Library Progress International *Print version ISSN 0970 1052*
Vol.44 No.2,July-December 2024: P.1004-1029 *Online version ISSN 2320 317X*

Original Article *Available online at www.bpasjournals.com*

Empirical Evaluation Of Component-Level Optimization Models For Communication Interfaces From A Pragmatic Perspective

Rahul Mahajan [1]*Dr Shrikant V. Sonekar [2]

[1] PGDT, Rastrasant Tukadoji Maharaj Nagpur University, Nagpur
[2] J D College of Engineering and Management, Nagpur.

How to cite this article: Rahul Mahajan, Shrikant V. Sonekar (2024). Empirical Evaluation Of Component-Level Optimization Models For Communication Interfaces From A Pragmatic Perspective. *Library Progress International,* 44(2), 1004-1029.

Abstract: An efficient mmWave communication interface requires optimized selection of channel-noise aware transmitter components, noise-reduction amplifiers, low-BER (Bit Error Rate) receiver-components and efficient modulation techniques. A wide variety of such optimization models are proposed by researchers, and each of them very in terms of their internal & external operating characteristics. For instance, channel modelling techniques focus on optimizing transmitter components, while amplifier & de-amplifier design models focus on modulation & demodulation component optimizations. Due to such a wide variation is component designs, it becomes ambiguous for designers to identify optimal models for the context-specific communication interface designs. To reduce this ambiguity, a detailed survey of modern-day mmWave communication interfaces is discussed in this text. This discussion includes analysis of these models in terms of their functional nuances, contextual advantages, application-specific limitations, and deployment-specific future scopes. It was observed that deep learning models & bioinspired optimization techniques outperform others in terms of communication efficiency under real-time use cases. Based on this discussion, readers will be able to observe similar recommendations and identify optimal models for their mmWave communication radio designs. This discussion is further extended via a comparative evaluation of these models in terms of their computational complexity, processing delay, efficiency of optimization, BER levels, and scalability levels. Using this comparison, readers will be able to evaluate these models, and use them for their performance-specific use cases. To further contemplate this discussion, these parameters were combined to calculate a novel Communication Interface Rank Metric (CIRM), which will assist readers to identify micro-level communication interfaces that have higher overall efficiency levels even under different noise and channel conditions.

Keywords: mmWave, Communication, Components, BER, Delay, Complexity, Channel, Noise, CCRM, Scenarios

[1] Introduction

Mobile devices in a cloud computing context serve as both sophisticated communication tools and sensors. The network's backbone has undergone several modifications in order to support the present range of access methods and provide higher service quality (QoS). The relevance of CR networks for efficiently managing spectrum resources with low interference between neighboring users has increased due to the IEEE 802.22 standard. The ability of CR to change its settings might allow other users to use the network's communication features. Software-defined radio (SDR), an innovative architectural concept, provides more than only CR, however. For 5G wireless communication networks, multiple-input, multiple-output (MIMO) systems are seen as a potential option. Scientific and industrial partners have used a range of cutting-edge technologies to handle the growth as the expected user base and data throughput from the network keep growing. A modern technique called massive MIMO [1] makes use of several antennas to increase spectral efficiency. Multiple-Input Multiple-Output (MIMO) and OFDM have also shown outstanding performance. In recent decades, MIMO-OFDM systems have drawn more attention from academics. A few papers [8] provide a short overview of the waveforms used in MIMO systems. Nevertheless, some studies [9–14] have looked at the estimation and modeling of MIMO channels. No prior synthesis work, to our knowledge, has concentrated on the most current research in channel estimation and equalization method for MIMO-OFDM systems. A review paper [16] that focuses on MIMO-OFDM systems used for underwater acoustic communication is the lone exception to this rule since the transmission circumstances there are completely different from those of over-air transmission. In-depth analyses of channel estimation and signal processing for huge MIMO systems may be found in [7]. The most modern MIMO waveforms, channel forecasts, and equalization algorithms must thus be thoroughly evaluated. The most current advantages of MIMO systems are thoroughly examined in this paper, along with a categorization of the MIMO-OFDM waveforms, channel estimators, and equalizers.

Due to the projected availability of channels with huge bandwidth at mmWave frequencies and the small wavelength of mmWave waves, massive MIMO communication over mmWave frequencies is being researched for use in 5G cellular networks [1]. Hybrid analog/digital designs are suggested for the efficient deployment of mmWave massive MIMO systems because to the high production costs and power consumption of the radio frequency (RF) components at mmWave frequencies [2]– [5]. In hybrid systems, the precoding/combining process is divided between the RF and baseband domains to maximize the use of the available RF connections. Since the receiver is brought to the channel through analog precoding and/or combining circuitry in hybrid systems, channel estimation is challenging. It is challenging to access the RF channel coefficients directly in the lower dimensional baseband domain because they are intertwined with the analog precoding and/or combining vectors [6]. It has been suggested that the compressed sensing (CS) framework may be employed to address the channel estimation problem by taking use of the sparse properties of mmWave channels in the angular domain [2, [7]- [10]. In the CS formulation, dictionary matrices and training precoder and/or combinder vectors make up the analogous measurement matrix. To take advantage of channel sparsity at the transmitter and/or receiver, dictionary matrices have fixed basis functions [6], and training precoder and/or combinder vectors are designed to reduce the coherence of the associated measurement matrix for specific channel recovery. The dictionary matrix's columns may either be the antenna array response vectors or the discrete spatial Fourier transform (DSFT) basis, which produces a sparse channel representation known as the virtual [11]- [13] or extended virtual channel model [6]. The number of DSFT bases used to take advantage of the sparsity of the angular channel on the transmitter and reception sides, which is determined by the size of the transmitter and receiver antenna arrays, limits the angular resolution of the virtual channel representation. Additionally, the short antenna arrays' Fourier transform properties [2] raise questions regarding power leakage problems in the angular spectrum and a decrease in the channel's sparsity level. In contrast to the amount of antennas, the redundant dictionary used in paper [14] has a considerably more constant DSFT basis, which improves angular resolution. But when the angular spectrum is sampled quicker with more DSFT bases, the length of the sparse angular channel vector that has to be recovered and the number of nonzero components in it will grow. More channel measurements (longer training sequences) are required for unique signal recovery [15, 16]. The expanded virtual channel representation's AOAs/AODs are likely derived from a quantized angle grid uniformly covering [0, 2] using a parametric channel model, with the array response vectors corresponding to these angles showing up as columns in the measurement matrices [6]. The number of multi-path components, which is less than the virtual channel model with standard or redundant dictionary matrices, determines the size of the angle grid, which in turn determines the sparsity of the channel vector. This implies that fewer data points are needed for CS channel estimate compared to VC channel estimation. Contrarily, the extended virtual channel model's array response vectors (columns of the dictionary matrices) might not be orthogonal because the model's angles are selected from a uniform grid, which decreases the accuracy of the CS reconstruction and increases the coherency of the equivalent measurement matrix [14]. The angle quantization error cannot be ignored in virtual or extended virtual channel models until the number of dictionary bases approaches infinity, which is obviously not possible due to the continuous nature of AOAs and AODs. Dictionary matrices for narrowband and broadband massive MIMO systems, respectively, are presented in [17] and [18]. These adaptive systems use multi-stage CS-based methodologies. An initial estimation of the AOAs/AODs is produced using coarse angle grids. The grids are then frequently adjusted around the anticipated angles to enhance the approximation. Hybrid designs [2, 3] based on either conventional random CS tools [7-9], [18] or adaptive CS techniques [2] have been presented with a range of different sparse channel models. Lens antennas [20, 21], networks of random or fixed phase shifters [4, 19], and/or low power switches may be used in these systems to create RF precoders or combiners.

Components available for optimization & their descriptions

Wireless communication systems involve the transmission of information over the airwaves, and they rely on a variety of components to ensure that information is delivered accurately and efficiently. Here are some of the key components that can be optimized to improve the performance of wireless communication systems:

1. Antennas: Antennas are the primary interface between a wireless communication system and the surrounding environment. They play a crucial role in transmitting and receiving signals, and their design can significantly impact the system's performance. Antennas can be optimized in terms of their gain, directionality, polarization, and frequency response to improve signal strength and minimize interference.

2. Modulation schemes: Modulation schemes determine how information is encoded and transmitted over the airwaves. Different modulation schemes have different trade-offs between data rate, bandwidth, and error rate. By selecting an optimal modulation scheme, wireless systems can maximize their data throughput while minimizing errors and interference.

3. Channel coding: Channel coding techniques are used to improve the reliability of wireless communication by adding redundancy to the transmitted signal. This redundancy allows the receiver to correct errors caused by noise and interference. Different channel coding schemes have different trade-offs between data rate and error correction capability, and selecting the right scheme can significantly improve the reliability of wireless communication.

4. Power control: Power control mechanisms adjust the transmitted power of a wireless system to maintain a desired level of signal strength at the receiver while minimizing interference with other systems. By optimizing power control, wireless systems can reduce power consumption, extend battery life, and improve overall system capacity.

5. Frequency allocation: Frequency allocation is the process of assigning different frequency bands to different wireless communication systems to avoid interference. Optimizing frequency allocation can improve the overall capacity and reliability of wireless communication systems by reducing the likelihood of interference and maximizing spectral efficiency levels.

Flow of this paper

As a result, researchers have created a wide range of optimization models, each having an own set of internal and external operations. Designers confront challenges when trying to choose appropriate models for context-sensitive communication interface designs due to the wide variety of component designs. To further understand the issue, the next portion of this paper gives a thorough overview of the available mmWave communication interfaces. An accurate assessment of these models' performance in terms of computational complexity, processing latency, optimization effectiveness, bit error rate (BER), and scalability is provided in the third section. In this part, we also recommend the creation of a new communication interface rank metric (CIRM). This method will make it easier for readers to find micro-level communication interfaces that are more effective overall despite noise and channel variations. The authors provide recommendations for enhancing the performance of the examined models across various network topologies at the conclusion of the review process.

[2] Empirical Review of different communication components

In this section, a detailed review of different transmitter, channel and receiver side components is described, which will assist readers to identify optimal models for efficiency improvement under real-time scenarios.

2.1. Transmitter Components

According to the referenced literature [1], multiple-input, multiple-output (MIMO) orthogonal frequency division multiplexing (OFDM) devices at millimeter waves are intended for sparse, group-sparse, and real-time channel predictions. Utilizing the circular sparsity of the stimulus response of the mmWave channel, researchers improve prediction accuracy (CIR). researchers first use a sparse Bayesian learning (SBL)-based approach, which offers a superior performance-to-complexity trade-off than traditional channel estimation, to identify the quasi-static channel for each individual subcarrier. The mean square error of the channel prediction is then reduced using a new group-sparse Bayesian learning (G-SBL) method (MSE). their G-SBL method stands out because it uses the frequency-domain (FD) link of the channel's frequency response while only transmitting pilots on a limited number of subcarriers (CFR). In order to further reduce the expense of the G-processing SBL, a low complexity (LC) version known as LCG-SBL is developed. Then, an online G-SBL (O-SBL) version is built, which uses temporal correlation and has a minimum processing delay to forecast doubly-selective mmWave MIMO OFDM channels. Last but not least, a mixed send precoder/receive combiner design is detailed, along with instructions on how to use channel state data with limited access (CSI). This device can quickly work on predicted CFRs for the beamspace domain. their trial findings contribute to the body of data supporting the validity of the research.

The time-domain channel forecast for a wideband mmWave MIMO OFDM system is the primary focus of the study described in [2]. Time-domain mmWave MIMO channels show sparse channel delay and, in particular, block sparsity across different compass directions when researchers broadcast frequency-domain pilot signals and a number of beamforming vectors. The time-domain channel estimation using block sparsity (TDCEBS) approach is then introduced. This method looks for the finest nonzero block predicting the biggest remnant at each repetition. researchers perform a detailed study of the system performance using the QuaDRiGa, which is suggested by 5G New Radio for creating broad mmWave MIMO channels. The model's findings show that the suggested TDCEBS scheme works better than the current systems.

