MIMO-OFDM Communication System: A Survey, PAPR Reduction, Precoding And Error Correcting Codes

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Abstract: Due to increased demand of wireless cellular communication, MIMO and OFDM based communication strategy have gained attraction in industrial and research field. Recently, MIMO-OFDM based cellular communication is widely adopted in various real-time applications. However, increased demand of good quality communication and increased number of uses raised several challenging issues. In this article, we present a comprehensive review study about MIMO-OFDM based communication. We mainly focus on important parameters of MIMO-OFDM which plays important role in MIMO-OFDM communication such as PAPR, pre-coding, spectral efficiency, error correcting codes, evolutionary computation, optimization schemes and various other approaches of QoS improvement of MIMO-OFDM. The complete review study shows that PAPR reduction and error correcting codes play important role to improve the system performance.

Index Terms : OFDM , MIMO-OFDM, PAPR, QOS , PTS,SLM , LDPC.

1. INTRODUCTION

The demand of wireless communication is growing swiftly and the increased technological advancements have led towards the use of wireless communication for various applications. Due to this increased demand and technology, the elevated data transmission rates and enhanced eminence of service communication is highly recommended which can also provide higher network capacity and throughput, hence, providing the better quality of wireless communication is a crucial and important task in this field of wireless communication [1]. For the uses of smart terminals, the necessities of high scale wireless communication networks developed rampantly. Therefore, in pursuance of assuring the quality of service (QoS) of mobile applications, the capability of the networks should also be augmented. To attain the better network capability, the spectrum efficiency (SE) can be increased. Furthermore, each year the carbon emissions and operator overheads upsurge through the extreme energy depletion of wireless communication networks [2, 3].Consequently, green communication has acquired extra attention in the academic and industrial fields, and the energy efficiency (EE) has been considered another instance of essential measurement tool for assessing the latest procedures and the efficiency of the spectrum [4–5].

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In wireless networks, the Multiple-input multiple-output (MIMO) method has gained excessive curiosity for over a decade since it may provide momentous escalations in throughput of network and consistency of link deprived of additional bandwidth or enhancing transmission capacity. Recently, in the 3rd generation long-term evolution (LTE) cellular systems and its latest versions, MIMO and orthogonal frequency division multiplexing (OFDM) have been popular as main methodologies. Furnished with numerous antennas, the evolved Node B interconnects with numerous sorts of user equipment and simultaneously, the frequency sources such as multiuser MIMO may enhance the efficiency of the spectrum, reliability of link, and efficiency of system power [6]. Recently, to improve these profits, enormous types of MIMO such as large-scale antenna network, extremely big MIMO and hyperactive MIMO have been employed in system [7]. In case of enormous MIMO network, numerous antennas have been employed to assist more than ten users concurrently. Hypothetical and magnitude outcomes signify that enormous MIMO may meaningfully expand the efficiency of the spectrum and concurrently decrease the radiated energy [8]. Entire characteristic of enormous MIMO have been briefd in Table1.

Table 1. *Characteristics of Massive MIMO*

	Key Feature	Reason
Advantages	High spectrum efficiency	Multiplexing and array gains are high which help to achieve the higher spectrum
	Increased reliability	Diversity gains are high in MIMO-OFDM systems.
	Increased energy efficiency	The UEs are used for concatenating the radiated energy.
	Efficient Precoder	Good conditions of data transmission for i.i.d. Rayleigh channels

	Reduced interference and improved security	UE channels are orthogonal and narrow beam
	Robust to individual element failure	Large number of antennas present in the network
Disadvantages	Pilot Contamination	Limited orthogonal pilots
	High signal process complexity	Due to large number of antennas and multiplexing UEs.
	High peak to average power ratio	Large amplitude variation
	Sensitive to beam alignment	Due to narrow beam, the beam alignment become sensitive to UE.
	Poor channel broadcasting	Due to blind positions of UE.

1.1. Overview of OFDM System and its components

It is a distinctive type of multicarrier modulation (MCM) in which a lone data flow has been communicated through a variety of lesser rate subcarriers. It is represented via Figure 1 and may be illustrated through either a modulation or a multiplexing method. Commonly it is employed to improve the sturdiness for frequency discriminatory fading and narrowband intrusion. In case of a single-carrier arrangement, a particular fade or interferer may affect the whole link to collapse, on the other hand in case of a multi-carrier arrangement; merely a minor proportion of subcarriers may be disturbed. To amend some subcarriers, error correction coding can be employed.

(A) OFDM Transmission scheme

It is known that OFDM transmission method is a sort of multichannel arrangement that evades the practices of the band limited filters as well as oscillators for every sub-channel. Initially this technique was hypothesized in the 1960s-1970s. As the small-rate modulations are fewer delicate to multipath, It is better to transmit a total of small rate streams in analogous than transmitting one excessive rate waveform. The frequency spectrum has been divided into adequate small sub-bands and as a result the channel influences are persistent through a provided sub-band.

