Review on Technology Developments in Hybrid Beamforming in millimeter wave in 5G

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Abstract:

The millimeter wave frequency band has a large amount of underused spectrum resources, which can effectively improve the congestion of the low-frequency spectrum, and due to the short millimeter wave wavelength, it can greatly reduce the physical size of the large-scale antenna system. Millimeter wave communication becoming one of the potential key technologies in 5G wireless communication system. Considering that the millimeter wave propagation path loss is serious, the millimeter wave system needs to use beamforming technology to improve the quality of transmission. In the millimeter wave large-scale multiple-input multiple output (MIMO) system,hybrid digital-analog beamforming has become an important alternative due to the high power consumption of digital beamforming and cost issues. However, imperfect phase shifter on the mm-Wave systems leads to degrade the performance and loss of efficiency. To overcome this issue, a low resolution phase shifters needs to develop in hybrid beamforming. This article first describes the research status of millimeter wave hybrid beamforming and impact of low resolution phase shifters. Introduces the key technologies in millimeter wave in 5G communication system, then gives the system model, and finally measurement parameters coverage, capacity, peak rate and time delay is discussed.

Keywords: Millimeter wave system, 5G communication system, Hybrid beamforming, Low resolution phase shifters, Large-scale antenna system, MIMO.

I. INTRODUCTION

The development of 5G technology is having a profound impact on the world [1]. Every day we see commercial deployment cases with higher speed and lower latency brought by 5G, which makes us stronger. Believe that we are entering a new era of Internet of Everything (IoE) [2]. According to Global System for Mobile Communications (GSMA) estimates, 5G millimeter waves [3] are used as high-speed access, industrial automation, medical health, intelligent transportation and so on.Compared with the previous 2/3/4G low and mid frequency bands, millimeter wave has the following advantages:

- Millimeter wave spectrum resources are very rich, and usually continuous bandwidth, which will bring users an unprecedented high-speed experience.
- Millimeter wave can provide lower delay.
- The millimeter wave antenna is smaller in size, and the equipment is lighter, making it easier to deploy.

At the same time, due to the natural properties of its own frequency band, millimeter waves also bring realistic challenges such as high path loss and short propagation distance. In this paper, key technologies and challenges of millimeter wave to explain how to use the advantages and advantages of millimeter wave's [4] wide frequency band, large bandwidth, and low latency is discussed. Finally, predictions for the future technological evolution of millimeter waves also discussed.

1.1 Development status of millimeter wave technology

A. Millimeter wave frequency bands allocation

The 3rd Generation Partnership Project (3GPP) defines two types of frequency ranges: FR1 (Frequency Range1) and FR2 (Frequency Range2). FR1 fixed which means is the low frequency part, which is commonly referred to as Sub-6G and FR2 is the high frequency part, that is, the frequency band of the millimeter wave [5]. The World Radio communication Conference (WRC-19), which held in December 2019, identified 24.25 GHz-27.5 GHz, 37 GHz-43.5 GHz, 66 GHz-71 GHz is the 5G global millimeter wave unified working frequency band, while 45.5 GHz-47 GHz and 47.2 GHz-48.2 GHz are regional millimeter wave frequency bands [6]. According to Global Mobile Suppliers Association (GSA) statistics, as of 2018, 97 operators (from 17 countries and regions) worldwide already have spectrum licenses for the millimeter wave frequency band. Among them, 22 have completed the commercial deployment of the millimeter wave frequency band [7].

B. Developmentsin standardization

From the perspective of 3GPP's overall planning for 5G [8], up to now the R16 version of the 5G international standard has been completed, and the R17 version is expected to be frozen in June 2021 (issued the release time is December 2021). Key points of different versions are discussed follows:

R15 version

In addition to clarifying the core technology and overall architecture of New Radio (NR) in 5G, this version defines 5 frequency bands of FR2 (n257, n258, n259, n260, n261). At the same time, the high frequency is different from the low frequency physical characteristics, such as sub-carrier spacing, frame structure, single-user MIMO and multi-user MIMO support, the support for dual connectivity and carrier aggregation is defined [9].

R16 version

This version is mainly considered from the perspective of network optimization, and has enhanced or supplemented features based on the definition of R15, which can be summarized in the following parts:

- **Physical layer enhancement features**: including two-step Random Access Channel (RACH), multiple Transmission points (TRP), integrated access backhaul, etc.
- **MIMO enhanced features**: including uplink power control based on MAC control information update, multi-beam (layer 1 CSI-RS SINR), low power

Demodulation reference signal enhancement of rate-to-peak-to-average ratio, etc.

- **UE energy-saving features**: including Physical Downlink Control Channel (PDCCH) wake-up signal, cross-slot scheduling adaptation, etc.
- **Mobility enhancement features:** including asynchronous NR-NR dual connectivity, early measurement reporting, Secondary Cell (Scell) dormancy, Master Cell Group (MCG) based on Radio Resource Control (RRC) resume SCell and Secondary Cell Group (SCG) configuration, fast MCG link repair, cross-carrier scheduling with different parameter sets, etc [10].

R17 Version

This version will mainly carry out some business expansion, and for millimeter wave, it will mainly optimize Fixed Wireless Accesses (FWA) business and Dual Connectivity (DC) enhancement. Such as introducing the maximum TRP of the FWA terminal in the n257/n258 frequency band can reach 23dBm, and the DC enhancement of multiple Radio Access Technology (RAT) involves a single SCG and SCell the more efficient activation and deactivation features, as well as support for conditional PSCell changes and additions [11].

C. Key Technologies and Challenges of Millimeter Wave

Subcarrier bandwidth and frame structure

The frame structure is slightly different with the selection of the sub-carrier interval. Take the 120 kHz sub-carrier interval as an example: each frame consists of two half-frames, and each frame contains 10 sub-frames.Each subframe contains 8 slots, and each slot contains 14 OFDM symbols (including CP).