Based on the channel state information (CSI) that is accessible to the recipient and/or the emitter, mixed beamforming methods have been developed to simplify and lower the cost of mmWave transceivers. A method for utilising the irregular character of mmWave networks has been widely researched. It is called orthogonal matching pursuit (OMP), and it is built on compressed sensing (CS). OMP-assisted adaptive codebook channel prediction is one method that has a straightforward design but struggles in low signal-to-noise situations (SNR). In order to overcome this difficulty, this article presents an improved adaptive codebook channel estimation method for OFDM mmWave systems. This method improves prediction performance by merging judgements based on data from various channels. their findings show that the suggested channel estimation can considerably increase estimation accuracy at low SNR without materially raising the intricacy of the deploying application scenarios.

According to research reported in [4], nonlinear distortions brought on by radio frequency (RF) power amplifiers (PA) and other RF circuits negatively affect the performance of hybrid mmWave multiple-input multiple-output (MIMO) orthogonal frequency division multiplexing (OFDM) systems due to the enormous bandwidth of millimetre wave (mmWave) and the high frequency design limitations of the integrated circuits involved. A nonlinear link between the hybrid precoder and data impulses is brought on by nonlinear irregularities in mmWave hybrid systems. Additionally, it results in intercarrier interference (ICI), which involves interruption from other subcarriers' precoders, in OFDM systems. The precision of the forecast of these parameters (channel gains and CFO) and signal identification may be significantly lowered by problems with cooperation with frequency selective channels and carrier frequency offset (CFO). Due to its nonlinearity, the chance distribution for correctly recognizing data is not Gaussian. researchers present a new prototype-aided maximum likelihood (ML)-based approach for predicting the CFO with PA disability in the time domain by building a low-dimensional equivalent channel matrix. High-dimensional MIMO channels, composite precoder-combiners, and nonlinearly warped PA components make up the corresponding low-dimensional channel matrix. researchers also suggest a Group-Sparse Bayesian Learning (GSBL)-based semi-blind time-domain channel estimator to take the CFO and nonlinearity of PA into consideration (G-SBL). Channel prediction is followed by the development of a method for getting the combined precoder and combiner vectors needed for data transfer. Due to the complex interplay between the precoder matrix and the data, an incremental particle filter (PF) method is suggested in addition to ICI for data identification. Both a real mmWave channel in an urban microcell (UMi) setting and a fictional mmWave channel based on geometry are used to assess the efficacy of the methods. To ensure that the CFO and channel estimator work as expected, the Cramer-Rao limit (CRB) and Bayesian CRB (BCRB) are built.

In the context of multi-user uplink channel estimation and data identity over frequency-selective fading channels when using OFDM, this letter proposes a prototype placement technique and the corresponding receiver strategy, as detailed in [5]. This significantly cuts down on the training period usually needed for a big MIMO system running at mmWave frequencies. To be more exact, the majority of subcarriers send only plane segments, with only a tiny percentage transmitting full data packages. While non-pilot subcarriers take advantage of the sparsity of mmWave channels in the delay-domain to handle channel estimation issues with the compressed-sensing (CS) approach, pilot subcarriers employ a low-rank matrix completion-based semi-blind channel estimation and data identification technique. The main idea is to retrieve all broadcast channels and contents. researchers found through modelling that their suggested method can significantly boost output with low initial expenses.

The literature referenced in [6] states that because of their high frequency and wide frequency range, millimeter-wave (mmWave) systems are vulnerable to nonlinear mistakes brought on by radio frequency power amplifiers (PAs). These nonlinearities produce intercarrier interference and exponential distortion in mmWave MIMO OFDM systems, which together with a frequency-selective channel and a carrier frequency offset (CFO) present major challenge to signal recognition. The channel advantages and CFO prediction accuracy decline as a result of the nonlinearity, and the orthogonality of the training samples is jeopardized. Additionally, the planned likelihood distribution for data recognition is difficult to modify mathematically due to the nonlinearity. In this paper, researchers propose a technique for quickly initializing the channel estimator and calculating the CFO while PA deterioration is prevalent. For data finding, researchers suggest a particle-filter-based approach that employs weighted random measures to forecast the challenging posterior distribution. Additionally, a sequential maximum likelihood-based semi-blind channel predictor is suggested for use when nonlinearity is a problem. The normalized mean square error, mean square error, and bit error rate are metrics that can be used to assess the performance of the prediction and detection. To ensure that the channel and CFO estimator behave as expected, the Cramer-Rao limit (CRB) and weighted Bayesian CRB are computed.

Hybrid beamformers are taken into consideration in the work outlined in [7] for the creation of wideband, cell-free, mmWave, massive MIMO-orthogonal frequency division multiplexing (OFDM) systems. Techniques for single and double phase shifter-based analogue RF precoder/combiners are suggested based on different beam reflection awareness hypotheses. Time Division Duplex (TDD) is used to conduct the digital precoding/combining step because it can handle uplink/downlink duality. Based on how well they can handle phase shift, MMSE or LMMSE channel estimators are used. The suggested mixed beamforming methods are assessed to see how well they perform under different scenarios using detailed computer models. Beam squint-aware designs outperform beam squint-unaware ones in normal wideband cell-free mmWave massive MIMO-OFDM situations where the spatial-wideband effect is brought on by a very high carrier frequency, a large system bandwidth, and a large-scale antenna array.

For the implementation of millimetre wave (mmWave) MIMO communications, analog/digital hybrid beamforming is regarded as a crucial multiple antenna technology because it can decrease the quantity of costly and power-hungry radio frequency (RF) networks while still allowing spatial multiplexing [8]. researchers suggest a new hybrid beamforming design for a wideband mmWave MIMO orthogonal frequency division multiplexing system using hardware-efficient low-resolution phase shifters and dynamic antenna subarrays (PSs). Multiple-antenna diversity can reduce the performance effect of using low-resolution PSs that are more in accordance with practical requirements by flexibly linking each RF chain to a non-overlapping antenna subarray via a switch network and PSs. For this dynamic hybrid beamforming architecture, a combined hybrid precoder and combiner is developed and applied to improve the total frequency efficiency of the mmWave MIMO-OFDM system. First, from the maximum spectrum efficiency problem, researchers deduce a minimal mean square error (MSE) problem. The next stage is to develop a reliable iterative hybrid beamformer algorithm using tried-and-true Block Coordination Descent (BCD) methods. The applicability and intricacy of the suggested technique are examined. The effectiveness of the suggested hybrid beamforming method using low-resolution PSs and dynamic subarrays has been shown by a number of modelling findings.

According to the study described in [9], the design of mixed beamforming for OFDM systems is highly challenging due to the fact that standard precoders and combiners are shared by all subcarriers. In order to increase the average attainable sum-rate for frequency-selective millimeter-wave massive MIMO-OFDM systems, this article suggests an innovative two-stage combined hybrid precoder and combiner architecture. The suggested approach formulates the design of the analogue precoder and combiner as a Tucker Tensor Decomposition (TTD) problem with a limited Tucker tensor in order to maximize effective baseband gains across all subcarriers while concurrently minimizing inter- and intra-user interferences. The answer is obtained by a predicted replacement least-squares technique, which is applicable to both SU and MU systems. The SVD of the useful baseband channel is used to create the SU digital precoder and combiner. The regularized channel diagonalization technique, which strikes a compromise between multiuser disruption and noise reduction, accomplishes this for MU systems. Computer modelling findings verify the suggested procedure's effectiveness.

A suggested orthogonal frequency-division multiplexing system for millimeter-wave (mmWave) communications is backed by compressed sensing aided index modulation in the study reported in [10]. It is beneficial to change the constellation symbol height and the quantity of active subcarriers in an OFDM-CSIM mmWave system that uses both traditional constellation symbols and the on/off state of subcarriers to transmit information in order to improve system capacity. researchers develop an adaptive OFDM-CSIM mmWave system with machine learning (ML) using compressed sensing (CS), hybrid beamforming (HF), and orthogonal frequency division multiplexing (OFDM) with index modulation (IM). To improve the system's output, a k-NN-based ML-assisted link change approach is created. their results show that when dealing with a wide variety of antenna setups, ML-assisted link adaptation has the ability to deliver a better outcome than threshold-based link adaptation. Additionally, the data rates of four different antenna arrays—the universal linear array (ULA), the uniform rectangle planar array (URPA), the uniform circular planar array (UCPA), and the uniform cylindrical array (UCPA)—over mmWave channels are contrasted and compared (UCYA). The UCYA antenna design achieves the greatest performance of these antenna setups, according to the results of this modelling research for different scenarios.

Work in [11] creates and describes techniques for the construction of mixed precoders/combiners for the best bit distribution in frequency-selective millimeter wave (mmWave) MIMO OFDM systems in order to maximize transmission rates. In the setup outlined above, the best fully digital fault-free precoder/combiner architecture is identified after the optimum bit allotment has been determined using a closed-form equation. The next stage is to build a model for the best receiver configuration and bit distribution for a mixed mmWave MIMO-OFDM application. It is shown that the relevant issue can be expressed as a Multiple Measurement Vector (MMV)-based sparse signal recovery problem, and an explicit algorithm is developed to address this issue using simultaneous orthogonal matching pursuit, allowing joint design of the RF and baseband components across all the subcarriers (SOMP). To address the drawbacks of the SOMP-based greedy strategy, a cutting-edge method based on MMV sparse Bayesian learning (MSBL) is developed. The modelling findings show that the mixed emitter performs similarly to its all-digital version, supporting the efficacy of the suggested designs.

Due to its capacity to balance spectrum efficiency (SE) and energy economy, MIMO-OFDM-IM (multiple-input multiple-output orthogonal frequency division multiplexing with index modulation) has recently attracted more attention, as explained in [12]. (EE). In this article, researchers explore the use of a hybrid analog-digital (HAD) beamforming design for MIMO-OFDM-IM in mmWave communication networks. The effect limitations of the multi-objective optimization problem (MOP) can be quickly resolved using this Pareto-optimal beam design. The MOP of the SE-EE trade-off is transformed into a workable strategy for resource utilization that is energy-efficient by positioning the Pareto-optimal set (POS) towards the Pareto front. The best beam design and power management techniques for downstream multi-user mmWave transmission are taken into consideration in this combinatorial-oriented method to resource distribution on the SE-EE relationship. To more easily assess the system's performance, researchers describe the mobile data flow using the Poisson Point Process (PPP) and the changing technique to improve the Pareto front's search efficiency. The suggested optimization technique significantly beats state-of-the-art approaches, as shown by empirical data from complicated models.

Two ANN methods for channel normalization of mmWave transmissions using a frequency range of 28 GHz are evaluated in the research described in [13]. To model the spatial structure of mmWave channels while taking into consideration the material characteristics of the barriers present at the study frequency, researchers used a reliable in-house three-dimensional ray-launching (3D-RL) technique. Using the created mmWave channels, researchers offline-trained a multilayer perceptron (MLP) neural network to equalise the incoming signal. Additionally, to obtain the locally equalized symbols, researchers online taught a neural network on an extreme learning machine (ELM) using the mmWave signal at the recipient end. Additionally, ANN systems' possible working time, bit error rate, and spectrum effectiveness were assessed. researchers contrasted ANN methods with the minimum mean square error and zero-forcing equalizers in the setting of an orthogonal frequency-division multiplexing transmission based on the 5G New Radio standard. researchers offer quantifiable data on the performance of the suggested ANNs, showing that the ELM strategy works better than the MLP approach while needing considerably less processing time than the considered normalization methods.

Work in [14] examines the challenges of downstream beamforming training and channel prediction for millimeter wave (mmWave) OFDM systems using an omni-directional antenna or antenna array at the recipient and a mixed analogue and digital beamforming structure at the emitter (i.e. base station) (i.e., user). By concurrently aiming a number of focused beams in various directions at the emitter, researchers can effectively explore the channel. The objective is to create a reliable beam teaching approach and channel forecast system. This topic is framed as a sparse encoding and signal recovery challenge using the sparse dispersion properties of mmWave channels. A channel prediction technique and a patchy sensor grid that can be used to compact the channel are therefore required. In this article, researchers suggest a method for decoding sparse bipartite graph codes that uses a group of bipartite graphs to encrypt the sparse channel and relies entirely on the existence of a No-Multi Ton-graph to encrypt the sparse channel (NMG). A speculative analysis shows that applying their approach can drastically cut down on training time. Simulations show that the suggested strategy works better than methods based on compressed sensing.