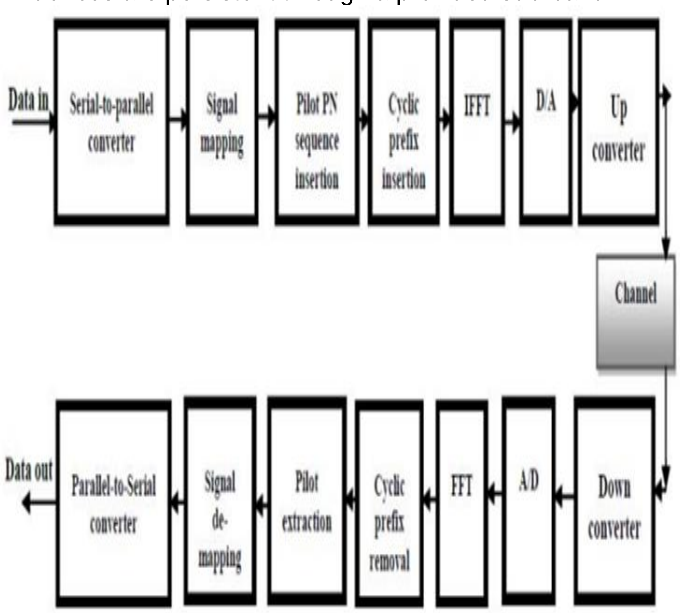

Fig.1. *Blok diagram of a Basic OFDM System*

(B) Multipath Channel

Numerous hindrances and surfaces of reflection are faced by the transmitted signal; consequently the expected signals from the similar source do not arrive at the same time. As a result, echoes are formed and affect the other arriving signals. The key features affecting the system are dielectric constants, absorptivity, conductivity and viscosity. To lessen the effect echoes in the system of an indoor atmosphere, the Multipath channel propagation has been implemented effectively and some measurements are required to lessen echo in pursuance of avoiding Inter Symbol Intrusion. A pictorial representation of Multipath propagation has been depicted in Figure 2.

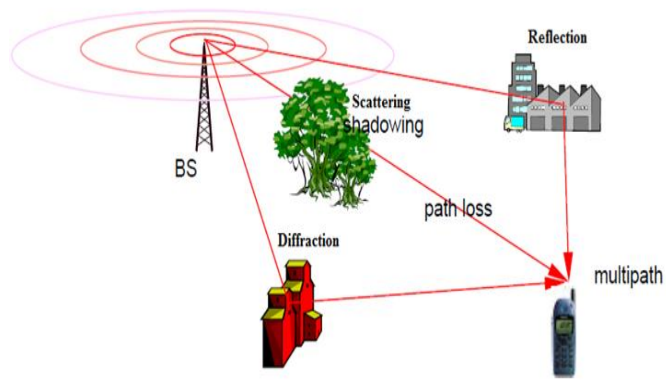

Fig.2. *Multipath Propagation Model*

(C) Inter Symbol Intrusion

It is a type of alteration of a signal in which one symbol affects with succeeding symbols. It is an undesirable event because the preceding symbols have analogous influence as of noise and it causes the communication little bit erroneous. Generally, it is instigated through multipath propagation or the intrinsic nonlinear frequency reaction of a channel affecting succeeding symbols to distort collectively. The existence of the intrusion in the structure causes inaccuracy in the assessing unit at the receiver end. Consequently, during the forming of the transmitting and receiving strainers, the goal is to lessen the consequences of intrusion and thus supply the digital data to its endpoint with the least probable error rate.

(D) Inter Carrier Intrusion

In an OFDM structure, the orthogonally loss in subcarriers is due to the existence of Doppler shifts and frequency and phase offsets. Consequently, interference is perceived among subcarriers. This occurrence is recognized as ICI.

(E) Cyclic Prefix (CP)

The Guard Interval or Cyclic Prefix is a sporadic addition of the end portion of an OFDM character which is augmented at the beginning of the character in the transmitter. At the receiving end, afore demodulation, this prefix has been detached. The augmentation of the CP is performed when the parallel to serial transformation take place. It is detached before the operation of DFT at the receiver end.

(F) Orthogonally in OFDM

In OFDM, the frequency bands are efficiently used by allowing the subcarriers to overlay each other in the frequency area. The N evenly spread out subcarriers will be orthogonal if the frequency parting among subcarriers is $\Delta f = \frac{1}{N.T_s} = \frac{1}{T}$, where $N.T_s$ is symbol period and rectangular windowing of the IFFT is accomplished. Certainly, in these situations the subcarriers can achieve a sinc waveform frequency reaction.

1.2. Overview of MIMO System and its components

In Space time structures, the antenna alignment has been revealed in Figure 3. At the transmitter and receiver ends, the Single-input-and-single-output (SISO) structure practices simply one antenna. Contrary, a single transmitting antenna and multiple receiving antennas have been used in Single-input-and-multiple-output (SIMO) structure. Many transmitting antennas and only one receiving antenna have been used by Multiple-input-and-single-output (MISO) configuration. Numerous antennas at transmitter as well as at receiver ends are used by Multiple-input-multiple-output (MIMO) structure. Transmitter and receiver equipped with many antennas gain antenna assortment without dropping the spectral efficacy. In a MIMO arrangement, various antennas are engaged at the transmitter and receiver ends and they are kept disjointed at sufficient distance. The distance among various base station antennas may be fixed as 10 counts as compared to the carrier wavelength and mobile station antennas may be disjointed via half carrier wavelength. Subsequently, autonomous channels among the transmitter and receiver sides are designed, in order to accomplish spatial range or space division multiplexing. The plan is to comprehend spatial multiplexing and data pipes through development of space magnitudes that are produced through multi-transmitter and receiver antennas.

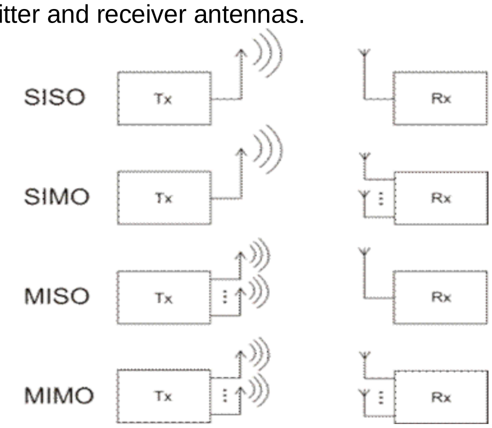

***Fig. 3**. Space Time Communication Systems.*

Like a main structure of succeeding generation wireless communication structures, MIMOs are proficient of assisting expressively greater data rates as compared to the UMTS (universal mobile telecommunication system) and the HSDPA (high-speed downlink packet access) centered 3G systems. By means of the terms, a MIMO structure uses numerous transmitter and receiver antennas for providing parallel data flows. As the information is conveyed via distinctive routes, a MIMO structure is proficient of using transmitting and receiving assortment, henceforth it is capable of sustaining consistent communications.

