International Journal For Recent Developments in Science & Technology
2581-4575
Crossref
A Peer Reviewed Research Journal

Sparse Hybrid Precoding and Combining in Milllimeter Wave MIMO Systems

Aditya Ratnakar Darbha
GMR Institute Of Technology Rajam, Andhra Pradesh
India 532127
20341A0402@gmrit.edu.in

ABSTRACT

Millimeter wave (mmWave) communication enables us to leverage a new frequency range between 30 GHz and 300 GHz in order to fulfil the growing capacity requirements for fifth generation (5G) wireless communication systems. Multiple-input multiple-output (MIMO) antennas can be used to get over the increased route loss and attenuation that mmWave frequencies have compared to microwave frequencies. Beamforming, also known as precoding at the transmitter in traditional microwave frequency MIMO systems, is done digitally. However, because to the higher cost and power consumption of system components at mmWave frequencies, the system is unable to construct one radio frequency (RF) chain per antenna. Hybrid precoders are replacing the transceiver in practical and power-efficient ways by achieving spatial multiplexing with fewer RF chains than antenna

INTRODUCTION

There are growing demands for bandwidth and capacity as a result of the development of communication systems and the emergence of powerful consumer gadgets. There is a global need for more spectrum and higher capacity because the available carrier frequency spectrum is only available in the extremely congested band between 700 MHz and 2.6 GHz. In this situation, millimetre wave (mmWave) technology seems to hold promise for upcoming wireless communication systems. As a result of its increased bandwidth channels, MmWave supports significantly better internet-based access and greater connectivity. MmWave technology is already a very important technology for wireless backhaul, and cellular systems may be able to self-backhaul. Multiple-input multiple-output (MIMO) systems work very well with mmWave technology since the size of the antenna arrays and related electronics will

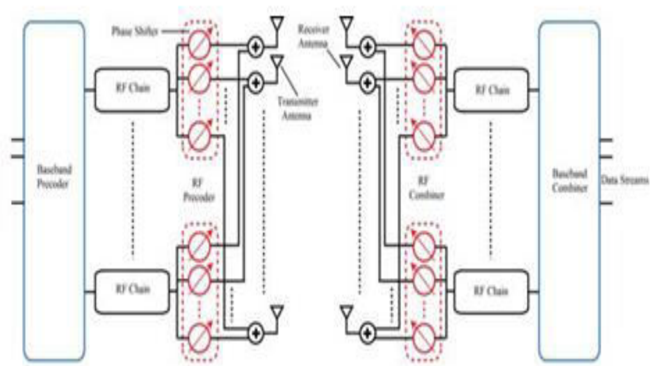


Fig. 1.1 Hardware block diagram of mmWave single-user fully-connected hybrid beamforming system.

Precoding, which can be expanded to accommodate multi-stream (or multi-layer) transmission, is commonly used to refer to beamforming at the transmitter. Techniques for

International Journal For Recent Developments in Science & Technology
2581-4575
Crossref
A Peer Reviewed Research Journal

merging signals can be applied at the receiver end. The digital precoder can fix analogue issues including eliminating lingering multi-stream interference. A low-complexity optimization issue solution that can be implemented at both the transmitting and receiving ends is called orthogonal matching pursuit (OMP). Another method similar to OMP is called gradient pursuit (GP), which offers the same performance as OMP while being a quick and inexpensive approximation method. In this study, GP is used to plot the spectrum efficiency and energy efficiency features while we compare the performances of the two approaches.

Analog beamforming, which may be applied both at the transmitter and the receiver, is one of the easiest methods for implementing MIMO in mmWave systems. This method frequently involves connecting antenna elements to a single RF chain through phase shifters, which only supports single stream transmission and does not offer gains for spatial multiplexing. Instead, hybrid beamforming can be used to support multi-user MIMO communication and spatial multiplexing. A mmWave single-user fully-connected hybrid beamforming system with restricted RF precoding constructed utilizing RF phase shifters is depicted in Fig. 1.1 as having a basic structural layout. A completely connected design results from connecting each RF chain with the same number of phase shifters as antennas.The one and only benefit of hybrid precoding, according to some, is that the digital precoder may remedy analogue restrictions such cancelling residual multi-stream interference in order to perform as well as unrestricted solutions. Although hybrid precoding already sacrifices hardware complexity and power consumption, there is still a lot of room to take advantage of energy and capacity efficient solutions.

The main focus of this study is on the spectrum efficiency and energy efficiency properties of a hybrid precoder, which are useful for analysing throughput and energy fluctuations in relation to system parameters and channel parameters. Plots of the simulation results are shown in relation to the number of RF chains and the signal-to-noise ratio (SNR). Orthogonal matching pursuit (OMP), which is implemented at the transmitter and receiver in the optimization problem's solution, seems to be a simple approach. The Gradient Pursuit (GP) method is presented as a novel approach to the optimization problem that achieves the same performance as OMP while being a quick and inexpensive approximation method.The two algorithmic solutions are compared for performance and runtime, and GP is used to plot the features of spectrum and energy efficiency.