According to [15], inquiries The effectiveness of link adaptation in radio communications depends on the accuracy of the channel information and the choice of transmission mechanism. In this article, it is suggested to use a deep learning-based link adaptation architecture for OFDM systems using millimeter-wave (mmWave) channels and compressed-sensing-assisted index modulation (OFDM-CSIM). To deliver the exact and immediate channel state information needed for link adaptation, a new multi-layer sparse Bayesian learning (SBL) method is suggested. In addition, an adaptive modulation approach that uses deep neural networks (DNNs) is suggested for choosing the best transmission method to maximize the possible data rate. Based on modelling outcomes, it appears that the suggested multi-layer SBL algorithm can deliver channel predictions that are more precise than those produced by traditional techniques. The DNN-based configurable modulator outperforms both the conventional average signal-to-noise ratio (SNR)-based solutions and the learning-assisted solutions based on the k closest neighbour (k -NN) method. Additionally, studies show that the multi-layer SBL approach and the DNN-assisted adaptive modulator outperform their traditional equivalents while needing considerably less processing complexity.

Fifth-generation mobile networks (5G) are the answer to the demanding mobile traffic requirements, according to studies discussed in [16], as they provide technologies that satisfy the requirements of different service kinds. For achieving fast data speeds, using millimeter-wave (mm-wave) frequency is the easiest way. Along with its other benefits, the analogue radio-over-fiber (ARoF) technology is very affordable, uses little energy, and effectively utilizes radio spectrum. Therefore, mm-wave ARoF is a strong option to support CPRI in the upcoming 5G fronthaul. The 5G specification has approved OFDM as a design, and mm-wave ARoF gear should also use it. However, one of the most negative aspects of mm-wave OFDM ARoF devices is phase noise. An experimental apparatus is used in this study to perform a phase noise analysis. With this setup, the system's overall phase disturbance can be progressively changed. A brand-new technique is also suggested for altering the phase noise in OFDM transmitters. researchers test the effectiveness of this approach using testing setups with different subcarrier spacings and phase noise levels. These outcomes show the applicability of mm-wave OFDM ARoF for 5G and beyond, as well as the effectiveness of the suggested approach.

A brand-new frequency-domain (FD) digital predistortion (DPD) method is put forth in [17] for OFDM receivers. The suggested technique in FD allows for flexible management of the linearization performance and the distribution of a range of linearization values. Additionally, due to frequency-merged users using a variety of encryption and decoding methods, the inband signal quality standards may limit the highest send power that can be used in the millimeter-wave (mmWave) bands. The effectiveness of the suggested FD DPD is demonstrated and validated using over-the-air (OTA) measurements on a 64-element phased-array running at 28 GHz carrier frequency.

The maximum attainable rate in the intra-wagon channel is found using a mix of multiple-input single-output (MISO) and orthogonal frequency division multiplexing (OFDM), or MISO-OFDM, as described in the study given in [18]. Actual wideband dispersion channel data at 28 and 37 GHz, two potential frequency bands for the implementation of upcoming 5G wireless communications networks, are used in this research. The location of the access point (AP) and user equipment (UE) inside the cart, with both 4 and 8 antennas at the AP, has been taken into account in four different situations. On the basis of modelling findings, the effectiveness of broadcast beamforming methods and quasi-orthogonal space-time block code (QSTBC) is examined and assessed. The modelling, the modelling, the modelling, the modelling, the modelling, the outcomes, the S signal sets. The implementation of mmWave-frequency 5G cellular networks, which are expected to support a broad range of digital apps at high data speeds, can be planned with the help of these results. They also aid in their understanding of the features of the intra-wagon channel.

In mixed-analog-digital designs for mmWave multiple-input multiple-output orthogonal frequency division multiplexing (MIMO-OFDM) systems, the study detailed in [19] investigates the channel prediction problem. researchers create a spatial-frequency channel model with multipath factors like time delay, complicated gain, and angle of departure/arrival using spatial- and frequency-wideband (dual-wideband) effects in huge MIMO situations. researchers describe their OFDM signal as a third-order low-rank tensor with vector components that comprise the channel parameters from the canonical polyadic (CP) model in order to train it. In this case, an incremental beam training approach is used. researchers suggest a channel estimation technique based on a structured CP decomposition and backed by spatial averaging to benefit from the Vander Monde (VM) characteristic of component matrices. With their own tensor modelling and parameter extraction processes, two different techniques are developed. The suggested approach does away with repetitive steps and an arbitrary beginning place by using basic linear algebra. The uniqueness requirement for the CP decomposition is also examined. The modelling outcomes show that the suggested approach works better than traditional methods in terms of prediction accuracy, resilience, and complexity.

According to research mentioned in [20], obtaining high dependability in mmWave communication systems requires precise phase noise (PN) forecast and rectification. The PN Estimation (PNE) has a high processing complexity as a result of its basic characteristics, such as spectrum dispersion and rapidly changing variations. In this article, researchers suggest a fresh, low-complexity model for PN correction in orthogonal frequency-division multiplexing systems. A test distribution plan is also included in the suggested structure with the intention of minimizing wastage. The core ideas are to approximate the real PN spectrum with its prominent components and to take advantage of the coherence frequency of mmWave systems. A non-iterative answer is found using computation of the linear least mean squared error. When compared to the intricacy of the existing techniques, the complexity of the suggested methodology is decreased by a ratio of more than 2.5. As a consequence of important system factors, researchers also obtain closed-form formulas for normalized mean squared errors (NMSEs), which help us understand how NMSEs behave in areas with low and high signal-to-noise ratios. Lastly, researchers look into a trade-off between cost and pilot waste to reveal a precise estimate of the PN spectrum sets.

The specifications for multiple-input, multiple-output (MIMO) car radars can be determined using a two-stage approach, according to [21]. In the initial stage, researchers perform low-complexity peak detection using a 3D constant false alarm rate (CFAR) detection method and geographic filtering to increase the radar's field of vision. The second step makes use of an ESPRIT-based DOA projection method to create high-quality pictures and identify target DOAs without knowing the goal number. Simulation findings show that the proposed approach beats traditional MIMO radars in terms of DOA prediction accuracy while maintaining the performance of the two-dimensional ordered statistic CFAR (2D OS-CFAR).

According to research [22], generalized beam modulation (GBM) is a newly suggested spectral efficiency (SE)-enhanced index modulation (IM) method for narrowband millimeter wave (mmWave) systems with composite transceivers in massive multiple-input multiple-output (mMIMO) systems. The extension of GBM from narrowband to wideband channels is a challenging job, in contrast to the majority of existing fully-digital IM methods, which can be readily applied to wideband channels via the orthogonal frequency division multiplexing (OFDM) approach. Due to the use of a single standard beamformer for all subcarriers in mixed OFDM systems, the per-subcarrier process is no longer separate for each user. Wideband GBM (wGBM) must therefore keep interoperability with mixed OFDM systems while retaining the advantages of GBM's improved SE. This is possible due to the wGBM design's use of a symbol-based strategy rather than the more traditional subcarrier-based strategy. researchers create a straightforward detector by breaking down the difficult symbol (block) detection into the more manageable subcarrier (sub-block) detection in order to prevent overly complicated detection in large-scale OFDM systems. A simple first-order Doppler converter is carefully created to increase the wGBM's resistance to Doppler. wGBM is superior to current alternatives in terms of both erroneous performance and energy economy, as shown by theoretical and analytical models.

The study described in [23] provided insight into Hybrid beamforming has been viewed as an essential component of mmWave communications because systems that work in mmWave frequency ranges need to use big antenna arrays to make up for the signal's significant transmission loss. Lately, the idea of a "intelligent reflecting surface" (IRS) has been put forth as a cutting-edge technological invention that, by utilizing inexpensive inactive reflecting components, can significantly boost the performance of mmWave communication systems. In this article, researchers look at how IRS can help mmWave MIMO systems create mixed beamforming. researchers first create a combined IRS reflection matrix and hybrid beamformer for narrowband MIMO systems by utilizing the big dimensions and patchy dispersion structure of mmWave channels. researchers then generalize the suggested joint design to broadband MIMO systems using OFDM modulation by taking advantage of the angular sparsity of frequency-selective mmWave channels. researchers discover through the use of models that the suggested hybrid designs can significantly improve the efficacy and spectrum efficiency of the pertinent systems.

A-IFoF/mmWave transmission is examined by currently accessible study [24] using a fixed mobile convergence design. Future mobile fronthaul designs are made possible by this design, which makes use of the passive optical network (PON) technology already in place. Strong, completely configurable gate array circuits in the access nodes use orthogonal frequency-division multiplexing to transform Ethernet-based traffic into signals at an intermediate frequency (IF) that can travel over optical heritage infrastructure (OFDM). For use in the field, it is feasible to send both 5G data and old domestic data using wavelength-division multiplexing and unutilized C-band channels. Through trials, researchers show how an A-IFoF/mmWave hybrid connection works with Telecom Italia's old Turin infrastructure. Four-QAM-OFDM and sixteen-QAM-OFDM intermediate frequency (IF) transmissions with 200MHz, 200MHz, and 400MHz bandwidth were produced using a radio frequency system-on-a-chip design (considered within the 3GPP New Radio specifications). The regular fiber-to-the-home options were visibly combined with these broadcasts. The A-IFoF signal was obliquely relayed into a 60 GHz wireless connection after propagation from the field. With an EVM of 10.5% for 16QAM-OFDM encoding at 400 MHz, PON/over-the-air broadcast performance was proven. This EVM is significantly lower than the 12.5%12.5% EVM needed by the 3GPP for 5G New Radio.

Reconfigurable intelligent surfaces (RISs) can modify the wireless surroundings to enhance contact effectiveness, according to study mentioned in [25]. An orthogonal frequency division multiplexing system for millimeter waves with numerous antennas is described in this article along with a joint multi-RIS transmission technique. The first thing we've done is developed a delay matching-based method for concurrently approximating the multipath channels and transmission delays of distributed RISs. This method only needs some input and requires very little training. The RIS phase shift issue is solved precisely as a result of this process. The downstream rate is then shown to scale logarithmically with the number of RIS reflecting components using an algebraic formula. These conclusions are supported by extensive modelling and computations.

For use in wideband mmWave massive multiple-input multiple-output (mMIMO) systems utilising pre-compensation aided generalised beam index modulation, researchers carefully develop a novel type of anti-Doppler index modulation (PC-GBIM) [26]. Two key components make up the PC-GBIM configuration that is being suggested. researchers start by converting hybrid narrowband to hybrid wideband systems and expanding beam index modulation (BIM) from single beam activation to multiple beam activation. Index modulation is made easier by the addition of a reliable first-order Doppler pre-compensator, which transforms the challenging block-based ML detection into the simple subcarrier-based ML detection. Double-selective channels outperform current options, as shown by theoretical studies and computer models.

Work in [27] claims that in high-mobility situations, millimeter wave (mmWave) MIMO devices built on orthogonal time frequency space (OTFS) waves can achieve high data speeds. This results in the development of transceivers with analogue beamforming (AB) or mixed beamforming capabilities (MB). researchers first identify the input-output link in this space using a delay-Doppler (DD)-angular domain channel model. Then, an innovative two-stage technique for calculating the right channel state information in the DD-domain is developed, as well as a broadcast beamformer, precoder, and receiver combiner architecture (CSI). The suggested architecture's RF TBF/ TPC and RC design, which optimizes the advantages of orthogonal beamforming, is its key feature. For mmWave-AB and mmWave-HB MIMO OTFS systems, the low-dimensional baseband CSI in the DD-domain is transformed into a block-sparse one. The development of improved CSI forecast methods using block-sparse Bayesian learning (BL) and BL follows (BS-BL). In order to describe the standard deviation of these predictions, researchers also compute the Bayesian Cramer-Rao bottom bounds for the CSI values (BCRLB). In contrast to other competing sparse signal recovery schemes, their modelling findings support the better CSI estimation performance of the BL-based schemes and show the enhanced efficacy of the suggested receiver designs.