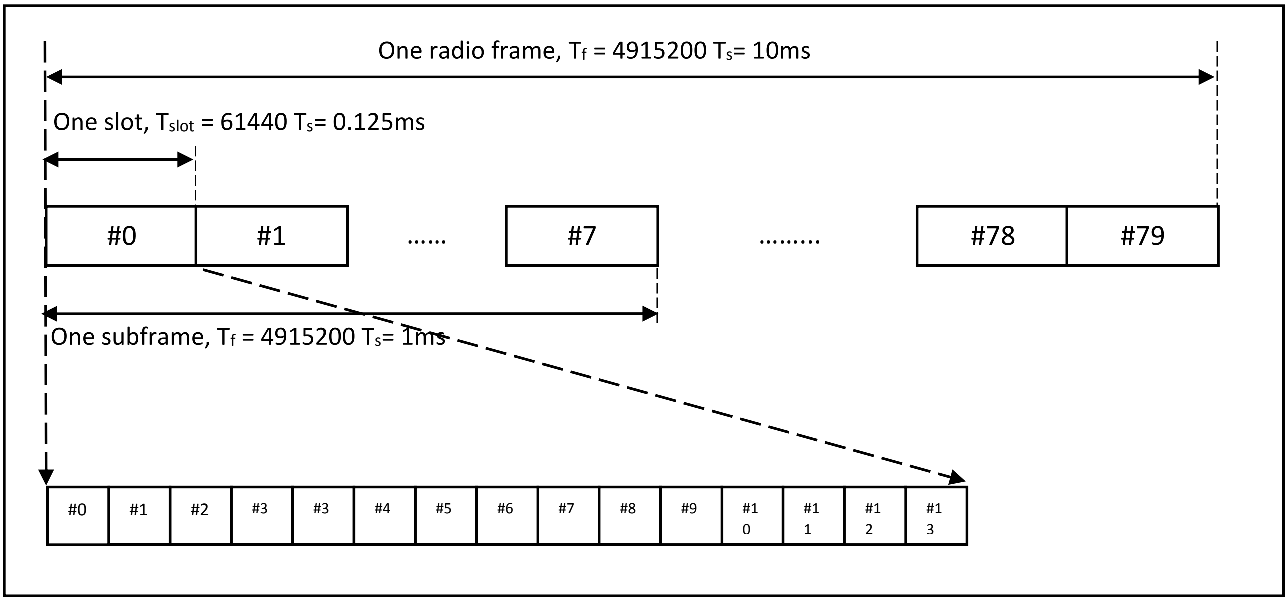

Figure 1: Schematic of millimeter wave frame structure

The NR standard supports semi-static or dynamic configuration of uplink (UL) and downlink (DL) ratios through RRC signaling or DCI scheduling. Most of the high-frequency frame structure has five time slots in an uplink-downlink conversion cycle, as shown in the figure 2. Choose different uplink and downlink ratios according to different needs, including pure downlink time slot (marked as D), pure uplink time slot (marked as U) and time slot for uplink/downlink conversion (marked as S). In the S time slot, Gap (GP) symbols are reserved for uplink and downlink switching, the number of symbols reserved by the GP depends on the uplink and downlink handover time on the User Equipment (UE) side and the planned cell radius.

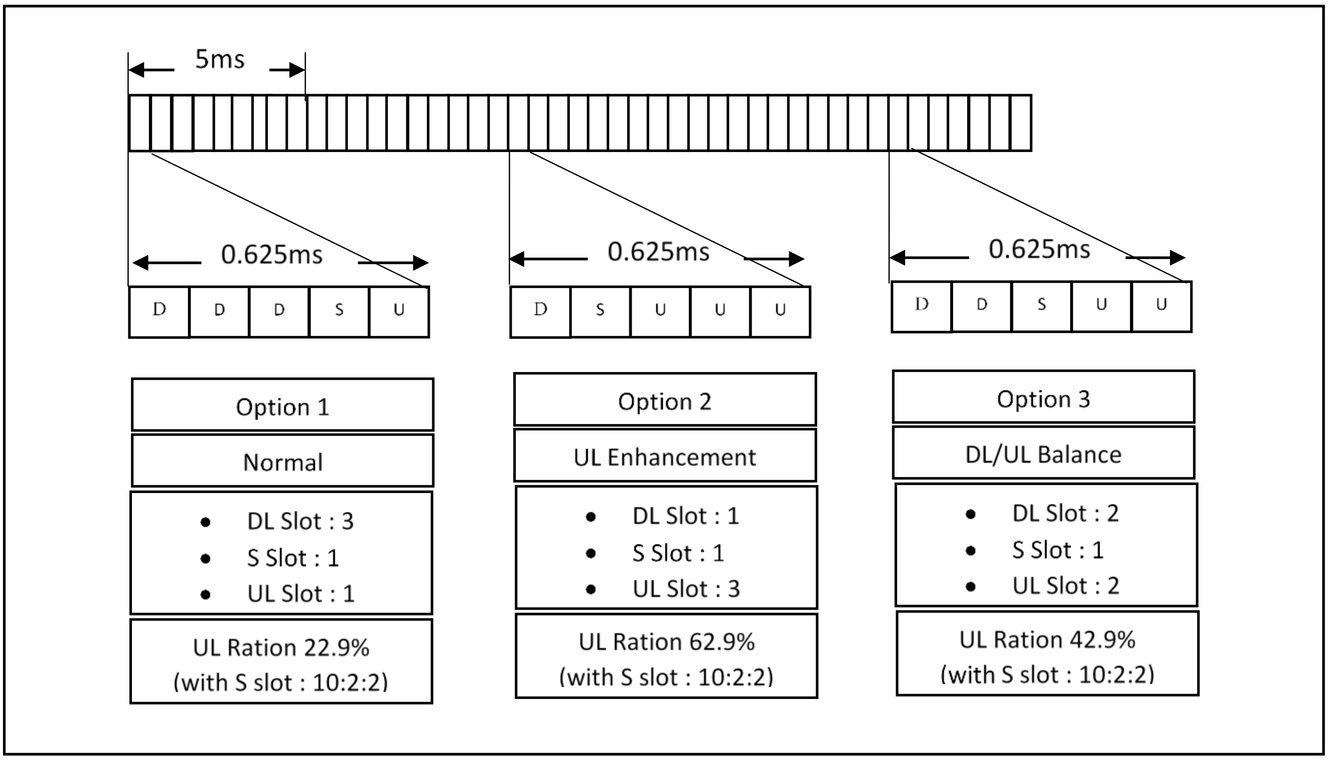

Figure 2: Common frame structure of millimeter wave

Compared with the three frame structures in figure 2, DDDSU is superior in downlink coverage and capacity, DSUUU is superior in uplink coverage and capacity, and DDSUU is more balanced with delay. On the one hand, DDDSU and DSUUU have an unbalanced ratio between the uplink and the downlink, and the delay is greater than that of DDSUU [12].

The design of the frame structure is closely related to the application scenario. If the high-frequency base station is mainly used in scenarios where downloading services are dominant, such as a common public network, the downlink-dominant frame structure is more suitable.If it is mainly used in scenarios such as uplink heat supplement and large-flow video upload, consider adopting a frame structure that is dominant in the uplink. For scenarios where there is a certain demand for uplink and downlink traffic, then it is better to adopt a balanced frame structure [13]. The rest of the paper as follows: section-II describes the exhaustive literature survey in hybrid beamforming in millimeter wave. The technology developments in large scale antenna structure explained in section-III. The Hybrid beamforming architecture and important parameters are discussed in section-IV. Antenna architecture and considerable measurement parameters for hybrid beamforming in millimeter is discussed in section-V and VI respectively.

II. LITERATURE

Didi Zhang et al., (2017) [14] has proposed a hybridly-connected structure with a design of a hybrid digital and analog precoders in mmWave MIMO systems. Based on the SVD of channel matrix, the optimal hybrid precoding sub-matrix can be achieved. The designed optimal precoders minimize the Euclidean distance. Based on the simulation results, the hybridly-connected structure is provided better results in terms of energy efficiency while showing insensitivity towards channel estimation errors than the fully-connected and partially-connected structures.

Narcis Cardona et al., (2017) [15] has focused on multi-user massive MIMO systems and evaluated the performance of non-linear block multi-diagnolization precoding. In case of hybrid digital and analog beamforming, it provides an intermediate solution between nonlinear and linear precoding. The non-linear block multi-diagnolization precoding shows better simulation outputs than the linear and half of the complexity of non-linear precoders.