1.3. Issues and challenges in MIMO and OFDM structures

The MIMO and OFDM structures are capable to provide improved system performance for wireless communication due to orthogonality and multi-user communication capacity. However, these systems suffer from various issues which are discussed in the below given table 2.

***Table 2**. Drawbacks of MIMO and OFDM Systems.*

Drawbacks of MIMO	Drawbacks of OFDM
Following are the disadvantages of MIMO: • The resource requirements and hardware complexity is higher compare to single antenna based system. Each antenna requires individual RF units for radio signal processing. Moreover advanced DSP chip is needed to run advanced mathematical signal processing algorithms. • The hardware resources increase power requirements. Battery gets drain faster due to processing of complex and computationally intensive signal processing algorithms. This reduces battery lifetime of MIMO based devices. • MIMO based systems cost higher compare to single antenna based system due to increased hardware and advanced software requirements.	• There exists high peak to average power ratio which could drift the system into the region of non-linearity and saturation, which reduces the power efficiency of systems. • The insertion of guard band reduces the spectral efficiency and thus total channel capacity is decrease. • In mobile environment the Doppler shift, carrier off set in case of higher number of carriers and spreading of OFDM symbol out of band spectrum are practical problems of OFDM systems. • It is more sensitive to CFO and carrier frequency drift than single carrier systems.

1.4. Work contribution

In this article, we study about MIMO-OFDM based wireless communication systems. recently, these systems are widely adopted in cellular communication. Thus, we present a review study about techniques to improve the performance of these systems. the main contribution of this work are as follows:

(a) Study about MIMO-OFDM systems
(b) Presenting a literature review study about PAPR reduction techniques in MIMO-OFDM.
(c) study about precoding techniques
(d) study about error correcting codes and their use in communication systems
(e) Role of evolutionary computation and optimization schemes in MIMO-OFDM based communication system

Rest of the article is organized as follows: section II presents a comparative analysis about recent techniques of PAPR reduction, precoding, spectral efficiency, and error correcting codes, section III presents concluding remarks.

2. LITERATURE REVIEW

This section presents the briefing analysis of current techniques in the field of MIMO-OFDM systems. In the previous section, we have studied about several advantages and disadvantages about these technologies. Based on that analysis, we have identified that the power consumption, spectral efficiency, better throughput and reduced data error are the challenging issues in this field. Here, we present some recent techniques to enhance the system enactment of MIMO-OFDM communications.

2.1. PAPR reduction techniques

Pachori et al., [17] have proposed an analogous combinational arrangement to decrease PAPR in MIMO–OFDM structure in Rayleigh fading atmosphere. The suggested technique logically includes both dynamic gradient project and fractional transmit series systems. It not only lessens the PAPR of MIMO–OFDM signals but also preserves the data flow and delivers low in-band ripples and out-of-band emissions. Furthermore, it also suggests fewer computation complexities as compared to a corresponding combinational method. Anoh et al., [9] have presented an enhancement for the efficiency of repetitive clipping and filtering procedure of OFDM signals. The main idea is to optimize the repetitive clipping and straining of OFDM signals to decrease complexity of model and handling resource management with a BER enactment adjustment. The investigation has protracted the previous basic minimization of ICF which removes the dependence on distinctive optimization software (specifically CVX) to create optimum strainers. On the basis of Lagrange multiplier optimization procedure, a less complex clarification has been bestowed and it lessens the number of repetitions obligatory to achieve an anticipated clipping inception. Through flexible rearranging of the clipping inception, rather than the standard technique of utilizing a hard/fixed-clipping inception value, a quicker merging to an anticipated clipping level and therefore in this way, an entailed PAPR has been accomplished. To solve the PAPR lessening issue of OFDM signals, Anoh et al. [10] have presented a unvarying dissemination method and employed the Lagrange multiplier (LM) optimization to lessen the number of repetition implicated in a flexible manner. Owing to the irregular diminution of the PAPR lessening method, they have compensated the resultant signal through a connected element which lessens the error floor of the in-band deformation of the clipped signal through the least mean square error process and consequently it improves the BER enactment. They have provided distinctive approaches for every supporting PAPR lessening via clipping trailed by straining with no direct dependence on a clipping ratio constraint. They have concluded that their method meaningfully lessens the PAPR of the OFDM signals (particularly with LM optimization) and it is superior to the standard flexible iterative clipping and straining functioning without LM optimization. Zakaria et al., [11] discussed about Partial transmit sequence (PTS) and descried its numerous advantages to reduce the PAPR in multicarrier modulation system. This method yields side information data as an outcome of the MCM signal maximization technique. The produced side data are needed to be communicated with the primary data through the channel for prosperous data retrieval at the receiving end. A functioning process for side information data broadcast has not recognized till date and investigations are being performed for this. Henceforth, the scholars have introduced a method which implants side data into the initial data set. Through their work, they have selected a WP-based PTS method as the MCM communication process. The recommended arrangement is known as WP-PTS with implanted side information data. Additionally, an appropriate method for rebuilding the primary data was also established. Hao et al., [12] presented a novel deep neural network combined with extended Selected Mapping (ESLM), namely ESLM-AE, to mitigate the high PAPR issue of DCO-OFDM signals. It uses an AE structure to represent the constellation mapping and de-mapping of the broadcast symbols. In the network, the ESLM method is added after the constellation mapping to lessen the high PAPR of the DCO-OFDM structure. By designing the loss function of neural network and considering both the BER and PAPR performance, auto encoder and SLM can be combined organically. Further, the phase factor of SLM can be determined and optimized accordingly in the network training process. Thus, it is expected that the proposed ESLM-AE method is more efficient in reducing the PAPR without deterioration of the BER performance. Satyavathi et al., [13] have selected Partial transmit sequence (PTS) related method for the diminution of PAPR and 3 foremost provisions are created for the customary PTS method. Initially, the time series which is to be grown is altered, next the structure is protracted through fused procedure of selective mapping and by PTS technique in which added fused approach is selected. Furthermore, the advantages of DHT are integrated with this structure. Joshi et al., [14] have equated the enactment of FFT (Fast Fourier Transform) OFDM with Discrete Wavelet Transform (DWT) OFDM. The DWT OFDM may work as a probable alternate for the FFT since there is no necessity of Cyclic Prefix owing to the overlying characteristics of DWT. It gratifies the orthogonally norm with the standard renovation of the beacon. Being the root of DWT OFDM, the DWT has various useful aspects as compared to FFT OFDM. Only by substituting the FFT block with DWT in OFDM structure, an improved enactment has been perceived that makes a fresh DWT-related OFDM structure. Meng et al., [15] introduced a novel direct pre-coder strategy for big-scale many user MIMO-OFDM structures to increase the efficacy of the structure. Contrasting to the prevailing pre-coder outline, the recommended pre-coding technique may eliminate MUI as well as efficiently decrease the PAPR by initiating phase features. Moreover, a suboptimum method with small convolution has been recommended. Liang et al., [16] The artificial bee colony-related selective learning (ABC-SLM) method, that is a new PAPR lessening method, has been recommended to lessen the peak to average power ratio (PAPR) in OFDM structures. Excessive PAPR may reduce the efficacy of high-power magnifier and is a chief drawback of OFDM structure. They have proposed a flexible ABC-SLM method to enhance the PAPR lessening enactment of ABC-SLM method. The recommended scheme is known as GA-ABC-SLM and it is joined the gene algorithm (GA) with the ABC-SLM method. Below give table 3 presents a comparative study in terms of objective of the work, methodology used and main contribution of these techniques.