The study described in [28] suggests an affine-preceded stacked pilot (SIP) architecture and channel state information (CSI) forecasting methods for mmWave MIMO-OFDM systems. The beam space channel vector's synchronous sparsity across the subcarriers is taken advantage of in the first step, which is the development of a multiple measurement vector (MMV) sparse Bayesian learning (SBL) based SIP (M-SIP) method. The mean squared error (MSE) of the channel estimate and the bit error rate are then reduced by utilising these results to modify the data-aided J-SIP strategy, which involves channel estimation and data identity (BER). Using the MMV sparse Kalman filtering-based SIP (MK-SIP) technique for tracking the CSI and the joint Kalman filtering-based SIP (JK-SIP) technique for data-aided CSI acquisition, the SIP-based simultaneous-sparse channel estimation framework is expanded to time-selective wideband or doubly-selective mmWave MIMO channels. Bayesian Cramér-Rao limits are established for the forecast of the mmWave MIMO-OFDM channel under quasistatic and doubly selective circumstances. The modelling findings, including actual channel realizations, are given to show efficiency increases when different measures like MSE and BER are taken into account.

2.2. Receiver Components

In order to ascertain the impact of non-Gaussian multipath component (MPC) amplitude distributions on the effectiveness of Compressed Sensing (CS) channel estimators for OFDM systems, the authors of [29] analyses modelling findings. The minimum number of dominant MPCs that any CS algorithm is predicted to require to correctly reflect the channel is described in the article. This image displays the channel's Compressibility Index (CI), which is obtained from the amplitude distribution of the fourth second of the MPC. Substantial reductions in the number of MPCs needed to correctly forecast channels are linked with rises in fourth-moment amplitude. The mean squared error (MSE) of any CS estimation technique is inversely proportionate to the fourth second of the MPC amplitude distribution. The numeric findings are validated using simulations for channels with lognormal MPCs, such as the NYU mmWave channel model. These computations show that the well-known CS method of Orthogonal Matching Pursuit performs nearly as well as the Basis Pursuit De-Noise algorithm at a much lower processing cost when the MPC amplitude distribution has a high fourth moment.

The present research on cellular multi-user mmWave communication, according to works mentioned in [30], concentrates on mixed baseband and RF precoding techniques to enable regionally dispersed numerous accesses with little disturbance. In these studies, it is assumed that M, the number of users, will be less than N, the number of RF units, and that M>NRF, the number of RF units, in which case M, the number of users, will be scheduled in the time domain with a single RF unit allocated to each user. Because OFDMA can concurrently service numerous customers in each traditional stream, it is expected that wideband channel usage will increase. For the MNRF situation, researchers suggest a sectored-cell model to achieve this. In this model, each beam supports multiple users within a sector, which is planned on a round-robin basis, and numerous RF networks support the wideband mmWave channel. researchers also suggest a time-frame-indifferent framework that allows all users in a particular region to utilised resources concurrently. In contrast to the usual full beam search technique for first access, this method has the benefits of a reduced initial access delay and better frequency economy. Then, researchers calculate the beamwidth and NRF that will collectively result in the greatest long-term average output. Furthermore, researchers suggest a low-complexity sector stay time optimization (LCS STO) that makes use of a varying time frame structure to improve the fairness of long-term user rates for users whose distribution is not uniform across the system. The results show that while the high data rate disturbance is increased with more NRF, the typical long-term usage rate is decreased. It is better to provide maximum rate support via a narrow beam as opposed to giving minimum rate support via a broad beam. Regardless of M, users can be assigned in any sequence, but the beamforming method has a better average user rate over the long run than the options.

Millimeter-wave (mmWave) signals are extremely prone to blockage because of their short frequency and weak ability to spread, which causes a significant reduction in observed signal strength, according to research reported in [31]. In recent years, relay stations (RS) have been looked at as a possible remedy for the blockage issue in millimeter-wave communication networks. researchers go over the important factors for a relay-assisted, millimeter-wave, OFDM-based cellular system in this paper. For the best RS selection under pressure, researchers offer a data-driven exploratory training structure and approach. Inter-symbol interference, which is brought on by different symbol time delays of pilot signals received from nearby RSs, is also handled in the relay-assisted mmWave cellular system. researchers then suggest two different types of pilot sequences, one based on the Zadoff-Chu sequence (ZCPS1) and the other on the m-sequence, that allow a mobile station to differentiate between pilot sources in multi-cell multi-relay settings (PS2). The connectedness of the PS2 is assessed by contrasting it with that of the PS1 and other variations (Gold sequence). Simulations are run using an obstruction model to verify the traits, limitations, advantages, and disadvantages of the suggested prototype sequences in RS-assisted mmWave cellular systems.

As next-generation supporting technologies move to the mmWave and even TeraHertz bands, high-bandwidth orthogonal frequency division multiplexing (OFDM) signal processing becomes more power-hungry, as stated in [32]. Due to OFDM's shortcomings, which include: (1) a high peak-to-average power ratio (PAPR); (2) a decline in bandwidth efficiency brought on by the cyclic prefix (CP) cost; and (3) the susceptibility t, this has happened. Over the past 60 years, many waveforms have been developed to deal with these issues, but they frequently ignore OFDM's other benefits, such as its high speed, subcarrier (SC) orthogonality, and ease of application to multiple-input, multiple-output (MIMO) systems. In light of this, researchers suggest a novel waveform dubbed multi-band discrete Fourier transform spread-OFDM with index modulation (MB-DFT-S-OFDM-IM), which combines several multi-carrier techniques to address the flaws of OFDM while maintaining its advantages. The PAPR originally declines due to DFT-precoding. Because of the IM architecture, MB-DFT-S-OFDM-IM can reach throughputs that are equal to or higher than those of OFDM. Finally, MB-DFT-S-OFDM-IM offers a variety of carrier frequencies, which raises the difficulty of shifting the carrier frequency. Fourthly, the suggested MB-DFT-S-OFDM-IM structure preserves the SC orthogonality and is unique due to the placement of the OOB filters in each sub-band before DFT. As a conclusion, researchers broaden the scope of the suggested MB-DFT-S-OFDM-IM to incorporate a variety of MIMO designs that combine the IM idea with the space-, time-, and frequency-domains across a number of unique, united platforms.

It is challenging to mutually optimise the sender and receiver in mmWave enormous multiple-input multiple-output (MIMO) systems, which call for a mixed computing design to significantly reduce complexity and expense. In this research, the writers develop a new joint hybrid processing framework (JHPF) for back propagation-based full-cycle optimization. A signal demodulator, a signal flow model, and a hybrid processing scheduler make up the suggested architecture. The aforementioned parts make use of neural networks (NNs) to simulate wireless signal transmission, create composite processing vectors for the recipient, and map recognized symbols back to their original bits. By minimizing the cross-entropy loss between the recovered and original bits, the suggested framework, whose trainability is shown mathematically, tacitly and collectively maximizes the analogue and digital processing vectors at the receiver. The training material can also be used with orthogonal frequency division multiplexing devices if it is organized differently. The suggested DL-JHPF beats current hybrid processing techniques, according to simulation findings, and is resilient in the presence of channel circumstances characterized by misaligned channel state information and channel length.

The study [34] examines 5G mmWave cellular networks with full-stack TCP/IP traffic and MAC routing, describing the difficulties and advantages of cross-layer methods like hybrid beamforming (HBF) and multi-user multiple input multiple output (MU-MIMO). This paper investigates the interplay between HBF methods and higher protocol levels, in contrast to earlier research on HBF and MU-MIMO, which concentrated on link-level analysis of full-buffer broadcasts. To do this, modelling of MU-MIMO and HBF has been added to earlier work on the full-stack assessment of mmWave cellular networks. new connections between the physical layer and the networking layers their research reveals HBF MU-efficiency. MIMO's One way to boost speed is to use space division multiple access, a feature of 5G networks (SDMA). A full-stack HBF solution can be used to achieve this; however, due to the solution's intricacy, caution is advised.

The latest version of mobile communication, according to study described in [35, is primarily built on orthogonal multiple access (OMA) methods like orthogonal frequency division multiple access (OFDMA). In an attempt to achieve the goals of increased bandwidth, increased adaptability, and reduced delay, non-orthogonal multiple access (NOMA) has been recognized as a potential technical development in radio access networks. A resource-to-symbol transformation is used as the multiple-access signature in the pattern division multiple access (PDMA), a non-exclusive multiple access (NOMA) method. In a millimeter-wave (mmWave) wireless access system, the usefulness of PDMA is rigorously demonstrated in this paper. The sophistication of parallel interference reduction (PIC) during processing is one advantage of PDMA. To increase the effectiveness of PDMA decoding, this paper develops and analyses a message forwarding method (MPA). researchers demonstrate experimentally how a novel PDMA system integrated with MPA can lower the sensitivity penalty and improve the modulation spectral efficiency compared to conventional power-domain NOMA (PD-NOMA) with successive interference cancellation using a radio-over-fiber (RoF) mobile fronthaul for a multi-user millimeter wave (mmWave) radio access system (SIC). The test findings show that PDMA can change itself to fit a variety of patterns, adjust to a broad range of channel circumstances, and become more adaptable in general.

Work in [36] asserts that one of the difficulties facing the 5G NR mmWave communication system is the requirement to build highly directed radio links and maintain contacts for mobile stations (MSs) moving through different environments. A popular method for catching individual beams in the first stage and then following them by searching nearby beam pairs in the second stage is beam skimming based on a limited codebook. However, this traditional technique incurs small overheads to hear neighboring beam pairs in the second stage in order to keep the best beam pair and has inevitable leftover AoA/AoD mistakes even after the best beam pair has been formed in the first stage. A new beam tracking protocol with minimal hearing overhead, a unique receiver structure made up of a beam planner and a beam tester, and a method with high accuracy for calculating leftover AoA/AoD error based on the mono-pulse ratio idea (MPRI) are all suggested as solutions to these problems. This approach is distinct due to the receiver structure, which draws inspiration from the mono-pulse ratio in radar systems and uses the cycle precursor in OFDM systems. It is also possible to use MSs with a single Radio connection. This technique can produce a more concentrated beam couple by using the suggested receiver structure and algorithm as an extension of the beam search in the first stage. Instead of searching for nearby beam pairs during the second stage of beam tracking, the residual AoA/AoD mistakes of the current best beam pair are computed. The suggested approach provides more accurate beam gathering while lowering the cost of beam finding costs (i.e., an average array gain rise of several dB). Lastly, researchers use a ray-tracing tool to show how well their approach works in real-world channel circumstances in outdoor settings.

According to study provided in [37], the operational freedom, cheap cost, and built-in line-of-sight air-to-ground lines of autonomous aerial vehicles (UAVs) have already attracted significant interest in the creation of communication systems based on UAVs. They can use physical layer protection to increase their camouflage ability (PLS). Drone usability is continuing to cause security worries. In this research, researchers examine how the PLS of the UAV-to-ground transmission network is affected by the 3D fractional-order Liu chaotic system and the 3D fractional-order Li chaotic system. A zero forcing (ZF) approach and effective orthogonal variable spreading factor (OVSF) methods are merged to lessen multi-user disturbance (MUI). To further decrease the bit error rate, various channel coding techniques with multi-user beamforming scaling are used (BER). Empirical findings show that the suggested system improves peak-to-average data rates and the signal-to-interference-plus-noise ratio. Using this technique, researchers were able to lower the level of harmful radioactivity by 119 dB. Furthermore, 16-QAM has a reduced BER for a signal-to-noise level of 6 dB.

In [38], a gridless channel prediction method for a mixed mmWave MIMO-OFDM system is given under the assumption of a frequency-selective channel. the planned the R-D Standard/Unitary Tensor-ESPRIT is derived following the debut of the DFT beam-space model, along with the findings of its study. researchers show that, in contrast to ESPRIT-type algorithms in complete DFT beamspace and element space, lower-dimensional DFT beamspace algorithms can offer a substantial performance boost under favorable circumstances. researchers then create a gridless channel forecast system using DFT beamspace methods with three-dimensional tensor ESPRIT. It is clear from computer model findings that the suggested channel estimation method can generate precise channel estimates with a minimum investment in training delays.

2.3. Channel Components

In the research detailed in [39], the issue of downstream channel prediction for mmWave orthogonal frequency division multiplexing (OFDM) systems are resolved using intelligent reflecting surfaces (IRS). researchers show that the received signals can be written as a low-rank third-order tensor that allows a tensor rank decomposition, also known as a canonical polyadic decomposition, by analyzing the intrinsic patchy dispersion characteristics of mmWave channels (CPD). The features of the channel are then identified using an organized CPD-based approach. The results of their research show that the training costs for their suggested technique, where U is the sparsity of the cascade channel, are as low as O (U2). The test findings presented here show how successful the suggested tactic is for different scenarios.