Jung Chieh Chen et al., (2016) [16] has proposed an iterative algorithm to tackle the problem of computational costly combinatorial involved in the hybrid beamforming design. It maximizes the spectral efficiency by determining the discrete PSs. The proposed algorithm effectiveness would verified even in case of using low-resolution PSs. It is a simple computational algorithm, which achieves obtaining the desired discrete PSs.

Jung Chieh Chen et al., (2016) [17] has presented an efficient algorithm to address the problem of large size of codebook hinders for optimal analog combiner and analog precoder pairs. The algorithm implements based on CEO framework to maximize the achievable rate in massive MIMO systems. The proposed technique obtains 98% of optimal results and it is reliable for different phase shifter resolutions and a wide range of SNR values.

Farhan Khalid et al., (2018) [18] has presented a novel low-complexity HBF design for massive MIMO downlink transmission in sparse mm-Wave channels. The better performance is showed by the proposed HRCD algorithm when employing low-resolution RF phase shifters than the BD-based HBF solutions. Jiang Jing et al., (2016) [19] has proposed an efficient hybrid digital or analog beamforming for downlink MIMO systems. The simulation results have showed good performance in terms of increased sum rate with the increased number of MU-MIMO users. The inter-user interference can mitigate by the analog beamforming and the system performance can improve by the digital beamforming through flexible baseband processing.

Mandar N. Kulkarni et al., (2015) [20] has demonstrated the analytical model to include different constraints of combiner and precoder for dense MIMO networks with multiple antennas. The performance of MU-MIMO may affect by the imperfect channel knowledge than SU-BF or SM as more channel state information is required for MU-MIMO at the transmitter.

Zheda Li et al., (2018) [21] has proposed an algorithm of WAMMSE based on channel covariance and intra-group effective channel to obtain the per-group digital precoders. Under the Kronecker channel model, the author has proved that the decoupling design of analog precoder and combiner optimality. The ‘virtual sectorization’ and intelligent hybrid beamforming is required for achieving the optimal trade-off between the suppression of inter-group interference and reducing the cost of CSI based on the simulation results. The proposed algorithm shows better results to support massive MIMO FDD downlink in different scenarios.

Sung Joon Maeng et al., (2017) [22] proposes digital precoding methods for mm-wave systems using a hybrid beamforming to decrease the received IBI from neighbouring cells and adjacent beams. The CBRS technique has showed that the required processing times can be reduced significantly for estimating the effective combined network channel. The IBI in mm-wave cellular systems can reduce by the proposed precoders with the estimated effective network channel.

Nima N. Moghadam and Mats Bengtsson et al., (2018) [23] have considered a realistic power consumption model for the PAs transmitter to estimate the system energy-efficiency. An optimization problem was proposed using the derived model and beamforming filters to maximize the energy efficiency. The numerical results show that the effective outputs in terms of energy and spectral efficiency using large number of transmit antennas for hybrid beamforming. Foad Sohrabi et al., (2016) [24] has designed a unified heuristic algorithm to design the hybrid precoders and combiners for partially-connected and fully-connected hybrid beamforming architectures in the MU-MISO systems. The proposed method shows the optimal performance by comparing with the existing techniques.

Xiaoyong Wu et al., (2018) [25] has proposed linear HBF designs with perfect CSI for a massive MIMO system downlink with closed-form solutions. If the number of BS antennas is large, the BC channel capacity could approach by the proposed HBF design with the increasing of least number of RF chains. The simulation results prove that the proposed design is outperformed than the state of the art for HBF systems. Binqi Yang et al., (2018) [26] has proposed and implemented the 64-channel DBF-based massive MIMO transceiver for 5G mmWave-communications. The proposed mm-Wave transceiver achieves the great PF performances based on the measured results. The spectral efficiency of 101.5 b/s/Hz and the multiple user peak data rate of 50.73 Gb/s have obtained using 20 data streams and four-channel UEs.

Dengkui Zhu et al., (2016) [27] has proposed a novel algorithm known as hybrid beamforming based on the second-order SCM with unified AB. The sufficient number of RF chains has derived to achieve the performance. Additionally, a novel practical SC algorithm is also proposed for determining the SCM using the HB algorithm. Based on the analyzation of simulation results, the SC technique is suffered from performance loss not more than 3% comparative to the perfect SCM. Guangxu Zhu et al., (2016) [28] has focused on developing innovative systematic design of hybrid analog beamformer through the Kronecker decomposition. The limitation of hybrid beamforming hardware is conquered and the complexity reduction is achieved by the proposed channel estimation scheme with customized design that involves the channel sparsity property.

Wendi Wang et al., (2018) [29] has investigated the effect of imperfect phase shifter on the mm-Wave systems performance and derived the loss of efficiency with closed-form expression in multi-stream point-to-point case. Due to the existence of gain error and phase-shifting error, the performance degradation indicates the severe results based on the analysis of simulation results.

Danilo De Donno et al., (2021) [30] has proposed a practical codebook design for mm-Wave systems. By comparing with 2-bit RF phase shifters and the number of antenna elements, the lower number of RF chains are included in the hybrid analog-digital architecture. The hybrid beamformer shows the results that the beam patterns shape are closer to the fully-digital architecture's beams.

Jung-Chieh Chen et al., (2021) [31] has proposed an iterative algorithm to determine the desired discrete phase shifters and to resolve the problem of costly computationally combinatorial involved in the hybrid beamforming. The proposed technique's effectiveness is validated for low-resolution phase shifters and can provide the discrete PSs in a few iterations.

Zihuan Wang et al., (2021) [32] proposes an efficient iterative algorithm for designing the low-resolution analog combiner and precoder pair for each data stream. By using the effective baseband channel, the digital precoder and combiner has computed to improve the spectral efficiency. The proposed algorithm results were verified based on one-bit resolution phase shifters.

P. Raviteja et al., (2017) [33] proposes a joint precoder and decoder design for improving the uplink system's sum rate. Separate precoders and detectors have designed to provide a trade-off between performance and complexity. Based on SCD and AMLD, the beamforming vectors of a receiver and the transmit beamforming vectors are used for detector and precoder designs respectively. The simulation results prove that the low-resolution phase shifters with both joint and separate designs outperformed than the conventional methods with high resolution PSs.

Table 1: Summary of Literature review

Paper	**MIMO System and RF chain**	**Hybrid Beamform Methodology**	**Phase Shifters & RF chains**	**Application Area**	**Channel Type**	**Effects on Performance Metric**
Didi Zhang, 2017	$N_t \times N_r = 128 \times 32$, $N_s = DS = 8$	Hybridly-connected structure.	RF chains equipped at each sub-array for an *N*t ×*N*r = 128 ×32	Millimeter wave massive MIMO systems	Gaussian distribution	The maximum achievablerate optimization problem wasdecomposed into a series ofsub-rate optimization problemsfor each stream.
Jung-Chieh 2017	N_r and $N_t =$ 36 and 144	Iterative hybrid transceiver design algorithm	$N_{tRF} = N_{rRF} = Ns = 3$	Hybrid precoding for millimeter wave MIMO	Saleh-Valenzuela channel	This algorithm finds thedesired discrete PSs tomaximize the spectralefficiency totackle this problem
Jung-Chieh Chen 2017		Exhaustive search algorithm (ESA)	MRF = NRF = D = 2	mmWave communication	Narrowband block-fading massive MIMO channel	Designing an analogbeamforming component of ahybrid beamforming system,examining codebook-basedanalog beamforming (includingtransm