***Table 3**. PAPR Reduction Comparison*

Authors	Main Objective	Methodology	Remarks
Pachori et al., [17]	PAPR reduction under Rayleigh fading	By combining, both active gradient project and partial transmit sequence schemes	Reduced computational complexity, better data rate
Anoh et al., [9]	PAPR reduction	Iterative clipping and filtering	A new clipping based on threshold is presented
Anoh et al., [10]	PAPR reduction and iteration minimization	compensate the output signal using a correlation factor that minimizes the error floor in the in-band distortion of the clipped signal using LM optimization	Better filtering approach using LM optimization strategy.
Zakaria et. al., [11]	PAPR reduction	Side information is generated and transmitted over channel and recovered at the receiver end by using wavelet packet (WP)-based PTS (WP-PTS) scheme	A new PTS scheme using wavelet packets is developed.
Hao et al., [12]	PAPR reduction in DCO-OFDM	Extended Selected Mapping (ESLM) using Neural Network, autoencoder and SLM.	Improved PAPR and reduced BER for DCO-OFDM
Satyavathi et al., [13]	PAPR Reduction and	PTS and SLM techniques are presented	Hybrid scheme is presented for PAPR reduction
Meng et al., [15]	Pre-coder design	Interference cancellation using direct precoder	PAPR reduction
Liang et al., [16]	PAPR reduction	artificial bee colony-related selective learning for PAPR and GA	Evolutionary computation for PAPR reduction

2.2. Pre-coding and Spectral efficiency

Basar et al., [18] have combined OFDM with index modulation (OFDM-IM) idea with MIMO communication to attain benefits of these two methods. The authors have focused on the employment and fault enactment examination of the MIMO-OFDM-IM method for subsequent 5G generation wireless networks. Maximum likelihood (ML), near-ML, MMSE and OSIC related MMSE sensors of MIMO-OFDM-IM are recommended, and their theoretic enactment has been examined. In enormous MIMO-OFDM structures equipped with frequency discerning channels, Zaib et al., [19] have tried to resolve uplink channel approximation. They have suggested an effectual dispersed minimum mean square error method which may attain immediate optimum channel approximations at lesser convolution through exploitation of the sturdy spatial association between elements of antenna array. The projected process includes resolving a condensed dimensional MMSE issue at every antenna pursued by a monotonous distribution of info across association between elements of neighboring array. Additionally, to improve the channel approximations and to decrease the number of preserved pilot tones, they have proposed a data-assisted approximation method which depend on discovery a group of utmost dependable data carriers. Additionally, they have used theoretical configuration to enumerate the pilot corruption, and then utilize this info to investigate the consequence of pilot contagion over channel MSE. In case of mmWave massive MIMO-OFDM structures, Gao et al., [20] have suggested a multiple-user uplink channel approximation method which converts the broad-band FSF channel into numerous analogous narrow-band flat fading channels. Precisely, the mmWave channels show the perceptibly angle domain sparsely because of the much difficult path loss for NLOS routes than that for LOS routes. According to their derivation, this sparsely manner is nearly unaffected inside the configuration bandwidth. Through utilization of such angle-domain designed sparsity of mmWave FSF channels, authors have proposed a DCS-based channel approximation method, in which both the transmitter pilot signal as well as receiver channel approximation method is expanded in the DCS concept of better enactment. The relay-aided enormous MIMO for cellular network was investigated by Chen et al., [21]. For downlink single-cell multi-user multi-relay enormous MIMO transmission, the precise closed-shape illustrations of spectral and energy efficiency were attained in the pilot-spoiled organization, in which the number of users is more than the pilot structure size. On the basis of the hypothetical outcomes of spectral and energy efficiency, authors have investigated the consequences of certain system factors (like total antennas at the BS (base station), transmission ability of the BS, and transmission ability of every RS (relay station). It also achieves the balance among spectral and energy efficiency through potential control. Precisely, the balance issue has been resolved via combined optimization across transmission power of the BS and every RS. It increases energy efficiency as well as satisfies the spectral energy requirements. Eraslan et al., [22] have bestowed a lesser-complexity link adaptation procedure for power proficient optimization of applied MIMO-OFDM structures. The chief influences of this study may be concise as follows: They have formulated the power proficient optimization of MIMO-OFDM structure through a complete scientific packet error rate enactment prototype related to post processing signal to noise ratio and a comprehensive power depletion prototype. They have examined the power proficiency and transmit energy association and show that energy efficiency is a single-spiky quasiconcave operation of the transmission energy. This evidence instigated them to develop a lesser-complex repetitive method which discovers near-optimum transmission energy. They have analyzed the association among the PPSNR and the singular amounts of the channel, and employ this association to trim the search space without the modes which employ greater number of spatial flows than the channel may assist. These procedures bound the search space into a considerably lesser set and henceforth decrease the computation convolution of the method through without reducing the enactment. Bhandari et al., [23] have projected a new channel estimate technique since the prevailing channel estimate methods were not sufficient to resolve the ISI issue. Occurrence of interference in MIMO-OFDM can cause poor enactment. They have recommended blind channel estimate which is united through independent component analysis, so this technique is known as fusion ICA and it minimizes the ISI consequences. Below give table 4 presents a comparative study in terms of objective of the work, methodology used and main contribution of these techniques.