In order to further enhance car and passenger safety, it is recommended by the study in [40] that exact trajectory projection techniques be used to provide anticipated safety information for critical decision-making in intelligent transportation systems. Learning-based algorithms have taken the place of conventional model-based trajectory projection algorithms because they are better able to handle complicated movements and interdependencies. However, the majority of algorithms tacitly presume that their execution takes place at centralized processing centers, following the collection of data from various exterior devices and the transmission of the findings back to the on-board components. This decreases the motorist's reactivity by lengthening the amount of time needed to compute and the wait before an action can be done. researchers suggest a distributed radar-specific framework with a deep-learning (DL) model, called predictive RadarNet, to predict future trajectories over binary range angle (RA) maps with a probabilistic representation consistent with the original radar RA maps for displaying the uncertainty of the estimated trajectories in order to decrease computation time and latency. researchers also created a prepossessing method that can further decrease the model size for minimal intricacy without losing any information. In addition, researchers found that the conversion to binary RA maps and future extrapolation of the initial radar RA maps are the two processes that make up the DL-functions models. researchers developed two models, each with a unique algorithmic center, to control the two processes. According to the test findings, the suggested automatic design based on predictive RadarNet (RNet) can produce precise predictions in a reasonably quick amount of time for real-time scenarios.

Studies referenced in [41] state that high-performance precoding methods for wideband multi-user (wMU) mmWave massive MIMO must be created in order to allow next-generation mmWave wireless communications (mMIMO). researchers will create a better listener for wMU mmWave mMIMO in order to maximize reciprocal comprehension because the majority of current methods are ad hoc, leaving performance guarantees inadequate (MI). The method recommended here is based on the popular hybrid block diagonalization (HBD-)based design, which is known for its capacity to find a balance between the adaptability of transmitter-end processing and the intricacy of user-end detection. The first time that HBD is shown to be ideal in the MI sense is in this article. Decomposing hybrid processing into its analogue and digital stages and then establishing HBD-related MI limits are the first steps in the construction of a receiver. High-performance HBD transceivers are created for both multi-aperture structure (MAS) and multi-beam structure through improvement of the strict MI limit (MBS). In order to achieve exceptional MI performance on typical hardware setups, the suggested HBD method does not require high-resolution analogue beamformers, extremely fragmented channels, or complicated algorithms.

Vehicle-to-vehicle (V2V) contact enhances both road safety and transit networks, according to the study detailed in [42]. Currently, there are only two ways to enable communication between moving cars. The first is the 3GPP's V2X specifications for tying cars to networks and other things (3GPP). Another approach makes use of the IEEE 802.11 networking family. What is intended by "specialised short-range comms" falls under this second group (DSRC). The use of the millimeter-wave (mmWave) frequency by the 3GPP V2X may boost capacity, but the reliability of the technology will eventually rely on the usability of the frequency. DSRC is being used more frequently as an option. - aided by technology, DSRC can get around this issue by using the mmWave bands. This study examines the viability of 802.11p technology operating at 28 GHz. To further improve the multipath resilience of the present setup being evaluated, numerous equalization methods are used under different use cases.

For wideband mmWave MIMO systems using hybrid architectures and low-resolution analog-to-digital converters, as detailed in [43], a channel predictor is suggested. (ADCs). The transmission delay across the antenna array must be taken into account when building the discrete time channel that represents the spatial wideband effect because of its importance in wideband mmWave massive MIMO systems. Inter-frame, inter-user, and inter-symbol interferences are also studied in cases where the impact of spatial wideband is not insignificant. The Newtonized Fully Corrective Forward Selfish Selection-CV-based (NFCFGS-CV-based) channel estimator is suggested to estimate the channel parameters over the continuum using the maximum, a posteriori (MAP) criterion. The CV approach decides the final state of the grid-less NFCFGS-CV CS strategy. It is proven that the minimal cubic error can be achieved using a CV-based terminal condition (SE). The outcomes of the experiment show that NFCFGS-CV works better than the most sophisticated grid-based CS-based channel estimators.

Current study assumes a previous subcarrier distribution, as outlined in [44], which enhances the hybrid precoder in a multi-user wideband millimeter wave (mmWave) transmission system. The mmWave beam gleam effect has a distinct impact on the subcarrier gain depending on the beam redirect orientation. Thus, the subcarrier distribution affects the radio frequency (RF) precoder's structure. Based on this finding, researchers suggest a mixed subarray precoder design in this article. The RF precoder and subcarrier dispersion are mutually estimated after the creation of the baseband precoders (BP). Their test findings show that the suggested technique has a number of benefits over the traditional approach, which prioritizes baseband precoder and RF design over subcarrier dispersal.

According to research outlined in [45], two modulation and detection methods are offered with the goal of enabling effective normalization of channels with random Doppler spread but no delay spread. The numerical challenge is the same for techniques designed for time-invariant delay spread channels, such as orthogonal frequency division multiplexing (OFDM). researchers use models to show that channels with a large Doppler spread and even a modest delay spread can be equalized, whereas balanced OFDM performs clearly worse in these circumstances. their findings imply that modulation and detection schemes employing novel modulation in combination with channel estimation and equalization methods may outperform modulation and detection schemes designed for static or slowly time-varying multipath channels (TVM), such as those present in high-mobility or mmWave deployments.

According to research compiled in [46], millimeter wave (mmWave) devices will be crucial to fifth-generation technologies. (5G). Precoding methods can be used to enhance spatial merging efficiency during the radio frequency (RF) stage. Investigating RF stage hardware flaws for mmWave communication systems is vital because they can impact the transferred data and the system's general performance. The phase noise problem is addressed by a MIMO system for mm-wave wavelengths in this article. The hybrid precoder (HP) design is also put under pressure to be optimized in the presence of phase noise. It is suggested that alternate reduction, a method for manifold optimization, be used to improve the performance of the fully digital precoder. The usage of energy is approached practically. For predicting the mmWave channel parameters and tracking the phase noise parameters, the Bayesian Cramér-Rao lower limits (BCRLBs), Kalman filter, least square (LS), and maximum posteriori (MAP) techniques are suggested. The suggested system with ideal hardware is contrasted with a non-ideal system that is prone to escalating temperature noise and collecting transmission hardware flaws. Spectral reductions for the suggested method are addressed in various settings (SEs). Research and experimentation show that at greater amounts of phase noise, the impact of the phase noise issue may reduce SE's efficacy.

In a multiple-input multiple-output (MIMO) transmission, Millimeter wave (mmWave) wide channels are differentiated by a constrained number of stimulus reactions in the angle-delay, or space-time (ST), domain, as per study mentioned in [47]. These traits will be even more pronounced in the THz range used by future goods. Low-rank (LR), which uses the algebraic structure of the channel matrix, and compressed-sensing (CS), which uses sparsity in the angular/delay domain, are contrasted. In addition to revised versions of the CS and LR techniques that significantly improve performance in terms of mean squared error (MSE), processing complexity, and delay, this article provides the first comprehensive evaluation of the two methodologies. Under the suppositions of set angles/delays, time-varying fading, and uncertain angle/delay diversity order, researchers derive the asymptotic MSE limit for any ST-MIMO multipath channel estimator while accounting for the deterioration brought on by inadequate separable channel models. researchers will show that both the CS and LR methods converge to the limit under specific circumstances. their analysis of the techniques' effectiveness shows the trade-offs they produce across a variety of metrics, including 3GPP channel models for 5G and beyond that are optimum and appropriate for cellular networks. Two brand-new, low-complexity estimation techniques are created using downstream broadcasts and are able to function with a constrained frequency or a small number of send recipients. The suggested algorithms can predict the channel parameters with reasonable accuracy while decreasing complexity by about half when compared to traditional methods, according to numerical findings.

Work in [48] addresses the channel forecast issue for mmWave MIMO systems using household electronics with a single receiver. Two new, simple forecast techniques (SFT) are created using radio signals in the downlink channel, and they work even with a constrained send antenna or capacity. In comparison to traditional approaches, numerical findings show that the suggested algorithms correctly forecast channel parameters while decreasing complexity by about 50% under different scenarios.

Due to its ability to achieve a higher multiplexing gain with fewer radio-frequency networks, generalized beamspace modulation (GBM) is a desirable uplink transmission choice for hybrid mmWave enormous multiple-input multiple-output systems, as stated in the aforementioned research [49]. researchers will look into Precoded WGBM (P-WGBM), a wideband GBM (WGBM) variation that makes use of the digital precoder to boost effectiveness, in order to achieve this. Sadly, despite the extension's perceived ease, it is quite difficult due to precoding limitations and calculational intricacy. In this letter, researchers build a problem for optimization to find the best precoder while preserving the GBM sharing quality. researchers create a precoding method that is almost perfect in order to maximize the precoding potential of beamspace. Simulation outcomes show that P-WGBM can maintain all of WGBM's key advantages while achieving a sizable coding improvement over WGBM at a low complexity cost.

According to study mentioned in [50], next-generation wireless communications in high mobility situations may benefit from millimeter-wave (mmWave) enormous multiple-input-multiple-output (MIMO) and orthogonal time-frequency space (OTFS) decoding. The huge processing issue of channel transmission caused by the enormous OTFS symbol size and the high density of antennas is one of the main difficulties for mmWave massive MIMO-OTFS systems. In order to solve this problem, it is suggested in this article to use the channel sparsity in the delay-Doppler-angle domain to guide an Orthogonal Matching Pursuit Vector (OMPV) for channel estimation. As a first move, researchers suggest an innovative idea design for the OTFS symbol structure in the frequency-time domain. researchers then define channel estimation as a problem of patchy signal recovery using the suggested prototype structure. Concurrent support detection and tensor decomposition are then added to the tensor-based OMP method, both of which significantly decrease the depth of signal processing. Numerical computations are carried out for various situations to confirm the supremacy and reliability of the suggested tensor-based OMP algorithm sets. Thus, it can be observed that a wide variety of optimization methods are proposed by researchers to improve communication performance of wireless equipments. A statistical survey of these models is discussed in the next section of this text, which will assist readers to identify optimal models for performance-specific use cases.

[3] Result analysis and comparison

As per the theoretical review of existing wireless communication optimization models, it can be observed that these models are highly variant in terms of their functional characteristics. Thus, in this section, a statistical performance evaluation of these models is discussed, which will assist readers to identify optimal models for different performance-specific deployments. These models are compared in terms of Bit Error Rates (BER), Communication Delay (D), Computational Complexity (CC), Cost of Deployment (CD) and Scalability levels. As these models were deployed on different communication networks, the comparative parameters were converted into Fuzzy Ranges of Low (L=1), Medium (M=2), High (H=3), and Very High (VH=4), which will assist readers to evaluate these models on similar scales. After referring these comparisons, readers will be able to select and deploy different models for low BER, low complexity, low delay, low cost & high scalability scenarios. Based on this strategy, the comparative analysis can be observed from table 1 as follows,

Model	BER	CC	CD	D	S
LCG SBL [1]	M	H	H	M	H
TDC EBS [2]	L	H	H	M	H
OMP [3]	M	VH	H	L	H
GSBL [4]	M	VH	H	H	H
CS [5]	L	M	H	H	H
CFO [6]	H	H	L	H	H
TDD [7]	H	H	VH	M	H
BCD [8]	M	H	VH	H	H
TTD [9]	H	M	H	H	H
kNN [10]	H	L	H	H	H
MMV MSBL [11]	H	H	H	H	L
PPP [12]	H	H	M	M	H
3DRL MLP [13]	H	H	H	H	H
NMG	H	M	H	H	VH