						ission precoding andreceiver combining).
Farhan Khalid 2018	NT = 128, NR = 16, MR = NS = L = 2, MT = KNS	Hybrid regularized channel diagonalization (HRCD)		Millimeter wave massive MIMO systems	mm-wave channels	HRCDprovides exceptionalperformance even when lowresolutionRF phase shifters areemployed, thus making it ahighlydesirable solution from the practical perspective
Jiang Jing 2016	Ns=2 and Nt=64	Energy-efficiency based multi-user hybrid beamforming for downlink millimeter wave (mmWave) massive MIMO systems.	$Ns \leq Nrf \leq Nt$	Simple time division duplex (TDD)	Geometric channel model	The analog beamforming isdesigned to select the optimal beam on SLNR criterion. The digital beamformingcan improve the system Performance through flexiblebaseband processing.
Mandar N. Kulkarni 2016	$\eta L = \eta N = 1, N_{BS} = N_{UE} = 64$	Hybrid beamforming enabled multi-user (MU) MIMO and single-user spatial multiplexing (SM) with single-user analog beamforming (SU-BF)	N_{BS} = 64 and $N_{RF} = U_M$ = 2	Massive MIMO	Rayleigh fading channel.	Beneficial to get tighter bounds on the laplace functional of the out-of-cell interference. The analytical model can also be extendedtoincorporate more realistic cross-polarized uniform planar arrays instead of ULA.
Zheda Li 2018	l_{BS} = 12 and l_{UE}= 1; 2; 4,	Hybrid digital/analog (HDA) beamforming structures	UE antennas and RF chains = N = 16, a_{UE} = 1, 2, 4 Number of BS antennas and RF chains=m=64, b=16	Massive MIMO systems	Kronecker channel model.	The functionality ofmultiple RF chains at the UE is explored.

Sung Joon Maeng, 2018		Four different digital precoding techniques (Type-1, Type-2, Type-3, and Type-4)is used to reduce IBI in mm-wave cellular systems with a hybrid beamformer		Millimeter wave massive MIMO systems		Reduce the IBI received from neighboring cells as well as adjacent beams in the serving cell
Nima N 2018	$N_{RF} = 5, N_s = 1$, $N_t = 16$	Nonlinear Power Amplification method	$N_{RF} = 5, N_s = 1$	Millimeter wave massive MIMO systems	Cluster channel model	The spectral and energy efficiency of hybrid beamforming for mmWave systems employing nonlinear PAs
Foad Sohrabi 2017	64x32 OFDM-based SU-MIMO system $N_c = 5$, $N_{sc} = 10$, $N_s = N_{RF} = 4$, K=32	Hybrid beamforming design for OFDM-based systems with large-scale antenna arrays	$N_c = 5$, $N_{sc} = 10$, $N_s = N_{RF} = 4$	Millimeter wave massive MIMO systems	mmWave channel model	The hybrid beamforming architecture is an appropriate scheme for broadband mmWave systems with frequency selective channels.
Xiaoyong Wu 2018	$N_s = 2, M_{MS} = 2, M_{BS}$	Novel HBF design with the least number of RF Chains for massive MIMO system	RF chains is constrained by $KN_S \leq M_{BS} \ll N_{BS}$		Genericchannelmodel, flatfadingchannel	Massive MIMOsystem withclosed-formsolutions havebeen proposed fordouble the leastnumber ofRFchains and theleast number ofRF chains.
Binqi Yang 2018		DBF-based massive MIMO transceiver for 5G millimeter-wave communications		Millimeter-wave array	Frequency-selective channel FDD	The measured results show that great RF performances have been achieved by the proposed millimeter-wave transceiver.

Dengkui Zhu, 2016	M = 256, and this Mh × Mv antenna array is placed as 16 × 16 for UPA and 256 × 1 for ULA	Hybrid beamforming (HB)HB algorithm with unified AB based on the spatial covariance matrix (SCM)	M = 256 RF chains	TDD and FDD massive	Geometrically based statistical channel	The sufficient number of RF chains is derived for the proposed HB to achieve the performance closeto complete digital beamforming without a reduced number of RF chains.
Guangxu Zhu 2017	N = 128, K = 1, M = 2 and L = 2.	Systematic design framework for hybrid beamforming for multi-cell multiuser massive MIMO systems	RF chains $N_{RF} = K = 4$	mmWave massive MIMO		Design of the analog beamformer based on Kronecker decomposition, which enforces the uni-modulus constraints on the analog beamforming coefficients and allows the inter-cell interference to be cancelled in analog domain

III. TECHNOLOGIES IN LARGE SCALE ANTENNA

MIMO, or Multiple Input Multiple Output (Multiple Input Multiple Output), is a method of using multiple antennas at the transmitting and receiving ends to obtain diversity gain and boost frequency. Techniques for spectrum utilization. The wireless transmission technology based on massive MIMO can make deep use of wireless resources in the space dimension, thereby significantly improving the spectrum efficiency and power of the system. Rate efficiency also has the advantages of increasing channel capacity and improving system performance [34].

A. *Single user MIMO*

Most high-frequency terminals are two transmitters and two receivers antennas (one *H* polarization and one *V* polarization are used in pairs). The transmitting antenna on the base station side can be two rounds, four shots or eight shots are also used in pairs with *H* polarization and *V* polarization. Therefore, for a single terminal, the uplink and downlink services are generally one stream or two streams. In the Line of Sight (LOS) path scenario, a group of *HV* antennas will naturally support two streams if the isolation is good enough. But in some Non-LOS (NLOS) scenes, especially due to reflection the polarization rotation of *H* and *V* will result in a group of *HV*antennas that can only support one stream. If the UE can support multiple panels, four transmissions and four receptions, and in some scenarios, LOS and NLOS paths exist at the same time, then a single UE can achieve up to four upstream and downstream flows [35]. The block diagram of SU-MIMO is depicted in figure 3.

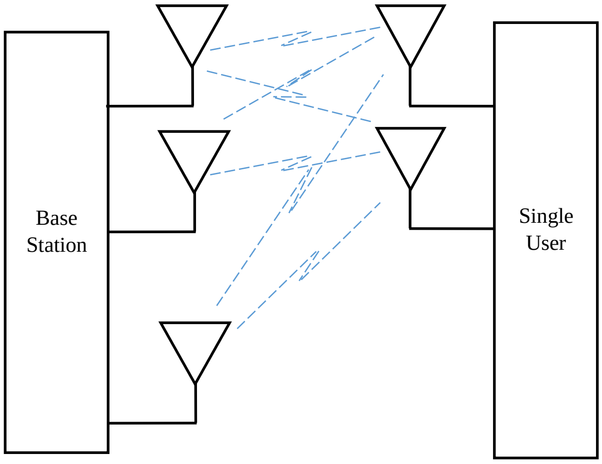

Figure 3: block diagram of single user MIMO

B. Multi User MIMO

High-frequency multi-user MIMO can be based on analog space division, or it can be two modes of space division with mixed analog and digital. When the number of analog channels is relatively large, the analog beam is relatively narrow, so the analog beam and the analog beam are naturally isolated in space. Mostly use the isolation to measure the analog beams.The distance in space, when the energy projection of one beam on another beam is very small, the interference of this beam to the other beam is very high. If it is small, better isolation will get. Conversely, if the energy projected by one beam in the direction of the other beam is relatively large, this beam has an impact on the other beam. The interference of the beam is large, and the isolation is not good.

