is initially converted to digital waveform and expanded. Companding scheme is largely used in speech processing where high peaks takes place occasionally. OFDM signal also shows similar feature where high peaks happen occasionally. Companding technique enhances the quantization resolution of small signals at the expense of the reduction of the resolution of large signals, given that small signals occur more often than large ones. As a result of companding, the quantization error for large signals is considerably large and that brings about degradation of BER performance at the receive end of OFDM system. Thus, the companding scheme enhances the performance of PAPR at the expense of BER performance of the OFDM system.

3) Performance Comparison of Different Techniques

There are many approaches to reducing PAPR of OFDM signal that have been proposed and implemented in literature. Therefore, reducing large PAPR by using a combination of different techniques is achievable. Table 1 is performance comparison of different PAPR reduction techniques.

Table 1. Comparison of PAPR reduction techniques [37]

Name of Schemes	**Name of parameters**		
	Distortion less	**Power increases**	**Data rate loss**
Clipping and Filtering	No	No	No
Coding	Yes	No	Yes
Partial Transmit Sequence(PTS)	Yes	No	Yes
Selective Mapping (SLM)	Yes	No	Yes
Interleaving	Yes	No	Yes
Tone Reservation (TR)	Yes	Yes	Yes
Tone Injection(TI)	Yes	Yes	No

4) Factors Influencing PAPR

Studies have shown close relationship of such factors like modulation techniques, number of subcarriers, N, and oversampling rate, L to PAPR. Nevertheless, the influence of each of these factors can be considered in terms of the extent to which it affects the performance of PAPR in OFDM system. These factors are briefly discussed:

1) Modulation schemes: It has been shown in literature that at a given number of subcarriers and oversampling rate, the various modulation schemes such as Binary Phase Shift Keying (BPSK), Quadrature Phase Shift Keying (QPSK), Quadrature Amplitude Modulation (QAM) –16QAM, 64QAM, 128QAM, 256QAM and so on, give results that show slight difference between different modulation methods. Therefore, it is adequate to say that the various modulation schemes only have minimum or less effects on the performance of PAPR [38].
2) Number of subcarriers (N): Using different number of subcarriers, N, has been shown to bring about different performance of PAPR in OFDM system due to varying information carried. The for a known OFDM system PAPR increases with increasing number of subcarriers.
3) Oversampling rate (L): Practically, it is not possible to precisely depict analogue OFDM signal due to the insufficient N points sampling. The reduction performance of PAPR is unduly accurate perhaps ignoring some of the signal peaks [39]. Usually, to evade this problem, oversampling rate, L, is employed. Achieving this is possible by taking L-N point Inverse Fast Fourier Transform (IFFT)/Fast Fourier Transform (FFT) of original data with zero padding operation of (L-1)*N. An important role is provided by oversampling for revealing the dissimilarity features of OFDM symbols in time domain. Usually, the more the oversampling rate the higher the value of PAPR. Nevertheless, an oversampling factor L = 4 is sufficient to catch the peaks [38].

IV. RESEARCH DIRECTION TOWARD PAPR PERFORMANCE OPTIMIZATION

In recent times, some algorithms using optimization algorithm such as genetic algorithm (GA) and evolutionary algorithm that offer improved PAPR reduction in OFDM compared with earlier discussed techniques have been proposed. Also, hybrid schemes that combine two or more of the earlier mentioned techniques and some of other approaches to reduce computational complexities in SLM and PTS are being proposed. Some of the proposed schemes using optimization or hybrid algorithm are briefly elaborated. A Generalized Opposition Biography Based Optimization (GOBBO) algorithm enhanced with Oppositional Based Learning (OBL) scheme has been integrated with Partial Transmit Sequence (PTS) to solve the problem of PAPR reduction by Goudos [40]. Reduced computational complexity Partial Transmit Sequence (PTS) technique based on firework algorithm (FWA) was proposed by Amhaimar et al [41] and was tested on IEEE 802.11a and 802.16e standards with results obtained outperforming other well known evolutionary algorithms such simulated annealing (SA), particle swarm optimization (PSO), and genetic algorithm (GA). Combining tone reservation (TR) scheme and phase information of the pilot tones, an effective reduction of PAPR in MIMO-OFDM was achieved by Manasseh et al. [42]. An approach involving repeated clipping and filtering (RCF) and tone reservation/injection algorithms to reduce PAPR of OFDM signal was presented by Singh et al. [43]. The application of RCF and SLM schemes to minimize the PAPR of OFDM signal to considerable extent was proposed by Manjula and Muralidhara [44]. A combination of precoding with RCF was employed to reduce PAPR in OFDM system was carried out by Dubey and Gupta [45]. A hybrid scheme that combines enhanced PTS and Mu-Law companding for PAPR reduction in OFDM system has been presented by Ibraheem et al. [46]. In order to solve the problem of computational complexity that is associated with selected mapping (SLM), Sudha and Kumar [47] used a time domain sequence separation to provide low complexity PAPR reduction in SLM-OFDM system. Ali and Hamza [48] proposed the use of SLM technique based on GA to reduce PAPR in OFDM system. Modified Artificial Fish Swam Algorithm (mAFSA) based PTS-OFDM system was proposed by Tekanyi et al. [49]. Shiragapur and Wali [50] examined the use of correction coding such as Hamming code, Reed-Muller code and