[14]					
DNN [15]	M	H	H	H	VH
ARoF [16]	H	L	H	M	H
FDD PD [17]	H	M	M	H	H
QS TBC [18]	M	H	H	H	M
VM [19]	L	M	H	H	H
PNE [20]	H	M	H	M	H
2DOS CFAR [21]	H	H	L	H	H
SEIM [22]	H	L	M	H	H
IRS [23]	M	L	H	H	VH
AI FoF [24]	H	M	H	M	H
RIS [25]	M	H	H	H	M
PC GBIM [26]	L	H	H	H	H
BSBL [27]	M	L	M	H	H
MMV SBL [28]	L	L	H	H	H
RECEIVER OPTIMIZATIONS					
MPC [29]	H	H	M	H	VH
LCS STO [30]	M	H	H	M	H
ZC PSI [31]	M	H	H	M	H
MB DFTS OF DMM [32]	L	M	M	H	H
DL JHPF [33]	L	H	H	H	H
HBF [34]	M	H	H	H	H
PDMA [35]	H	M	H	H	VH
MPRI [36]	H	H	M	H	H
ZF [37]	H	H	H	M	H
ESP RIT [38]	M	L	H	H	H
CHANNEL OPTIMIZATIONS					
CPD [39]	H	L	M	L	VH
RNet [40]	H	M	H	L	H

MAS MBS [41]	H	H	H	M	H
DSRC [42]	M	H	H	M	H
NFC FGS [43]	H	L	M	L	H
BP [44]	H	M	M	H	VH
TVM [45]	L	L	H	H	H
HP KF [46]	H	M	H	H	H
CSLR [47]	H	H	H	M	H
SFT [48]	M	H	VH	L	H
PW GBM [49]	H	H	H	M	VH
OMPV [50]	H	L	H	H	H

Table 1. Comparative analysis of different models for optimization of wireless communication components

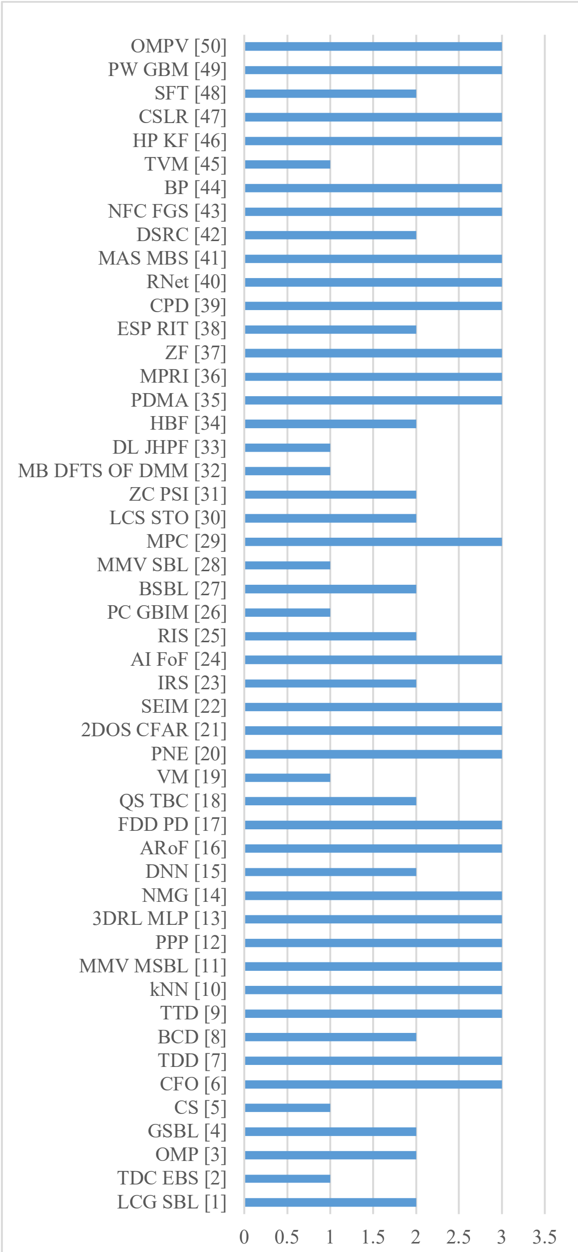

Figure 1. BER Levels of different optimization models

As per this evaluation, and figure 1, it can be observed that TDC EBS [2], CS [5], VM [19], PC GBIM [26], MMV SBL [28], MB DFTS OF DMM [32], DL JHPF [33], and TVM [45] showcase low BER performance, thus can be used for a wide variety of high-data rate applications.

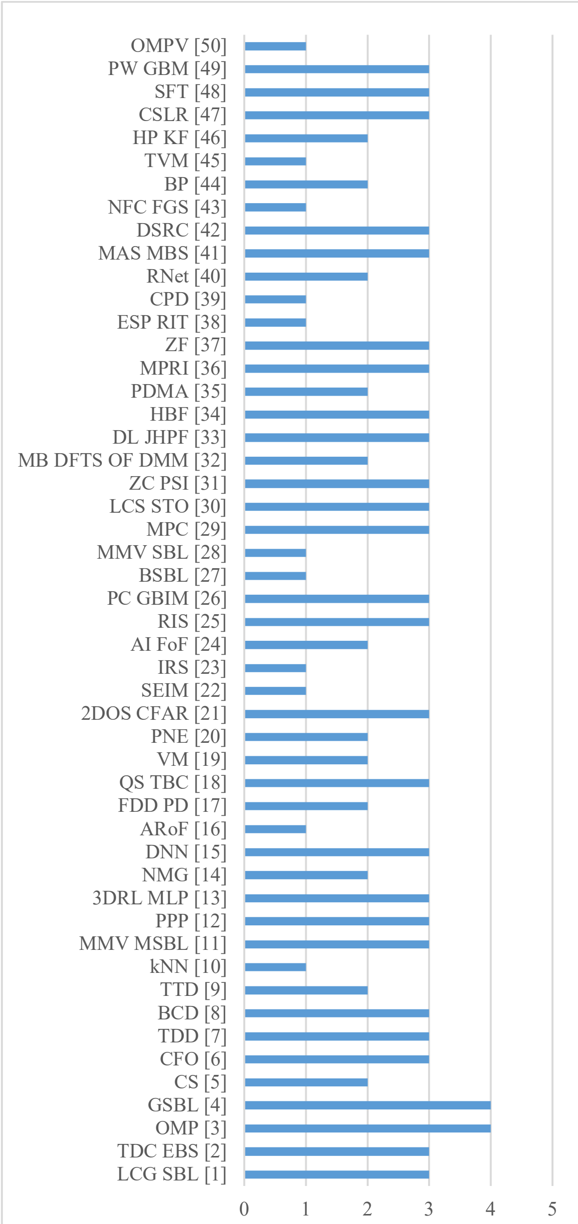

Figure 2. Computational Complexity Levels of different optimization models

Similarly, as per figure 2, it can be observed that kNN [10], ARoF [16], SEIM [22], IRS [23], BSBL [27], MMV SBL [28], ESP RIT [38], CPD [39], NFC FGS [43], TVM [45], and OMPV [50] are able to achieve lower computational complexity, thus can be used for IoT and other low complexity deployments.

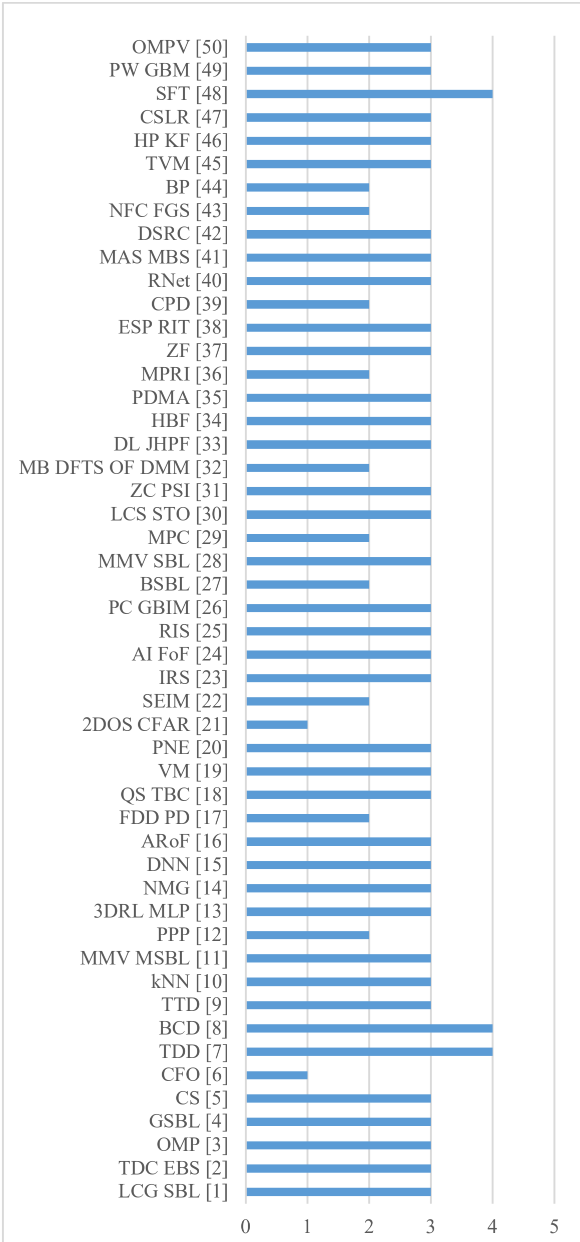

Figure 3. Deployment Costs of different optimization models

Upon referring figure 3, it can be observed that CFO [6], 2DOS CFAR [21], PPP [12], FDD PD [17], SEIM [22], BSBL [27], MPC [29], MB DFTS OF DMM [32], MPRI [36], CPD [39], NFC FGS [43], and BP [44] are able to showcase lower deployment costs, thus can be used for cost-aware application scenarios.

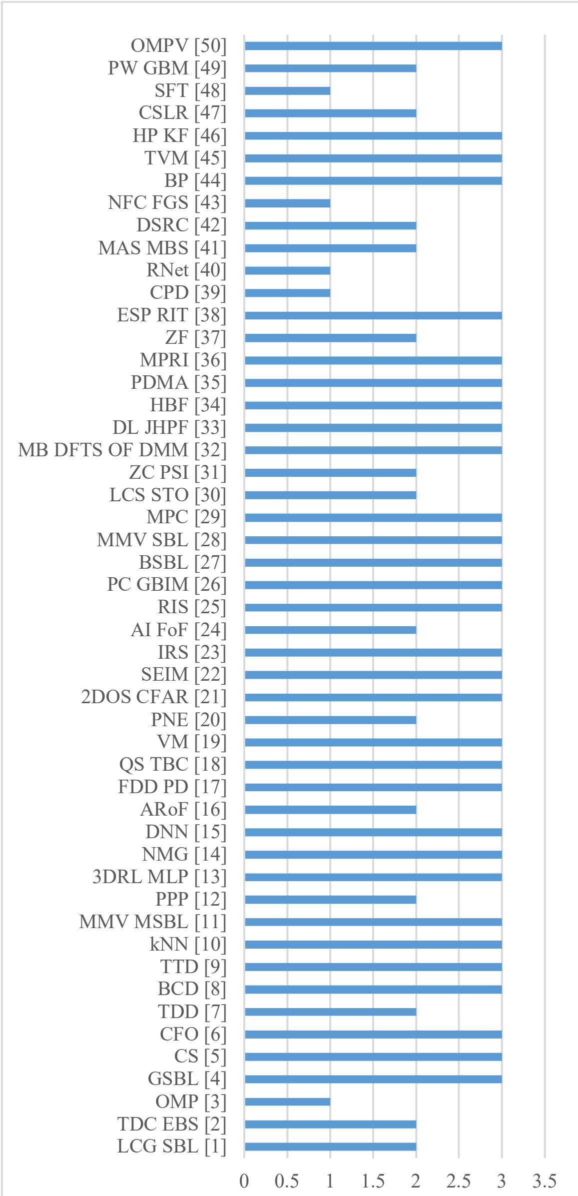

Figure 4. Computational Delay of different optimization models

In terms of communication & computational delay, as per figure 4, it can be observed that OMP [3], CPD [39], RNet [40], NFC FGS [43], and SFT [48] are able to perform high-speed computations, thus can be used for low-delay deployments.