The narrower the beam design, the better the isolation between each other, and the more suitable for analog space division. However, the narrow beam design is not conducive to beam tracking in mobile scenes. For scenarios where the beam width is very wide and the beams overlap each other a lot, relying solely on the strategy of simulating space division cannot meet the requirements of multi-user MIMO. It is required that the interference between streams is relatively large, which is the space division mode that needs to consider the analog-digital mixing [36]. The schematic block diagram of MU-MIMO is shown figure 4.

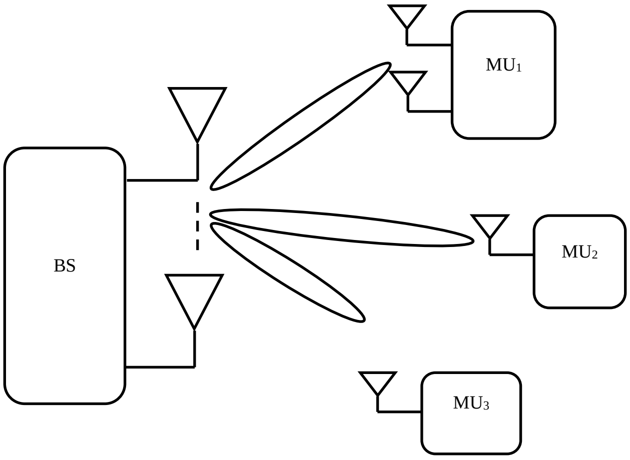

Figure 4: Block diagram of multi user MIMO

Multi-user MIMO mode based on mixed analog and digital, when the interference between the paired UE beams is relatively large, it is necessary to consider the mixed multi-user MIMO strategy. The base station obtains the channel of the paired UE through the measurement of the Sound Reference Signal (SRS)channel, and then uses the interference cancellation algorithm to calculate the downlink Beam Forming (BF) weight, the paired UE multiplies the calculated BF weight when sending downlink data, so as to achieve better results through digital weights and analog beams the effect of air separation.

2. Hybrid Beamforming

Beamforming is a signal pre-processing technology based on antenna arrays. The base station uses Channel State Information (CSI) feedback from the UE or measures the uplink signal (TDD system), adjust the weighting coefficient of each element in the antenna array to generate a directional beam, so as to obtain a significant array gain. Therefore, beamforming technology has great advantages in expanding coverage, improving edge throughput, and interference suppression. In order to improve cell edge usage user throughput and coverage performance require the base station side to support the beamforming function of the antenna array.

In NR high frequency, consider a limited number of digital channel MIMO technology solutions to reduce energy consumption and reduce equipment costs, that is, through digital domain and analog domain performs joint beamforming, that is, Hybrid Beamforming (HBF). As shown in the figure 5, the transmitter (or receiver) consists of multiple sub-arrays to form an antenna array, each of the sub-arrays can independently use the RF phase shifter to control the beam. In the analog domain, a low-cost phase shifter is used to achieve a single transmission of high-frequency signals. Broadcast direction beamforming. In the digital domain, by using a baseband processor, joint beamforming in multiple propagation directions is realized [37].

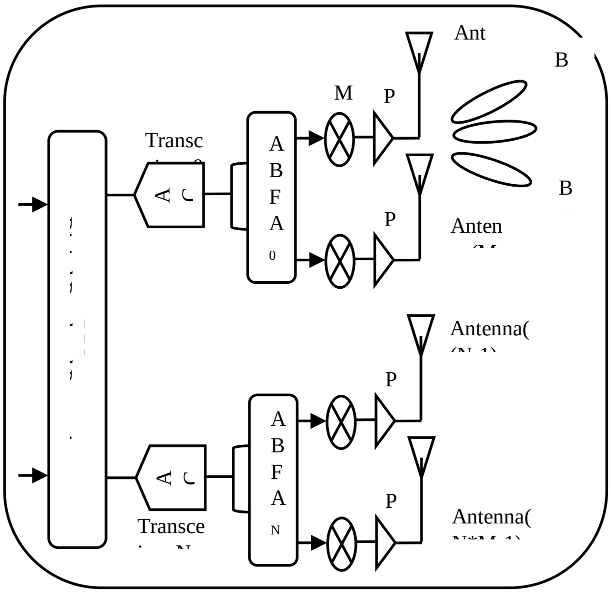

Figure 5: Block diagram of Hybrid Beamforming

A. Beam management

Beam management includes functions such as beam scanning, beam tracking, beam blocking, and beam recovery. The purpose of beam management is to improve the base station and UE signal transmission gain reduces interference, thereby increasing the data transmission rate of the system and enhancing coverage.

B. Beam scheme

The characteristics of the millimeter wave frequency band, such as large attenuation and short propagation distance, will have a negative impact on coverage and capacity. Generally, it is compensated by simulating beamforming gain attenuation, while designing corresponding analog beams for different channels.

C. Beam scanning and tracking

In order to ensure sufficient signal gain in the end, the beam generated by a large-scale antenna array usually needs to be very narrow, and the base station needs to use a large number of narrow beams.The beam can ensure that users in any direction in the cell can be effectively covered. In this case, traverse and scan all narrow beams to find the best transmission beam strategy appears to be time-consuming and laborious, which is not in line with the user experience expected by 5G.In order to quickly align the beam, the 5G standard adopts a hierarchical scanning strategy, that is, scanning from wide to narrow. Hierarchical scanning can be randomly selected according to the needs of each user the best beam is constantly switched, and the best beam will change with the location of the user. At the same time, in order to better track users, to use beam tracking strategy.

D. Beam recovery

In the high-frequency system, both the base station and the terminal use directional antennas. When the beam directions of the two match each other, the traffic channel can obtain a relatively high increase.Benefit, the throughput of data transmission is also relatively high. However, when the beam directions of the base station and the terminal do not match, the gain obtained by the traffic channel is very small. There may even be a radio link failure (RLF) situation.The high frequency is determined by the channel and propagation characteristics. In a mobile NLOS scenario, the transmission path of the channel may change very quickly, due to the possibility of occlusion.It will cause the rapid birth and death of the path, so it may cause the beam tracking to fail. In order to quickly restore the link and avoid the flow of the channel, you can start the beam fast recovery process.

3. Antenna Architecture in HBF in millimeter wave

The application of millimeter wave antenna technology to 5G mobile communications has both disadvantages and advantages. Because of the ultra-short wavelength, the signal propagation distance is strictly limited, which causes signal dead zone and weak zone. On the contrary, the ultra-short wavelength can make the millimeter wave naturally have the advantages of integrating radio frequency components and realizing compact packaging. The antenna is concentrated in a very small area, which facilitates the use of high-directivity beamforming technology to compensate for the attenuation loss in millimeter wavelength distance propagation. At the same time new technology, introduction of the concept also enriches the form of electronically controlled beam scanning.