Golay code combined with SLM and Mu-Law companding for PAPR reduction in OFDM system. VijayaLakshmi and Reddy [51] proposed a technique for PAPR reduction using two optimization algorithms called Social Spider Optimization (SSO) and Adaptive Artificial Bee Colony (AABC) for SLM scheme in MIMO-OFD system. Sudha and Kumar [52] proposed a combination of conventional SLM and clipping algorithms for PAPR reduction.

The study so far shows that the issue of peak-to-average-power ratio (PAPR) is a major challenge in MIMO-OFDM networks. Many approaches and intelligent algorithms have been proposed by various researchers to decrease PAPR and yet improvement in terms of reduced computational complexity occasioned by increase in number of sub-carriers (or sub-blocks) is required.

Since some studies in literature have implemented hybrid techniques besides the various PAPR reduction methods. In this paper, a hybrid method techniques is presented for PAPR reduction. A three algorithm (hybrid) method was chosen in this paper to optimze PAPR performance in MIMO-OFDM because it is believed to exploit the various advantages of each of the technique to overcome their individual weaknesses. Figure 5 shows the proposed OFDM system model with the three algorithms namely, precoding, repeated clipping and frequency domain filtering (RCF) and the mu-law. The OFDM signal is initially acted upon by the precoding algorthm, then after the outcome is passed on to the RCF algorithm, and finally to the mu-law companding scheme.

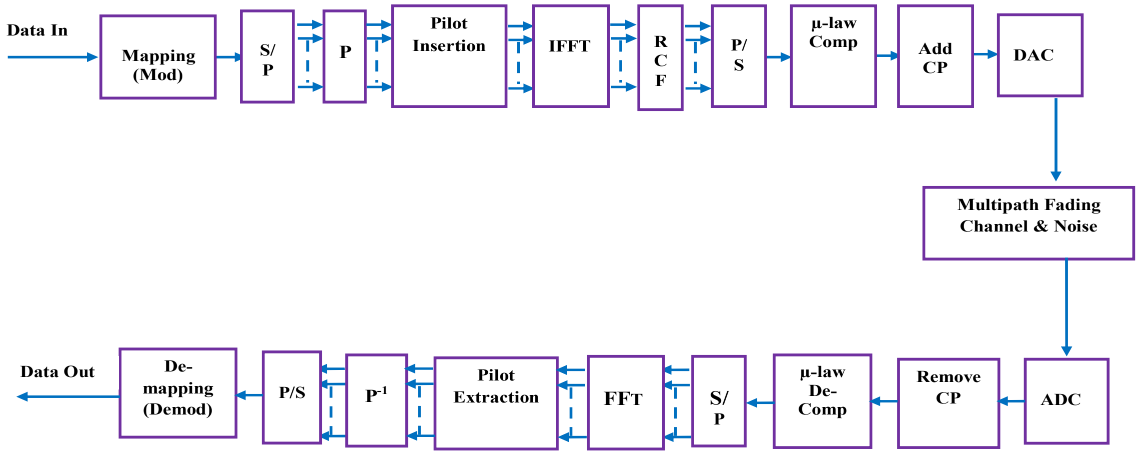

Fig. 5 OFDM system model for PAPR reduction using hybrid scheme

V. CONCLUSION

Firstly, this paper has provided an overview of Multi-Input Multi-Output (MIMO) system and Orthogonal Frequency Division multiplexing (OFDM). Simultaneously, the advantages and disadvantages of OFDM technology have been presented. The focus of this paper is to examine the performance of a major problem that occur in OFDM wireless communication, that is, high peak to average power ratio (PAPR) of OFDM signal. Discussion has been offered on how to reduce PAPR by different techniques. Finally, a hybrid scheme is proposed as way forward.

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