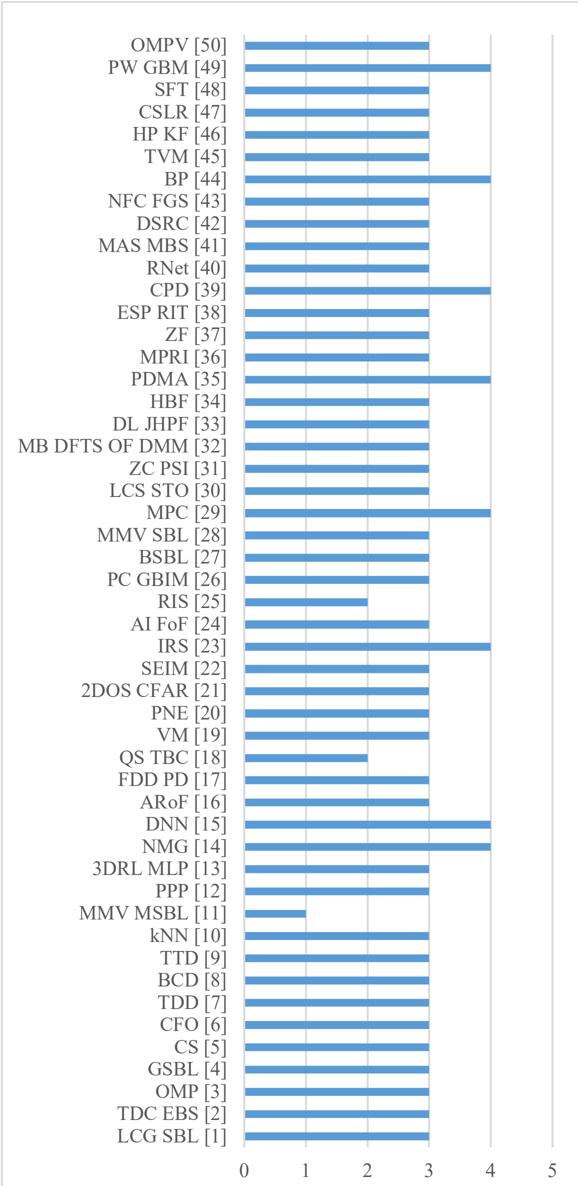

Figure 5. Scalability of different optimization models

Figure 5 indicates that NMG [14], DNN [15], IRS [23], MPC [29], PDMA [35], CPD [39], BP [44], and PW GBM [49] showcase higher scalability, thus can be used for a wide variety of network scenarios. All these metrics were combined via equation 1 to evaluate Communication Interface Rank Metric (CIRM), as follows,

$$CIRM = \frac{1}{BER} + \frac{1}{CC} + \frac{1}{CD} + \frac{1}{D} + \frac{S}{4} \ldots (1)$$

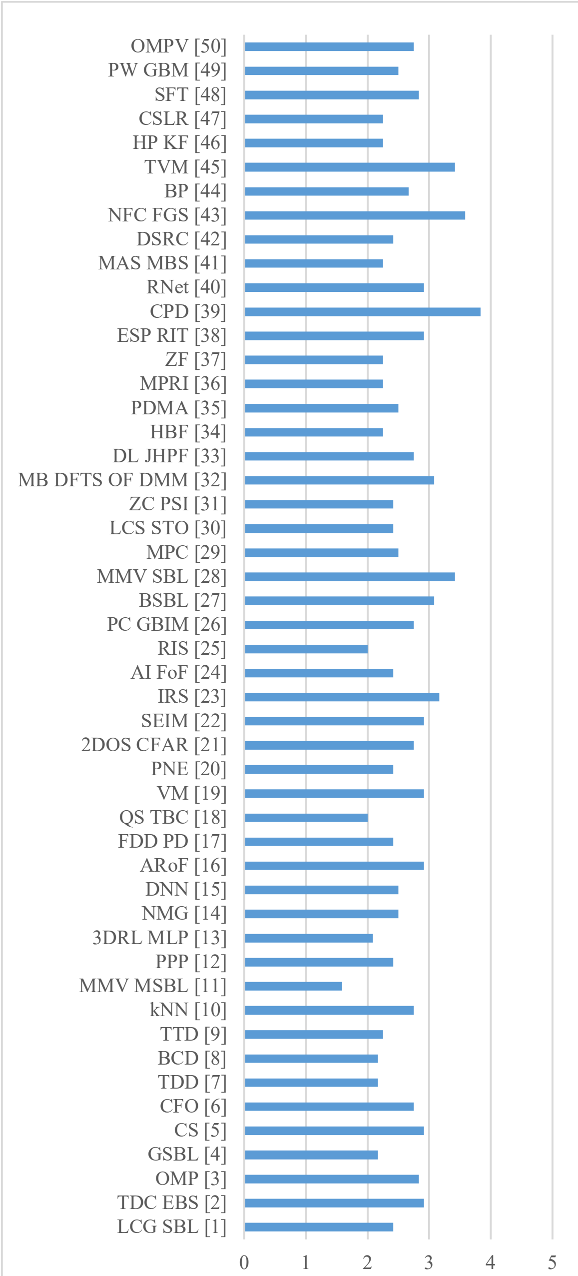

Figure 6. CIRM of different optimization models

Based on this evaluation and figure 6, it can be observed that CPD [39], NFC FGS [43], MMV SBL [28], TVM [45], IRS [23], BSBL [27], MB DFTS OF DMM [32], TDC EBS [2], CS [5], ARoF [16], VM [19], SEIM [22], ESP RIT [38], RNet [40], OMP [3], and SFT [48] are capable of deployment for low BER, low complexity, low cost, high speed and high scalability scenarios. Thus, researchers must use these models to improve overall quality & performance of wireless communication components.

[4] Conclusion & Future work

Researchers have developed a large number of distinct methods for optimising wireless components, each of which is distinct in terms of its internal and external operational characteristics. In contrast, amplifier and de-amplifier design models focus on improving the performance of modulation and demodulation components. It is difficult for designers to identify the most effective models for designing context-specific communication interfaces due to the wide variation in component designs. TDC EBS, CS, VM, PC GBIM, MMV SBL, MB DFTS OF DMM, DL JHPF, and TVM exhibit low BER performance and are therefore applicable to a wide range of high-data-rate applications. It was found that kNN, ARoF, SEIM, IRS, BSBL, MMV SBL, ESP RIT, CPD, NFC FGS, TVM, and OMPV are capable of achieving lower computational complexity and can therefore be used for IoT and other deployments with low complexity.

In terms of deployment costs, CFO, DOS CFAR, PPP, FDD PD, SEIM, BSBL, MPC, MB DFTS OF DMM, MPRI, CPD, NFC FGS, and BP are able to demonstrate lower deployment costs and can therefore be utilised in cost-conscious application scenarios. In terms of deployment delay, it can be observed that OMP, CPD, RNet, NFC FGS, and SFT are capable of high-speed computations and can therefore be used for deployments with minimal delay.

In terms of applicability, it was observed that NMG, DNN, IRS, MPC, PDMA, CPD, BP, and PW GBM exhibit greater scalability and are therefore applicable to a wide range of network scenarios. All of these metrics were combined to determine the Communication Interface Rank Metric (CIRM), and based on this evaluation, it was determined that CPD, NFC FGS, MMV SBL, TVM, IRS, BSBL, MB DFTS OF DMM, TDC EBS, CS, ARoF, VM, SEIM, ESP RIT, RNet, OMP, and SFT are deployable in scenarios requiring low BER, low complexity, low cost, high speed, Therefore, researchers must implement these models to enhance the quality and performance of wireless communication components.

In future, researchers can create an augmentation of these models in order to improve overall QoS performance of different wireless components. Use of bioinspired models including Elephant Herding Optimization, Genetic Algorithm, Antlion Optimization, etc. can be combined with deep learning techniques in order to further optimize model performance under real-time network scenarios.

[5] References

[1] S. Srivastava, C. S. K. Patro, A. K. Jagannatham and L. Hanzo, "Sparse, Group-Sparse, and Online Bayesian Learning Aided Channel Estimation for Doubly-Selective mmWave Hybrid MIMO OFDM Systems," in IEEE Transactions on Communications, vol. 69, no. 9, pp. 5843-5858, Sept. 2021, doi: 10.1109/TCOMM.2021.3085344.

[2] Y. Wang, C. Qi, P. Li, Z. Lu and P. Lu, "Channel Estimation for Wideband mmWave MIMO OFDM System Exploiting Block Sparsity," in IEEE Communications Letters, vol. 26, no. 4, pp. 897-901, April 2022, doi: 10.1109/LCOMM.2022.3148911.

[3] Y. Zhang, M. El-Hajjar and L. -L. Yang, "Adaptive Codebook-Based Channel Estimation in OFDM-Aided Hybrid Beamforming mmWave Systems," in IEEE Open Journal of the Communications Society, vol. 3, pp. 1553-1562, 2022, doi: 10.1109/OJCOMS.2022.3207797.

[4] P. Priya and D. Sen, "Particle Filter Based Nonlinear Data Detection in Presence of CFO for Frequency Selective mmWave MIMO-OFDM Systems," in IEEE Transactions on Vehicular Technology, vol. 70, no. 6, pp. 5892-5907, June 2021, doi: 10.1109/TVT.2021.3078103.

[5] F. Han, X. Wang and H. Deng, "A Very-Low Pilot Scheme for mmWave Hybrid Massive MIMO-OFDM Systems," in IEEE Wireless Communications Letters, vol. 10, no. 9, pp. 2061-2064, Sept. 2021, doi: 10.1109/LWC.2021.3092073.

[6] P. Priya and D. Sen, "Data Detection With CFO Uncertainty and Nonlinearity for mmWave MIMO-OFDM Systems," in IEEE Systems Journal, vol. 16, no. 3, pp. 3734-3745, Sept. 2022, doi: 10.1109/JSYST.2021.3093333.

[7] G. Femenias and F. Riera-Palou, "Wideband Cell-Free mmWave Massive MIMO-OFDM: Beam Squint-Aware Channel Covariance-Based Hybrid Beamforming," in IEEE Transactions on Wireless Communications, vol. 21, no. 7, pp. 4695-4710, July 2022, doi: 10.1109/TWC.2021.3132414.

[8] H. Li, M. Li, Q. Liu and A. L. Swindlehurst, "Dynamic Hybrid Beamforming With Low-Resolution PSs for Wideband mmWave MIMO-OFDM Systems," in IEEE Journal on Selected Areas in Communications, vol. 38, no. 9, pp. 2168-2181, Sept. 2020, doi: 10.1109/JSAC.2020.3000878.

[9] G. M. Zilli and W. -P. Zhu, "Constrained Tensor Decomposition-Based Hybrid Beamforming for Mmwave Massive MIMO-OFDM Communication Systems," in IEEE Transactions on Vehicular Technology, vol. 70, no. 6, pp. 5775-5788, June 2021, doi: 10.1109/TVT.2021.3076691.

[10] H. Liu, S. Lu, M. El-Hajjar and L. -L. Yang, "Machine Learning Assisted Adaptive Index Modulation for mmWave Communications," in IEEE Open Journal of the Communications Society, vol. 1, pp. 1425-1441, 2020, doi: 10.1109/OJCOMS.2020.3024724.