The array antenna is currently the best solution. There are two architectures for the array antenna:

1. A fully digital beamforming (BF) massive MIMO system can produce optimal performance. But hardware complexity and cost (number of RF channels), and the complexity and energy consumption of signal processing are increasing rapidly.
2. Analog beamforming is economically more popular than digital beamforming, but the performance is not up to the effect of digital beamforming performance, nor can it be achieved better MIMO performance.

Therefore, mixed analog-digital beamforming is used in NR high frequency. As shown in the figure below, the transmitter (or receiver) consists of multiple sub-arrays to form an antenna array, where each sub-array, the column can independently use the RF phase shifter to control the beam. In the analog domain, a low-cost phase shifter is used to achieve beamforming of a single panel of high-frequency signals; in the digital domain, by using the baseband processor, joint beam forming in multiple panel directions is realized.

A significant feature of millimeter wave signals is that the attenuation in the air is large, and the diffraction energy the power is weak, so the millimeter wave antenna needs to have a narrow beam with high gain to offset propagation loss and interference suppression. At the same time, using the space division of the multi-beam antenna. Multiple access technology is serving multiple users on the same time-frequency resource due to this, total spectrum efficiency and the spectrum efficiency of edge users have been greatly improved.This kind of high-gain, multi-diversity millimeter wave multi-beam antenna is a common implementation method [38]. The formulas are: phased array antenna and lens antenna, below we briefly introduce these two multi-beam antennas.

A. Phased array antenna

A phased array antenna is an array antenna with a controllable radiation beam. It is mainly composed of an antenna array, a feeder network and a beam forming controller, etc., through the phase shift network adjusts the excitation amplitude and phase of the array element to change the direction of the radiation beam, and can flexibly control the number and shape of the beam to achieve fast scanning and track. Millimeter phased array antenna units are most widely used in microstrip, waveguide slot, and dielectric resonator structures [39].

B. Lens antenna

Although the phased array antenna has the advantages of high gain, fast scanning speed, and flexible control, its beam coverage is limited and the beam difference is large. The working frequency band is narrow, the loss is large, and the phase shift network is complex and expensive, which limits the application of phased array antennas in some specific scenarios. The line is a good alternative. Lens antennas are a kind of antennas that use geometrical optics principles for analysis and design. It can design lens shapes or dielectric constant distribution is used to correct the phase difference of the antenna aperture surface to obtain excellent radiation performance. The lens antenna has low-cost, wide-band, the electrical network has the advantages of simple, and each beam has a full-aperture gain, and can achieve a wide range of beam scanning. The disadvantages of complex lens antenna design, large size, and heavy weight have gradually been overcome. It will definitely be used in 5G high-frequency antennas [40].

4. Measurement performance metrics

In this section the measurement performance metrics for Hybrid beamforming in 5G millimeter wave is discussed.

A. Coverage

The 5G millimeter wave frequency band is high, the propagation loss is high, the diffraction and diffraction ability are weak, and it is greatly affected by the obstacles such as buildings, vegetation, rain and snow, human body or vehicle body, etc.The penetration loss from outdoor to indoor is relatively large and coverage is relatively limited. This is the biggest challenge faced by 5G millimeter wave communication systems.

According to the propagation characteristics of millimeter waves, millimeter waves are suitable for basic LOS scenes (such as outdoor or indoor LOS, outdoor rich reflection scenes) and similar LOS low penetration scenarios (such as outdoor vegetation penetration and indoor glass penetration) are difficult to cover scenes such as outdoor building blocking and indoor high penetration loss.

The path loss in the millimeter wave propagation process is relatively large, and the free space loss is positively correlated with the carrier frequency. Under the same path loss model, the millimeter wave is 26 GHz. The path loss of the carrier is about 17.42dB higher than that of the 3.5 GHz carrier, and the theoretical propagation distance is only about one-sixth of the 3.5 GHz. High frequency is relative to low frequency, the reflection and diffraction loss of buildings are greater. For example, the reflection loss of concrete is about 10dB, and the diffraction loss is usually greater than 18dB. High frequency outdoor environment, the impact of vegetation such as trees is also very obvious, and the impact of weather (especially heavy rain scenes) is also greater. High frequency penetration from outdoor to indoor, the ability is even worse, it can penetrate for single glass, wood, ice and snow and other materials, for concrete materials and indoor multi-layer walls, etc., in extreme cases 26 the penetration loss of GHz is close to 100dB higher than that of 3.5 GHz. High-frequency signals are greatly affected by human body occlusion. If there are too many the personal body is blocked, and the signal attenuation is very obvious.

Table 2: Comparison of penetration loss (dB) of different materials between 3.5 GHz and 26 GHz

	Ordinary multi-layer glass	IRR glass	Coagulation+_	wood	Tree decline (tree depth 2 meters)	Rain fading (heavy rain 10mm/hr)	Snow	Ice	Human body loss
3.5G	2.7	24.05	19	5.27	7.67	0.00	0	0	3
26G	7.2	30.8	109	7.27	16.46	1.57	4	2	9-13

In addition to the above-mentioned propagation characteristics, the actual coverage of millimeter waves is also affected. The influence of system configuration parameters. Under normal circumstances, millimeter waves can be reduced by Sub Carrier Spacing (SCS), increase uplink or downlink resources, increase the number of transceiver antennas, increase antennas gain, increase transmit power, optimize Resource Block (RB) allocation and other means to expand coverage.For millimeter wave single-site coverage, the overall coverage depends on the uplink and downlink control the comprehensive coverage effect of the channel and the uplink and downlink traffic channels.

B. Peak rate

The 5G millimeter wave technology has abundant frequency resources, large bandwidth, and extremely high peak rate. This is one of the biggest advantages of 5G millimeter wave systems. Based on 3GPP TS 38.306, the peak rate calculation method is as follows:

$$(Mbps) = 10^{-6}\sum_{j=1}^{J}\left(V_{layaers}^{(j)}.Q_m^{(j)}.F^{(j)}.R_{max}.\frac{N_{PRB}^{BW(j),\mu}.12}{T_s^{\mu}}.\left(1-OH^{(j)}\right)\right) \quad (1)$$

Among them, peak rate and carrier number J, order μ, The number of spatial reuse layers $V_{layers}^{(j)}$, modulation order $Q_m^{(j)}$ scale factor $F^{(j)}$, Maximum channel coding Bit rate R_{max}, The total number of PRBs included in the evaluation bandwidth $N_{PRB}^{BW(j),\mu}$positively correlated, And OFDM symbol duration T_s^{μ} And system overhead $OH^{(j)}$ Present Negative correlation. The peak rate of 5G millimeter waves can be improved in terms of increasing available resources and reducing overhead. At the same time, the millimeter wave frequency band is multiplexed by TDD, different TDD frame structure configurations correspond to different proportions of uplink and downlink resources, which directly affect the uplink and downlink peak rates.

C. Capacity

The 5G millimeter wave has a large capacity, which is another major advantage of 5G millimeter wave over Sub-6G.High-frequency capacity performance is mainly reflected in two aspects: the number of users and the average cell throughput. Among them, the number of users can be connected through RRC, the number of users, CAPS and the number of users per scheduling period are characterized, and the cell throughput rate can be characterized by the average throughput rate and the edge throughput rate.