***Table 4** Error Correcting and Spectral Efficiency*

Authors	Main Objective	Methodology	Remarks
Basar et al., [18]	Error reduction	OFDM with index modulation (OFDM-IM) using Maximum likelihood (ML) based MMSE detector	A new design of OFDM with index modulation is developed.
Zaib et al., [19]	Channel estimation	MMSE based channel estimation is presented and later pilot contamination identification is developed.	reduced dimensional MMSE problem and channel estimates and/or reduce the number of reserved pilot tones
Gao et al., [20]	Uplink channel estimation	Distributed compressive sensing scheme for channel estimation	the transmit pilot signal and receive channel estimation algorithms are developed
Chen et al., [21]	Improving the spectral efficiency and energy efficiency	A joint optimization strategy is developed which considers power of BS and relay station.	New optimization schemes are introduced for SE and EE optimization
Eraslan et al., [22]	Energy optimization	Efficiency maximization approach is developed which uses packet error rate and SNR.	The algorithm limits the search space into a much smaller set and hence reduce the computational complexity

Precoding

Ghirmai et al., [25] MIMO-OFDM structure contains of numerous sub-carriers and every one of the sub-carrier has its personal channel. When pre-coding of these structures is achieved on the basis of subcarrier, the produced burden will also be massive. Authors have suggested a pre-coding approach which is known as per-band pre-coding. Here a set of sub-carriers are pre-coded using one pre-coder. This method diminishes the overhead of response and permits the development of PM assortment approaches. It has small computation convolution. They have also suggested numerous per-band PM assortment approached for ML and LMMSE recipients. Guo et al., [26] have examined the capacity optimization issue for MIMO-OFDM structures with inadequate CSI. Though, the transmitter-receiver strategies for MIMO-OFDM structures have been comprehensively examined by researchers. However, till date none has provided precise answers for source distribution for MIMO-OFDM structures with statistical channel approximation faults. On the basis of applied channel approximation method, the authors have derived the channel approximation faults and the vigorous source distribution issue has also been articulated. Initially, the configuration of the optimum vigorous pre-coder has been developed and then the maximization issue has been considerably simplified. Additionally, on the basis of the dual Lagrangian technique, a vigorous power distribution procedure has been suggested. The recommended method may be deliberated like a variation of water-substantial solution. Taghizadeh et al., [27] have addressed the direct pre-coding and decoding strategy issue for a duplex OFDM communication structure among two MIMO bidirectional nodes. The consequences of machine deformations cause remaining self-intrusion and inter-carrier trickle. Initially, the function of a FD MIMO OFDM transmitter-receiver is formed in the effect of identified hardware deficiencies. Afterwards, a substituting quadratic convex technique is specified to attain a MMSE outline for the stated structure. The projected outline is then protracted to increase the structure sum rate, relating the weighted-MMSE technique. The projected technique results in a monotonous enhancement, directing a required conjunction to a static point. Jacobsson et al., [28] considered the download link of a massive multiuser MIMO structure which is fortified with the with small-resolution digital-to-analog converters BS. On the basis of various prevailing outcomes, the authors have assumed that the current arrangement functions across a frequency discerning wideband channel and employs OFDM to make simpler equilibrium at the user equipment. Additionally, they have considered the essentially applicable situation of oversampling digital-to-analog converters. Theoretically they have analyzed the un-coded BER enactment through direct pre-coders and quadrature PSK using Buss gang's formula. Yao et al., [29] introduced a peak to average power ratio conscious pre-coding algorithm which manipulates the extreme degrees-of-freedom spatial for big-scale MIMO antenna structures. Normally, it needs discovery an answer for a non-convex maximization issue. Rather than soothing the issue of minimizing the peak power, they have presented an applied semi-definite moderation structure which permits a precise and effectual estimate of the theoretic peak to average power ratio conscious pre-coding enactment of OFDM-focused enormous MIMO structures. The structure permits the amalgamation of channel vagueness and inter-cell synchronization. Gupta et al., [30] presented that the performance of cellular communication is improved by MIMO systems. System performance has been enhanced to next level through blind channel approximation methods when data symbols are transferred in chunks. For approximately all SNR ratio quantities, these approximation methods are computationally costly. The authors have used sporadic precoder-centered blind channel approximation to handle issues such as convolution, channel order excessive approximation and expansion of bandwidth. The system consistency may also be enhanced, when pre-coder coefficients are selected without any dependence or least association with noise coefficients. Below give table 5 presents a comparative study in terms of objective of the work, methodology used and main contribution of these techniques.