[11] M. Majumder, H. Saxena, S. Srivastava and A. K. Jagannatham, "Optimal Bit Allocation-Based Hybrid Precoder-Combiner Design Techniques for mmWave MIMO-OFDM Systems," in IEEE Access, vol. 9, pp. 54109-54125, 2021, doi: 10.1109/ACCESS.2021.3070921.
[12] Y. Yang, S. Dang, M. Wen and M. Guizani, "Millimeter Wave MIMO-OFDM With Index Modulation: A Pareto Paradigm on Spectral- Energy Efficiency Trade-Off," in IEEE Transactions on Wireless Communications, vol. 20, no. 10, pp. 6371-6386, Oct. 2021, doi: 10.1109/TWC.2021.3073692.
[13] D. F. Carrera, C. Vargas-Rosales, N. M. Yungaicela-Naula and L. Azpilicueta, "Comparative Study of Artificial Neural Network Based Channel Equalization Methods for mmWave Communications," in IEEE Access, vol. 9, pp. 41678-41687, 2021, doi: 10.1109/ACCESS.2021.3065337.
[14] H. Wang, J. Fang, P. Wang, G. Yue and H. Li, "Efficient Beamforming Training and Channel Estimation for Millimeter Wave OFDM Systems," in IEEE Transactions on Wireless Communications, vol. 20, no. 5, pp. 2805-2819, May 2021, doi: 10.1109/TWC.2020.3044462.
[15] H. Liu, Y. Zhang, X. Zhang, M. El-Hajjar and L. -L. Yang, "Deep Learning Assisted Adaptive Index Modulation for mmWave Communications With Channel Estimation," in IEEE Transactions on Vehicular Technology, vol. 71, no. 9, pp. 9186-9201, Sept. 2022, doi: 10.1109/TVT.2022.3181825.
[16] J. P. Santacruz, S. Rommel, U. Johannsen, A. Jurado-Navas and I. T. Monroy, "Analysis and Compensation of Phase Noise in Mm-Wave OFDM ARoF Systems for Beyond 5G," in Journal of Lightwave Technology, vol. 39, no. 6, pp. 1602-1610, 15 March15, 2021, doi: 10.1109/JLT.2020.3041041.
[17] A. Brihuega, L. Anttila and M. Valkama, "Frequency-Domain Digital Predistortion for OFDM," in IEEE Microwave and Wireless Components Letters, vol. 31, no. 6, pp. 816-818, June 2021, doi: 10.1109/LMWC.2021.3062982.
[18] C. Sanchis Borrás et al., "Millimeter Wave MISO-OFDM Transmissions in an Intra-Wagon Environment," in IEEE Transactions on Intelligent Transportation Systems, vol. 22, no. 8, pp. 4899-4908, Aug. 2021, doi: 10.1109/TITS.2020.2983028.
[19] Y. Lin, S. Jin, M. Matthaiou and X. You, "Tensor-Based Channel Estimation for Millimeter Wave MIMO-OFDM With Dual-Wideband Effects," in IEEE Transactions on Communications, vol. 68, no. 7, pp. 4218-4232, July 2020, doi: 10.1109/TCOMM.2020.2983673.
[20] M. Chung, L. Liu and O. Edfors, "Phase-Noise Compensation for OFDM Systems Exploiting Coherence Bandwidth: Modeling, Algorithms, and Analysis," in IEEE Transactions on Wireless Communications, vol. 21, no. 5, pp. 3040-3056, May 2022, doi: 10.1109/TWC.2021.3117782.
[21] Y. -C. Lin, T. -S. Lee, Y. -H. Pan and K. -H. Lin, "Low-Complexity High-Resolution Parameter Estimation for Automotive MIMO Radars," in IEEE Access, vol. 8, pp. 16127-16138, 2020, doi: 10.1109/ACCESS.2019.2926413.
[22] Y. Fan, S. Gao, X. Cheng, L. Yang and N. Wang, "Wideband Generalized Beamspace Modulation (wGBM) for mmWave Massive MIMO Over Doubly-Selective Channels," in IEEE Transactions on Vehicular Technology, vol. 70, no. 7, pp. 6869-6880, July 2021, doi: 10.1109/TVT.2021.3085575.
[23] S. H. Hong, J. Park, S. -J. Kim and J. Choi, "Hybrid Beamforming for Intelligent Reflecting Surface Aided Millimeter Wave MIMO Systems," in IEEE Transactions on Wireless Communications, vol. 21, no. 9, pp. 7343-7357, Sept. 2022, doi: 10.1109/TWC.2022.3157880.
[24] K. Kanta et al., "Analog fiber-wireless downlink transmission of IFoF/mmWave over in-field deployed legacy PON infrastructure for 5G fronthauling," in Journal of Optical Communications and Networking, vol. 12, no. 10, pp. D57-D65, October 2020, doi: 10.1364/JOCN.391803.
[25] M. He, W. Xu, H. Shen, G. Xie, C. Zhao and M. Di Renzo, "Cooperative Multi-RIS Communications for Wideband mmWave MISO-OFDM Systems," in IEEE Wireless Communications Letters, vol. 10, no. 11, pp. 2360-2364, Nov. 2021, doi: 10.1109/LWC.2021.3100479.
[26] Y. Fan, S. Gao, X. Cheng and L. Yang, "Pre-Compensation-Assisted Generalized Beam Index Modulation (PC-GBIM) for mmWave Massive MIMO Over Doubly Selective Channels," in IEEE Wireless Communications Letters, vol. 10, no. 2, pp. 411-415, Feb. 2021, doi: 10.1109/LWC.2020.3033452.
[27] S. Srivastava, R. K. Singh, A. K. Jagannatham, A. Chockalingam and L. Hanzo, "OTFS Transceiver Design and Sparse Doubly-Selective CSI Estimation in Analog and Hybrid

Beamforming Aided mmWave MIMO Systems," in IEEE Transactions on Wireless Communications, vol. 21, no. 12, pp. 10902-10917, Dec. 2022, doi: 10.1109/TWC.2022.3188040.
[28] S. Srivastava, J. Nath and A. K. Jagannatham, "Data Aided Quasistatic and Doubly-Selective CSI Estimation Using Affine-Precoded Superimposed Pilots in Millimeter Wave MIMO-OFDM Systems," in IEEE Transactions on Vehicular Technology, vol. 70, no. 7, pp. 6983-6998, July 2021, doi: 10.1109/TVT.2021.3089167.
[29] F. Gómez-Cuba and A. J. Goldsmith, "Compressed Sensing Channel Estimation for OFDM With Non-Gaussian Multipath Gains," in IEEE Transactions on Wireless Communications, vol. 19, no. 1, pp. 47-61, Jan. 2020, doi: 10.1109/TWC.2019.2941192.
[30] N. Varshney and S. De, "Multi-RF Beamforming-Based Cellular Communication Over Wideband mmWaves," in IEEE Transactions on Communications, vol. 70, no. 4, pp. 2772-2787, April 2022, doi: 10.1109/TCOMM.2022.3147510.
[31] Y. J. Kim, Q. Sultan and Y. S. Cho, "Pilot Sequence Design for mmWave Cellular Systems With Relay Stations in the Presence of Blockage," in IEEE Access, vol. 8, pp. 80454-80467, 2020, doi: 10.1109/ACCESS.2020.2990710.
[32] C. Xu et al., "Space-, Time- and Frequency-Domain Index Modulation for Next-Generation Wireless: A Unified Single-/Multi-Carrier and Single-/Multi-RF MIMO Framework," in IEEE Transactions on Wireless Communications, vol. 20, no. 6, pp. 3847-3864, June 2021, doi: 10.1109/TWC.2021.3054068.
[33] P. Dong, H. Zhang and G. Y. Li, "Framework on Deep Learning-Based Joint Hybrid Processing for mmWave Massive MIMO Systems," in IEEE Access, vol. 8, pp. 106023-106035, 2020, doi: 10.1109/ACCESS.2020.3000601.
[34] F. Gómez-Cuba, T. Zugno, J. Kim, M. Polese, S. Bahk and M. Zorzi, "Hybrid Beamforming in 5G mmWave Networks: A Full-Stack Perspective," in IEEE Transactions on Wireless Communications, vol. 21, no. 2, pp. 1288-1303, Feb. 2022, doi: 10.1109/TWC.2021.3103575.
[35] S. Shen, Y. -W. Chen, Q. Zhou, J. Finkelstein and G. -K. Chang, "Demonstration of Pattern Division Multiple Access With Message Passing Algorithm for Multi-Channel mmWave Uplinks via RoF Mobile Fronthaul," in Journal of Lightwave Technology, vol. 38, no. 21, pp. 5908-5915, 1 Nov.1, 2020, doi: 10.1109/JLT.2020.3005905.
[36] H. Kim, C. -B. Chae and K. S. Kim, "Hybrid Precoding Based on Monopulse Ratio for Millimeter Wave Systems With Limited Feedback," in IEEE Access, vol. 8, pp. 175329-175346, 2020, doi: 10.1109/ACCESS.2020.3025181.
[37] J. J. Sadique, S. R. Sabuj, S. E. Ullah, S. K. Joarder and M. Hamamura, "UAV-Aided Transceiver Design for Secure Downlink OW-DFTs-OFDM System: A Multi-User mmWave Application," in IEEE Access, vol. 10, pp. 34577-34590, 2022, doi: 10.1109/ACCESS.2022.3162628.
[38] J. Zhang, D. Rakhimov and M. Haardt, "Gridless Channel Estimation for Hybrid mmWave MIMO Systems via Tensor-ESPRIT Algorithms in DFT Beamspace," in IEEE Journal of Selected Topics in Signal Processing, vol. 15, no. 3, pp. 816-831, April 2021, doi: 10.1109/JSTSP.2021.3063908.
[39] X. Zheng, P. Wang, J. Fang and H. Li, "Compressed Channel Estimation for IRS-Assisted Millimeter Wave OFDM Systems: A Low-Rank Tensor Decomposition-Based Approach," in IEEE Wireless Communications Letters, vol. 11, no. 6, pp. 1258-1262, June 2022, doi: 10.1109/LWC.2022.3163661.
[40] Y. -C. Lin, M. -X. Gu, C. -H. Lin and T. -S. Lee, "Deep-Learning Based Decentralized Frame-to-Frame Trajectory Prediction Over Binary Range-Angle Maps for Automotive Radars," in IEEE Transactions on Vehicular Technology, vol. 70, no. 7, pp. 6385-6398, July 2021, doi: 10.1109/TVT.2021.3082213.
[41] S. Gao, X. Cheng and L. Yang, "Mutual Information Maximizing Wideband Multi-User (wMU) mmWave Massive MIMO," in IEEE Transactions on Communications, vol. 69, no. 5, pp. 3067-3078, May 2021, doi: 10.1109/TCOMM.2021.3053967.
[42] Y. Sadovaya and S. V. Zavjalov, "Dedicated Short-Range Communications: Performance Evaluation Over mmWave and Potential Adjustments," in IEEE Communications Letters, vol. 24, no. 12, pp. 2733-2736, Dec. 2020, doi: 10.1109/LCOMM.2020.3016634.
[43] I. -S. Kim and J. Choi, "Spatial Wideband Channel Estimation for mmWave Massive MIMO Systems With Hybrid Architectures and Low-Resolution ADCs," in IEEE Transactions on Wireless Communications, vol. 20, no. 6, pp. 4016-4029, June 2021, doi: 10.1109/TWC.2021.3054998.

[44] N. Varshney and S. De, "RF Beamforming and Subcarrier Allocation Using Beam Squint in mmWave Systems," in IEEE Wireless Communications Letters, vol. 11, no. 4, pp. 678-682, April 2022, doi: 10.1109/LWC.2021.3137482.
[45] T. R. Dean, M. Chowdhury, N. Grimwood and A. J. Goldsmith, "Rethinking Modulation and Detection for High Doppler Channels," in IEEE Transactions on Wireless Communications, vol. 19, no. 6, pp. 3629-3642, June 2020, doi: 10.1109/TWC.2020.2967039.
[46] O. S. Faragallah, H. S. El-Sayed and M. G. El-Mashed, "Estimation and Tracking for Millimeter Wave MIMO Systems Under Phase Noise Problem," in IEEE Access, vol. 8, pp. 228009-228023, 2020, doi: 10.1109/ACCESS.2020.3045045.
[47] A. Brighente, M. Cerutti, M. Nicoli, S. Tomasin and U. Spagnolini, "Estimation of Wideband Dynamic mmWave and THz Channels for 5G Systems and Beyond," in IEEE Journal on Selected Areas in Communications, vol. 38, no. 9, pp. 2026-2040, Sept. 2020, doi: 10.1109/JSAC.2020.3000889.
[48] A. Fascista, A. De Monte, A. Coluccia, H. Wymeersch and G. Seco-Granados, "Low-Complexity Downlink Channel Estimation in mmWave Multiple-Input Single-Output Systems," in IEEE Wireless Communications Letters, vol. 11, no. 3, pp. 518-522, March 2022, doi: 10.1109/LWC.2021.3134826.
[49] S. Gao, J. Li, X. Cheng and L. Yang, "BER-Minimizing Precoded Wideband Generalized Beamspace Modulation for Hybrid mmWave Massive MIMO," in IEEE Wireless Communications Letters, vol. 11, no. 2, pp. 278-282, Feb. 2022, doi: 10.1109/LWC.2021.3125778.
[50] X. Wu, S. Ma and X. Yang, "Tensor-based low-complexity channel estimation for mmWave massive MIMO-OTFS systems," in Journal of Communications and Information Networks, vol. 5, no. 3, pp. 324-334, Sept. 2020, doi: 10.23919/JCIN.2020.9200896.