The cell throughput rate of high frequency in multi-cell and multi-user scenarios is mainly affected by the networking environment and system capabilities. Among them, the networking environment includes scenarios, propagation characteristics, and user distribution. System capabilities include bandwidth capabilities, MIMO capabilities, and multi-user scheduling. The networking environment the impact of the throughput rate is very obvious. The cell throughput requirements of indoor or outdoor hotspot scenes are significantly higher than those of rural scenes. The throughput rate is significantly higher than that of the NLOS environment, and the higher the proportion of users with well-distributed and mid-point users, the higher the cell throughput rate. System capacity to cell throughput the improvement of the rate is particularly critical, increasing the system bandwidth, optimizing MU-MIMO pairing and increasing the proportion of MU-MIMO, and optimizing multi-user scheduling algorithms (such as EPF-enhanced proportional fairness algorithm) and improve resource allocation efficiency, thereby further improving cell throughput.

D. Time delay

5G millimeter wave technology, relative to Sub-6G air interface delay display it can reduce the time delay of 5G air interface less than 1ms. Extension requirements, applicable to scenarios such as 5G Industrial Internet of Things, AR/VR, etc.Generally, the shorter the time slot length of the air interface in the 5G network, the delay of the physical layer is smaller. 5G millimeter wave system air interface time slot length the minimum degree can be as low as 0.125 milliseconds, which corresponds to 5G mid- and low-frequency 1/4 of the system. The time slot length corresponding to different frequency bands is reported in table 3.

Table 3: Time slot length corresponding to different frequency bands

Frequency band	Subcarrier spacing	Time slot length
1 GHz	15/30kHz	1/0.5ms
1 GHz ~ 6 GHz	15/30/60kHz	1/0.5/0.25ms
24.25 ~ 52.6 GHz	60/120kHz	0.25/0.125ms

IV. CONCLUSION

The rich spectrum resources of the millimeter wave system make it one of the potential key technologies of 5G mobile cellular networks. Due to huge propagation path loss in millimeter wave, it needs to apply beamforming technology to improve the quality of the transmission link. Considering the hardware limitations of millimeter wave systems, large-scale antennas and channel sparse characteristics, hybrid beamforming has become one of the main technologies of 5G millimeter wave communication systems. This article discuss the technology developments of millimeter wave hybrid beamforming in 5G communication system. The advantages of digital beamforming and analog beamforming, the key technologies of hybrid beamforming are discussed. As an emerging technology of millimeter wave MIMO systems, hybrid beamforming still has many open research topics: hybrid beamforming of multi-user millimeter wave MIMO systems, channel estimation and receiver design, etc. Current researches on millimeter wave hybrid beamforming are based on the assumption of narrowband channel model. The statistical model of broadband millimeter wave channel is different from narrowband. Therefore, millimeter wave beamforming technology under wideband channel model is the focus of future research. Based on hybrid beamforming, it can overcome RF hardware limitations, achieve a compromise between system performance and hardware cost, and support the advantages of multi-stream transmission. This design of hybrid beamforming with low resolution phase shifters will provide better efficiency. Therefore, the communication transceiver using this structure can be widely used in the future of various medium and large-scale communication systems.

V. REFERENCES

[1] Rupendra NathMitra and Dharma P.Agrawal, "5G mobile technology: A survey" ICT ExpressVolume 1, Issue 3, December 2015, Pages 132-137.

[2] Dai Kimura, Hiroyuki Seki, Tokuro Kubo and Tomohiko Taniguchi, "Wireless network technologies toward 5G" APSIPA Transactions on Signal and Information Processing , Volume 4 , 2015 , e12.

[3] GSMA, 2016. 5G Spectrum Public Policy Position. Available online at https://www.gsma.com/spectrum/wp-content/uploads/2016/06/GSMA-5G-Spectrum-PPP.pdf

[4] T.S. Rappaport et al., "Overview of Millimeter Wave Communications for Fifth-Generation (5G) Wireless Networks - With a Focus on Propagation Models", IEEE Trans. Antennas and Propagation, vol. 65, no. 12, pp. 6213-30, Dec. 2017.

[5] M. Rumney, K. Technologies, P. Kyosti and L. Hentila., "3GPP Channel Model Developments for 5G NR Requirements and Testing" 12thEuropean Conference on Antennas and Propagation (EuCAP 2018)-IET, 2018 page (5 pp.)

[6] Michael J. Marcus et al., "WRC-19 Issues: A Survey" IEEE Wireless Communications, Volume: 24, Issue: 1, February 2017. Page(s): 2 - 3.

[7] GSA, 2018 "LTE and 5G market statistics – end of year update". Available online at https://gsacom.com/paper/lte-5g-market-statistics-2018

[8] GSMA, 2018 "Road to 5G: Introduction and Migration" Available online at https://www.gsma.com/futurenetworks/wp-content/uploads/2018/04/Road-to-5G-Introduction-and-Migration_FINAL.pdf

[9] "Multiplexing and channel coding (release 15) for radio access network", 3GPP Tech. Rep., 2018.

[10] 3gpp, "a new logo for 5g specifications," [online]. available:. http://www.3gpp.org/news-events/3gpp-news/1825-5g-logo_news.

[11] 3gpp release 16 and 17, Available online at: https://www.5gamericas.org/wp-content/uploads/2020/01/5G-Evolution-3GPP-R16-R17-FINAL.pdf

[12] Francisco J. Martin-Vega et al., "Key Technologies, Modeling Approaches, and Challenges for Millimeter-Wave Vehicular Communications", IEEE Communications Magazine, Volume: 56, Issue: 10, OCTOBER 2018, Page(s): 28 – 35.

[13] Fatimah Al-Ogaili and Raed M. Shubair, "Millimeter-wave mobile communications for 5G: Challenges and opportunities", 016 IEEE International Symposium on Antennas and Propagation (APSURSI), 26 June-1 July 2016

[14] D. Zhang, Y. Wang, X. Li and W. Xiang, "Hybridly Connected Structure for Hybrid Beamforming in mmWave Massive MIMO Systems," in IEEE Transactions on Communications, vol. 66, no. 2, pp. 662-674, Feb. 2018, doi: 10.1109/TCOMM.2017.2756882.

[15] Cardona, N., Correia, L.M. & Calabuig, D. Key Enabling Technologies for 5G: Millimeter-Wave and Massive MIMO. Int J Wireless Inf Networks 24, 201–203 (2017).

[16] J. Chen, "Hybrid Beamforming With Discrete Phase Shifters for Millimeter-Wave Massive MIMO Systems," in IEEE Transactions on Vehicular Technology, vol. 66, no. 8, pp. 7604-7608, Aug. 2017, doi: 10.1109/TVT.2017.2670638.

[17] J. Chen, "Efficient Codebook-Based Beamforming Algorithm for Millimeter-Wave Massive MIMO Systems," in IEEE Transactions on Vehicular Technology, vol. 66, no. 9, pp. 7809-7817, Sept. 2017, doi: 10.1109/TVT.2017.2677957.

[18] F. Khalid, "Hybrid Beamforming for Millimeter Wave Massive Multiuser MIMO Systems Using Regularized Channel Diagonalization," in IEEE Wireless Communications Letters, vol. 8, no. 3, pp. 705-708, June 2019, doi: 10.1109/LWC.2018.2886882.