***Table 5** Precoding Techniques*

Authors	Main Objective	Research outcome	Methodology	Remarks

Ghirmai et al., [25]	Precoder design for MIMO OFDM system	Sub-band Precoder design	Group of sub-bands are precoded using per-band precoding	Reduced feedback overhead and reduced computational complexity
Guo et al., [26]	MIMO Capacity maximization using imperfect CSI	Precoder design and power allocation methods	Resource allocation based on the channel estimation error.	Joint Precoder and resource allocation
Taghizadeh et al., [27]	Precoding and decoding	Increased sum rate	Convex optimization for Full Duplex MIMO-OFDM system	A new design to improve the weighted MMSE.
Jacobsson et al., [28]	Improving BER using precoding	Improved BER and precoder architecture	Downlink Massive MIMO BER improvement using direct precoding and Bussgang's formula	zero forcing detector is employed and information theoretic model is developed for sum rate maximization.
Yao et al., [29]	PAPR aware precoding	PAPR reduction	Non-convex optimization	semi definite relaxation framework for PAPR reduction.
Gupta et al., [30]	Channel estimation	Periodic Precoder design	based blind channel estimation using periodic precoder	Improved system reliability and reduced complexity.

2.3. Error correcting codes in MIMO-OFDM systems

Agarwal et al., [24] have introduces a summary of MIMO–OFDM wireless approach which considers developments in design of physical-layer, numerous spatial and temporal codes, spatial–frequency codes and competent integrated forward error rectification method. It lessens the BER performance. Additionally, the authors have outlines the development of numerous enactment metrics which were described previously in this field. The development result has been surveyed through a quadratic nonlinear method to evaluate the stimulating enactment metrics. As BER and SNR investigation is proved as the stimulating enactment investigation of the MIMO–OFDM structure. Wang et al., [31] have investigated vigorous receiver strategy for pilot tainted channel approximation in huge multiple-antenna configurations. Using bounded channel approximation faults, they have handled the multiple-user recognition issue through a fresh concept of exploitation of the FEC code assortment. Contrasting the customary method focused on worst-case channel fault, they have distributed several channel codes between pilot intrusion users. Next they have developed a quadratic encoding recipient to use the distinct FEC signature of end user over a group of direct code limitations. Daoud et al., [32] have presented a fresh method which minimizes the PAPR in a MIMO–OFDM configuration through linear coding. The authors have described the theoretic working of the method via analytical derivation of method. Experimental outcomes exhibited that through LDPC, we can achieve better enactment than the prevailing available turbo encoding in context of PAPR decrease proportion. Additionally, the existing method reveals a substantial decrease in peak to average power ratio and an enhancement in BER devoid of up surging the computation convolution. Li et al., [33] have proposed a joint decoding method to recuperate low-density parity-check code-word and PTS phase features, for OFDM structures with a low PAPR. Though, the error-correcting enactment of the combined decoding method majorly based on the partition of the OFDM subcarriers into clusters in the PTS technique. Through a pseudorandom division, the combined decoding method offers satisfactory error-correcting enactment only if the total of PTS clusters is quite small. The authors have formulated a maximization issue to enhance the combined decoding enactment through optimization of the separation. Additionally, two greedy-based procedures are suggested to address the issue. Wang et al., [34] have proposed a fresh linear encoding tactic for the mutual recognition and deciphering of LDPC-centered spatial-temporal coded bacons in multiple-antenna OFDM configuration. Whereas customary recipients normally disconnect the recognition and deciphering procedures as two different sets or need repetitive turbo interchange of external info among the decipherer and soft sensor. They have formulated a combined linear program through exploitation of the restrictions forced on the data characters, training characters and channel cipher. By considering the massive quantity of LDPC parity check disparities, they have presented a flexible method to considerably decrease the difficulty of the combined LP recipient. Aoki et al., [35] have analyzed that the main disadvantage in linear pre-coding of download link multiple-user MIMO structure is the upsurge in the transmission power whenever a channel is linked. Alternatively, nonlinear lattice pre-coding in download link multi-user MIMO structure is proficient of minimizing the transmission power via addition of a modeling order to the initial transmission sequence. Though, standard lattice pre-coding should not be straight employed to prevailing bit-interleaved coded MIMO-OFDM structure as the lattice pre-coding and error rectifying ciphers must be planned individually. The authors have projected embedding of lattice pre-coding into the error rectifying ciphers which are employed in the primary multiple-user MIMO-OFDM structure using linear pre-coding. Main benefit of the proposed method is that the reception process at user terminals planned for the primary structure can remain unchanged to assist the lattice pre-coding. Shubhi et al., [39] a conventional turbo decoding scheme gives satisfactory enactment in perfect MIMO structures, momentous enactment dilapidation happens in a loaded MIMO structure if the total number of transmitting antennas are greater than receiving antennas. The authors have proposed a combined deciphering method for turbo cipher. Through this decoding, computation of soft information is performed for every arrangement of bits obtained from every stream rather than disjointedly between every stream. In addition, to unite the lattice figures from every stream, a super-lattice illustration was presented. Below give table 6 presents a comparative study in terms of objective of the work, methodology used and main contribution of these techniques.

Table 6 *Error Correcting Codes in MIMO-OFDM*

Authors	Main Objective	Error Correcting scheme	Methodology	Remarks
Wang et al., [31]	Receiver design for large antenna system	Forward error correction	Channel codes are distributed among users and FEC signatures are utilized using quadratic programming.	A FEC enabled MIMO-OFDM system is developed.
Daoud et al., [32]	PAPR reduction using error correcting codes	LDPC	Linear LDPC coding to reduce the PAPR.	Linear LDPC is developed with reduced complexity.
Li et al., [33]	PAPR reduction	LDPC	Combined LDPC and PTS scheme	Greedy optimization is developed to solve the decoding problem.
Wang et al., [34]	Error correctins	LDPC	Linear programming optimization with LDPC	Reduced complexity and improved reliability
Aoki et al., [35]	Linear pre-coding for downlink communication	NA	Linear precoding for downlink communication	Combined architecture of MIMO with error correcting codes.