[19] Jiang Jing, Cheng Xiaoxue, Xie Yongbin, "Energy-efficiency based downlink multi-user hybrid beamforming for millimeter wave massive MIMO system", The Journal of China Universities of Posts and Telecommunications, Volume 23, Issue 4, 2016, Pages 53-62.

[20] M. N. Kulkarni, A. Ghosh and J. G. Andrews, "A Comparison of MIMO Techniques in Downlink Millimeter Wave Cellular Networks With Hybrid Beamforming," in IEEE Transactions on Communications, vol. 64, no. 5, pp. 1952-1967, May 2016, doi: 10.1109/TCOMM.2016.2542825.

[21] Z. Li, S. Han, S. Sangodoyin, R. Wang and A. F. Molisch, "Joint Optimization of Hybrid Beamforming for Multi-User Massive MIMO Downlink," in IEEE Transactions on Wireless Communications, vol. 17, no. 6, pp. 3600-3614, June 2018, doi: 10.1109/TWC.2018.2808523.

[22] Maeng, Sung J., Su H. Park, and Yong S. Cho 2018. "Hybrid Beamforming for Reduction of Inter-Beam Interference in Millimeter-Wave Cellular Systems" Sensors 18, no. 2: 528.

[23] N. N. Moghadam, G. Fodor, M. Bengtsson and D. J. Love, "On the Energy Efficiency of MIMO Hybrid Beamforming for Millimeter-Wave Systems With Nonlinear Power Amplifiers," in IEEE Transactions on Wireless Communications, vol. 17, no. 11, pp. 7208-7221, Nov. 2018, doi: 10.1109/TWC.2018.2865786.

[24] F. Sohrabi and W. Yu, "Hybrid Analog and Digital Beamforming for mmWave OFDM Large-Scale Antenna Arrays," in IEEE Journal on Selected Areas in Communications, vol. 35, no. 7, pp. 1432-1443, July 2017, doi: 10.1109/JSAC.2017.2698958.

[25] X. Wu, D. Liu and F. Yin, "Hybrid Beamforming for Multi-User Massive MIMO Systems," in IEEE Transactions on Communications, vol. 66, no. 9, pp. 3879-3891, Sept. 2018, doi: 10.1109/TCOMM.2018.2829511.

[26] B. Yang, Z. Yu, J. Lan, R. Zhang, J. Zhou and W. Hong, "Digital Beamforming-Based Massive MIMO Transceiver for 5G Millimeter-Wave Communications," in IEEE Transactions on Microwave Theory and Techniques, vol. 66, no. 7, pp. 3403-3418, July 2018, doi: 10.1109/TMTT.2018.2829702.

[27] D. Zhu, B. Li and P. Liang, "A Novel Hybrid Beamforming Algorithm With Unified Analog Beamforming by Subspace Construction Based on Partial CSI for Massive MIMO-OFDM Systems," in IEEE Transactions on Communications, vol. 65, no. 2, pp. 594-607, Feb. 2017, doi: 10.1109/TCOMM.2016.2625794.

[28] G. Zhu, K. Huang, V. K. N. Lau, B. Xia, X. Li and S. Zhang, "Hybrid Beamforming via the Kronecker Decomposition for the Millimeter-Wave Massive MIMO Systems," in IEEE Journal on Selected Areas in Communications, vol. 35, no. 9, pp. 2097-2114, Sept. 2017, doi: 10.1109/JSAC.2017.2720099.

[29] W. Wang, H. Yin, X. Chen and W. Wang, "Performance Loss of Hybrid Beamforming with Imperfect Phase Shifters in Millimeter Wave Systems," 2018 IEEE 88th Vehicular Technology Conference (VTC-Fall), 2018, pp. 1-5, doi: 10.1109/VTCFall.2018.8690614.

[30] D. De Donno, J. P. Beltrán, D. Giustiniano and J. Widmer, "Hybrid analog-digital beam training for mmWave systems with low-resolution RF phase shifters," 2016 IEEE International Conference on Communications Workshops (ICC), 2016, pp. 700-705, doi: 10.1109/ICCW.2016.7503869.

[31] J. Chen, "Hybrid Beamforming With Discrete Phase Shifters for Millimeter-Wave Massive MIMO Systems," in IEEE Transactions on Vehicular Technology, vol. 66, no. 8, pp. 7604-7608, Aug. 2017, doi: 10.1109/TVT.2017.2670638.

[32] Z. Wang, M. Li, Q. Liu and A. L. Swindlehurst, "Hybrid Precoder and Combiner Design With Low-Resolution Phase Shifters in mmWave MIMO Systems," in IEEE Journal of Selected Topics in Signal Processing, vol. 12, no. 2, pp. 256-269, May 2018, doi: 10.1109/JSTSP.2018.2819129.

[33] P. Raviteja, Y. Hong and E. Viterbo, "Millimeter Wave Analog Beamforming With Low Resolution Phase Shifters for Multiuser Uplink," in IEEE Transactions on Vehicular Technology, vol. 67, no. 4, pp. 3205-3215, April 2018, doi: 10.1109/TVT.2017.2779407.

[34] S. Han, C. I, Z. Xu and C. Rowell, "Large-scale antenna systems with hybrid analog and digital beamforming for millimeter wave 5G," in IEEE Communications Magazine, vol. 53, no. 1, pp. 186-194, January 2015, doi: 10.1109/MCOM.2015.7010533.

[35] F. W. Vook, A. Ghosh and T. A. Thomas, "MIMO and beamforming solutions for 5G technology," 2014 IEEE MTT-S International Microwave Symposium (IMS2014), 2014, pp. 1-4, doi: 10.1109/MWSYM.2014.6848613.

[36] Z. Gao, L. Dai, D. Mi, Z. Wang, M. A. Imran and M. Z. Shakir, "MmWave massive-MIMO-based wireless backhaul for the 5G ultra-dense network," in IEEE Wireless Communications, vol. 22, no. 5, pp. 13-21, October 2015, doi: 10.1109/MWC.2015.7306533.

[37] I. Ahmed et al., "A Survey on Hybrid Beamforming Techniques in 5G: Architecture and System Model Perspectives," in IEEE Communications Surveys & Tutorials, vol. 20, no. 4, pp. 3060-3097, Fourthquarter 2018, doi: 10.1109/COMST.2018.2843719.

[38] F. Sohrabi and W. Yu, "Hybrid Digital and Analog Beamforming Design for Large-Scale Antenna Arrays," in IEEE Journal of Selected Topics in Signal Processing, vol. 10, no. 3, pp. 501-513, April 2016, doi: 10.1109/JSTSP.2016.2520912.

[39] J. Kim, J. Han, J. Park and J. Kim, "Design of phased array antenna for 5G mm-wave beamforming system," 2016 IEEE 5th Asia-Pacific Conference on Antennas and Propagation (APCAP), 2016, pp. 201-202, doi: 10.1109/APCAP.2016.7843168.

[40] Y. J. Cho, G. Suk, B. Kim, D. K. Kim and C. Chae, "RF Lens-Embedded Antenna Array for mmWave MIMO: Design and Performance," in IEEE Communications Magazine, vol. 56, no. 7, pp. 42-48, July 2018, doi: 10.1109/MCOM.2018.1701019.