2.4. Evolutionary computation and optimization algorithms

According to, Lahcen et al., [36], the PTS strategy is an adaptable and effective manner utilized to resolve the peak average ratio issue for OFDM structures, however the key disadvantage of partial transmit sequence method is the excessive computation convolution instigated by the comprehensive exploration of segment. The authors have anticipated a condensed computation convolution partial transmit sequence method on the basis of a uncomplicated approach of Fireworks Algorithm to decrease peak average ratio in WLAN-OFDM configuration. The firework algorithm is a novel swarm intelligence based method which is capable to attain an operational optimization investigation with a small intricacy level weighting procedure employment. Lu et al., [37] Conventional Multi-User Detection (MUD) algorithms for the Multi-Input, MIMO-OFDM structure fail to consider the detection performance and algorithm complexity simultaneously. To address this problem, a new Joint Intelligent MUD (JI-MUD) algorithm that aims to increase the MUD enactment of the MIMO-OFDM structure and to decrease the intricacy of the algorithm was proposed. First, a new MUD technique founded on the genetic algorithm (GA) for the MIMO-OFDM structure was presented. Utilizing the results of the Minimum Mean Square Error (MMSE) procedure as the early populace and the condition of the Maximum Likelihood (ML) procedure as the fitness function, the proposed algorithm performs genetic operations through the roulette wheel selection operator, two-point crossover operator, and adjacent bit reverse mutation operator, which generate a new population. Second, a Hybrid GA (HGA) was presented by combining the simulated annealing and particle swarm optimization algorithms. Cheng et al., [38] have analyzed that the OFDM is an assuring method which achieves greater data rates in a mobile atmosphere. In wireless network structures, signal deformation and transmission diminution are initiated through multipath consequences assures to attain information linked to the channel stimulus reaction through channel approximation to deliver reparation. They have merged a back propagation neural network for the approximation of channel and recompense beacons via a GA to increase enactment and the conjunction level. According to, Amhaimar et al., [39] the PTS is a favorable and uncomplicated technique which is proficient to attain an actual peak average ratio decrease enactment, however it needs a thorough exploration to discover the optimal stage issues that instigates excessive computation intricacy amplified thru the number of sub-blocks. They have proposed a condensed computation intricacy partial transmission sequence strategy on the basis of a new swarm intelligence procedure known as FWA. Experimental outcomes established the suitability and the efficacy of the anticipated process which may successfully decrease the computational intricacy whereas possessing better peak average ratio decrease. Furthermore, it is concluded through the outcomes that the projected partial transmission sequence method-based fire work algorithm, evidently overtakes the newest and significant progressive methods in this field such as simulated annealing, PSO and GA. Prasad et al., [41] have concluded that the PTS method has certain problems like excessive computation convolution because of its comprehensive examining of optimum stage features. In pursuance of resolving this problem, a ascended PSO procedure is applied to partial transmit sequence procedure to discover the optimum stage features for dropping the peak average ratio at a quicker convergence rate and lesser computation intricacy. In M-MIMO structures, Rao et al., [42] have analyzed that the optimum transmission antennas assortment remains as a main restriction. With the increase in the number of antennas, the energy depletion also upsurges. Actually, to achieve greater capability, extra transmission antennas are needed and it instigates an increase in energy depletion. Henceforth, to solve such type of issues of M-MIMO structures, the authors have focused on attaining the election of optimum number of transmission antennas via bearing in mind a multiple-objective issue which maximizes the capability and comparative power proficiency. To achieve this goal, the projected new optimization procedure enhances the number of transmission antennas. Henceforth, for optimum selection of antennas, better GSA has been employed on the basis of a velocity vector, and henceforward the planned strategy is known as MV-GS and it regulates the number of transmitting antennas and selection of the antennas in an optimum manner. Hassan et al., [43] have introduced a fresh arrangement based on the utilization of following able methods: fuzzy logic and GA with the proposal of a prevalent diminution method, PTS is bestowed to reduce the likelihood of excessive PAPR presence in MIMO-OFDM structure for Rayleigh fading channel. The partial transmit sequence arrangement is used in a STB coding prototype whereas the designated signal for transmission has least peak average ratio. Below give table 7 presents a comparative study in terms of objective of the work, methodology used and main contribution of these techniques.

Table 7 *QoS Improving Techniques in MIMO-OFDM*

Authors	Main Objective	Optimization Technique	Methodology	Remarks
Lahcen et al., [36]	PAPR Reduction	Fireworks Algorithm (FWA)	PTS complexity reduction using FWA	Low-complexity and effective optimization
Lu et al., [37]	Multi-user detection in MIMO-OFDM.	Hybrid Genetic algorithm	, a new Joint Intelligent MUD (JI-MUD) algorithm where GA and MMSE are used.	Hybrid GA and simulated annealing optimization is introduced
Cheng et al., [38]	Multipath effect minimization.	Genetic Algorithm	back propagation neural network for the estimation of channel and compensation signals with a genetic algorithm	Machine learning and optimization based strategy is presented to improve the system performance.
Amhaimar et al., [39]	PAPR reduction using PTS.	fireworks algorithm	PTS and FWA based optimization strategy.	Comparative analysis o different types of optimization algorithms.
Prasad et al., [41]	PAPR reduction	PSO	PSO is incorporated with PTS	PTS suffer from computational complexity
Rao et al., [42]	Power or energy efficiency	Gravitational search algorithm,	Optimal transmitting antenna selection using GSA	Increased number of antenna consume more energy hence optimal antenna selection is developed
Hassan et al., [43]	PAPR reduction for MIMO-OFDM	Fuzzy logic and GA	PTS with optimization	PTS with STB is presented

2.5. Other techniques to improve the performance of MIMO-OFDM performance

Zheng et al., [44] have analyzed that because of the dependency of subcarrier symbols inside every sub-block and the sturdy inter-channel intrusion. This is difficult to perceive the conveyed data efficiently during enacting of low computation responsibility on the receiver. They have proposed two varieties of small-complexity sensors linked to the SMC concept for the recognition of MIMO-OFDM-IM beacons. The initial sensor pulls samples freely at the sub-block level whereas the 2nd sensor pulls samples at the subcarrier level with additional decreased convolution. To certain the restriction of the sub-carrier amalgamations inside of every sub-block, the next sensor is additionally united with a thoroughly planned legitimacy inspection technique. Xiong et al., [45] have investigated that the concurrent wireless information and power allocation for the non-reformative MIMO-OFDM relaying structures. By taking into account, two applied receiver designs, they have presented two methods, TSR and PSR. To study the limitation of the system enactment, they have formulated two maximization challenges to exploit the complete attainable info rate via the complete channel CSI supposition. As both issues are non-convex and have unknown solution approaches. Initially they have derived few obvious outcomes via theoretic examination and subsequently made operative procedures for the problems. Arithmetical outcomes revealed that the enactments of both methods are significantly disturbed by the relay location. Precisely, TSR and PSR display quite dissimilar conducts to the disparity of relay location. The attainable info rate of PSR gradually reduces if the relay transfers from the source to the target. On the other side, in case of TSR, the enactment is moderately poor if the relay is situated in the center of the source and the target. For channel approximation and data detection in MIMO-OFDM, Pham et al., [46] have proposed a repetitive scheme with inadequate CP and an inadequate number of pilot subcarriers. Inadequate CP causes amplified ISI and ICI. The intervention degrades pilot subcarriers employed for channel approximation and influences the recognition procedure. They have proposed a multistep channel approximation procedure and it is supported through a lesser number of pilot subcarriers. Initially, the number of channel routes and the channel covariance matrix are attained from the channel least square guesses at the pilot subcarriers. Afterwards they have formulated a determined likelihood procedure to estimate the time-domain channel. To facilitate data detection, an extra-performance BDMA algorithm was recommended for trellis-based equilibrium. For the MIMO-OFDM-IM structure Hu et al., [47] have projected two subcarrier based sensors. The planned SW-MAP sensor attains the similar performance for BER as the sub-block based brute-force MAP via noticeably condensed computation convolution. Moreover, to decrease the computation convolution, they have planned a HSW-SMC sensor that attains near-optimum error enactment. The HSW-SMC sensor guesses the most-probable ASPs and the analogous most-probable transmitted symbol vectors mutually. In case of the grouping with the biggest posteriori likelihood at every subcarrier level in the HSW-SMC sensor has proscribed AICs, the authors have suggested a lesser-complex sphere decoding examination procedure to attain the estimation of the MIMO-OFDM-IM sub-block that attains near-optimum enactment with significantly small computation convolution. Adian et al., [48] have deliberated a MIMO-OFDM-related CCRN network in which there exist numerous reformative transmits to collaborate with the CBS in aiding an SU. The goal of the author is to enhance the transmit covariance matrices at the CBS and the transmitting point and find the optimum subcarrier coupling, relay obligation, where the dual-decomposition method is employed as a contrivance. The optimum resource distribution is achieved via the discrete energy restrictions in the CBS and conveys point and the intrusion energy restriction on the chief structure. Furthermore, because of the excessive computation convolution of the optimum method, a sub-optimal technique was also recommended. The combined distribution of the sources in the recommended sub-optimal technique is attained by considering the decode-and-forward assistance approach, the intrusion obligatory on the basic network, and the energy resources at the CBS and the transmit points. Below give table 8 presents a comparative study in terms of objective of the work, methodology used and main contribution of these techniques.

***Table 8 Comparative** Analysis of MIMO-OFDM Techniques*

Authors	Main Objective	Methodology	Remarks
Zheng et al., [44]	Interference cancellation	sequential Monte Carlo based detectors	Two detectors are used to draw sub-block samples and subcarrier samples.
Xiong et al., [45]	Energy consumption optimization	Time switching based relaying (TSR) and power splitting-based relaying (PSR) protocols are developed.	Optimization problems are formulated based to maximize the performance.
Pham et al., [46]	channel estimation and data detection for MIMO	multistep channel estimation process	Maximum likelihood for channel estimation and bi-directional
Hu et al., [47]	Detectors for MIMO-OFDM-IM system	a low-complexity sphere decoding-like active state search algorithm to obtain the estimate of the MIMO-OFDM-IM sub-block	This work reduces computational complexity and presented a new method for detector.
Adian et al., [48]	Optimal subcarrier, and relay selection for Cognitive MIMO OFDM	Optimal resource allocation to the users based on CBS, relay and interference.	Decode and forward scheme is applied for joint allocation and resource optimization.

3. CONCLUSION

In this work, we focus on the MIMO-OFDM communication system due to their significant nature of improving the wireless cellular communication. MIMO communication system have several advantages and disadvantages, hence, to overcome the limitations of MIMO, recently, MIMO-OFDM communication systems is developed which improved the communication performance but due to increased demand of good QoS communication, these systems face several challenges. Several approaches have been introduced to improve the performance of MIMO-OFDM. In this work, we review these techniques of MIMO-OFDM and present a comparative study to identify the research gap in this research direction. This review study revealed that the PAPR reduction techniques can be improved further with the help of optimization schemes. Similarly, the error correcting codes are also important factor which affects the QoS of the system.

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