In this essay, the following notations have been used: $A^{(i)}$ denotes the i^{th} column of **A**; **A**, **a**, and a stand for a matrix, a vector, and a scalar, respectively; The transposition and conjugate transposition of A are denoted as A^T and A*, respectively; the Frobenius norm, trace, and determinant of A are represented by $\|A\|_F$, tr(A), and det(A), respectively; the p-norm of an is represented by $\|a\|_p$; [A|B] denotes horizontal concatenation; diag(A) creates a vector using the diagonal elements of A; I_N.A complex variable's expectation and real component are represented by the symbols [.] and R., respectively.

It suggests a fully-connected hybrid precoder concept that results in a mmWave MIMO system with efficient capacity. Consider a sub-connected architecture for an energy-efficient design, where each RF chain is connected to only a portion of transmitter antennas, needing fewer phase shifters than a fully-connected architecture. This low-complexity algorithmic solution and energy-

2581-4575
International Journal For Recent Developments in Science & Technology
Crossref
A Peer Reviewed Research Journal

efficient hybrid precoding design are based on successive interference cancellation (SIC), which offers near-optimal performance.In order to develop a hybrid precoder, it takes into account both fully-connected and partially connected structures. While the latter exhibits higher energy efficiency, the fully integrated structure appears to perform better in terms of capacity. It is suggested in an energy-efficient optimization to employ the ideal number of RF chains to create the hybrid precoder. explains the relationship between spectral efficiency and energy efficiency for various hybrid beamforming system setups in more basic terms.

LITERATURESURVEY

Paper-1

In paper-1, it claims that 5G must offer a high level of flexibility and scalability by design in order to handle a variety of use cases and business models. It should also demonstrate fundamental changes in price and energy usage. Although the commercial rollout of 5G is anticipated to differ from operator to operator, NGMN encourages ecosystem participants to work toward the provision of universal and market-ready solutions by 2020.

Paper-2

In the paper-2,they noted that the investigation of the underutilizedmillimetre wave (mm-wave) frequency spectrum for future broadband cellular communication networks was prompted by the bandwidth shortage experienced by wireless operators worldwide. In this paper, the authors outline the rationale behind new mm-wave cellular systems, methodology, and measurement hardware, as well as a range of measurement findings that demonstrate the viability of using 28 and 38 GHz frequencies with steerable directional antennas at base stations and mobile devices.

Paper-3

In the paper-3, they noted that new tiered network cellular architectures, which would probably employ a lot more cell sites than those available today, have recently attracted a lot of interest. Providing backhaul to all of these cells and developing effective methods to use higher frequency bands for mobile access and backhaul will be two of the biggest problems. This article suggests using outdoor millimetre wave communications for mobile access within a cell and backhaul networking between cells.

METHODOLOGY

Finding a global optimization solution to the joint optimization problem over transmitter and receiver precoders is typically challenging. The design can therefore be divided into two separate optimization issues, one focusing on designing F_{rf}, F_{bb} for the precoder and the other on creating W_{rf}, W_{bb} for the combiner.The mutual information obtained through Gaussian signaling measuring the mutual dependence between the two matrices is given by:

$$I(\mathbf{F}_{rf}, \mathbf{F}_{bb}) = \log_2 \det \left(\mathbf{I} + \frac{\rho}{Ns\sigma n2} \mathbf{H}\mathbf{F}_{rf} \mathbf{F}_{bb}\mathbf{F}^*_{bb}\mathbf{F}^*_{rf}\mathbf{H}^* \right)$$

where, $\mathbf{F}_{rf}$→ RF precoder matrix of size $N_t \times N_t^{rf}$

$\mathbf{F}_{bb}$→ baseband precoder matrix of size $N_t^{rf} \times N_s$

We are very concerned about hardware complexity, spectral efficiency, and energy consumption for baseband processing and analogue processing entities such as analog-to-digital converters (ADCs), digital-to-analog converters (DACs), RF chains, phase shifters, and power amplifiers when designing hybrid

2581-4575
International Journal For Recent Developments in Science & Technology
Crossref
A Peer Reviewed Research Journal

precoders and combiners for mmWave MIMO systems. Utilizing these resources sparingly can help the system run very energy-efficiently. For instance, the energy efficiency would drop as the number of RF chains increased since more energy would be consumed. To build an energy-efficient hybrid beamforming system, measuring the energy efficiency features with regard to the number of RF chains is quite helpful.
The hybrid precoder optimization problem can be written as:

$$(F^{opt}_{rf}, F^{opt}_{bb}) = \max_{F_{rf}, F_{bb}} I(F_{rf}, F_{bb}),$$

$$\text{s.t.} F_{rf} \in \mathcal{F}_{rf},$$

$$\|F_{rf}F_{bb}\|^2_F = N_s,$$

Here, $\mathcal{F}_{rf}$ → the set of $N_t \times N_t^{rf}$ matrices having elements of constant magnitude
It is challenging to produce general solutions to the issue with such a non-convex restriction. Therefore, certain presumptions and approximations can be used to create the nearly ideal hybrid precoder in order to ease the aforementioned issue. The Euclidean distance between $F_{rf}F_{bb}$ and the channel's ideal fully digital precoder F_{opt} can be used to modify Equation (7). In order to be as close to the ideal matrix F_{opt} in the unconstrained space as possible, the hybrid precoder $F_{rf}F_{bb}$ might be placed in a limited space. Therefore, for optimal throughput, the Euclidean distance $\|F_{opt}-F_{rf}F_{bb}\|_F$ should be as minimal as possible. The first Ns columns of VH make up the ideal matrix F_{opt}.We can restrict F_{rf} to be a set of basis vectors at(φ^t_{il}, θ^t_{il}) in order to find the best low dimensional representation of the optimal matrix F_{opt} because the array response vectors at(φ^t_{il}, θ^t_{il}) are constant-magnitude phase-only vectors and F_{rf} denotes the set of N_t N_t^{rf} matrices having elements of constant magnitude.Using these assumptions and approximations, the hybrid optimization problem can be stated as:

$$(F^{opt}_{rf}, F^{opt}_{bb}) = \min \|F_{opt} - F_{rf}F_{bb}\|_F,$$

$$\text{s.t. } F^{(i)}_{rf} \in \{a_t(\phi^t_{il}, \theta^t_{il}), \forall i,l\} \; \|F_{rf}F_{bb}\|^2_F = N_s,$$

where, Euclidean distance is given by

$$d(p,q) = \sqrt{\sum_{i=1}^{n}(q_i - p_i)^2}$$

The problem becomes a sparsity limited reconstruction problem with one variable when the $F_{rf}^{(i)}$ is included. The necessary sparse approximation issue is thus provided by:

$$\widetilde{F}^{opt}_{bb} = \min \|\mathbf{F}_{opt} - \mathbf{A_t}\widetilde{\boldsymbol{F}}_{bb}\|_F,$$

$$\text{s.t. } \|\text{diag}(\widetilde{\boldsymbol{F}}_{bb}, \widetilde{\boldsymbol{F}}^*_{bb})\|_0 = N^{rf}_t,$$

$$\|\mathbf{A_t}\widetilde{\boldsymbol{F}}_{bb}\|^2_F = N_s,$$

where, $\mathbf{A}_t$ -→$N_t \times N_{cl}N_{ray}$ matrix consisting of array response vectors

$\widetilde{\boldsymbol{F}}_{bb}$→$N_{cl}N_{ray} \times N_s$ baseband precoder matrix

The matrices A_t and F_{bb} assist in obtaining F_{rf}^{opt} and F_{bb}^{opt} since the relevant N_t^{rf} columns of A_t will supply the RF precoder matrix F^{rf}_{opt} and the N_{rf} non-zero rows of F_{bb} will give us the baseband precoder matrix F^{opt}_{bb}. In essence, equation (9) reformulates equation (8) as a sparsity restricted reconstruction issue with a single variable.Now that the issue can be approached as a sparse approximation problem, an algorithmic solution called orthogonal matching pursuit (OMP) can be applied. The receiver side uses the same algorithmic solution

2581-4575
International Journal For Recent Developments in Science & Technology
Crossref
A Peer Reviewed Research Journal

with just minor adjustments and follows a problem definition and optimization target. The hybrid combiner design has been left out of this work because it uses a similar mathematical formulation to the hybrid precoder design, with the exception of the added transmitter power constraint at the transmitter.It should be noted that the hybrid combiners $W_{rf}W_{bb}$ can be built to minimize the mean-squared-error (MSE) between the transmitted and processed received signals by employing the linear minimum mean square error (MMSE) receiver if the hybrid precoders $F_{rf}F_{bb}$ are assumed to be fixed.To solve the given problem, we can use either Orthogonal Matching Pursuit (OMP) or Gradient Pursuit (GP) algorithms. The ratio of spectral efficiency $\mathscr{R}$ to total power consumption P_{tot} is known as energy efficiency. The sum of the power used for transmission, baseband processing, and analogue processing units is the overall power consumption

$$\varepsilon = \frac{R}{Ptot} = \frac{R}{Pcp+NrftP_{rf}+Nps(Pps+Ppa)} bits/Hz/J \,,$$

N_{ps}, P_{cp}, P_{rf}, P_{ps}, and P_{pa} stand for the number of phase shifters, common transmitter power, power per RF chain, power per phase shifter, and power per power amplifier, respectively.

The high value of Prf and significant rise in each RF chain are directly related to the energy consumption of the RF chains, which is a big concern. One may assume that Nps is equivalent in a hybrid precoder structure that is fully coupled.

Now that the issue can be approached as a sparse approximation problem, an algorithmic solution called orthogonal matching pursuit (OMP) can be applied. The receiver side uses the same algorithmic solution with just minor adjustments and follows a problem definition and optimization target. The hybrid combiner design has been left out of this work because it uses a similar mathematical formulation to the hybrid precoder design, with the exception of the added transmitter power constraint at the transmitter.It should be noted that the hybrid combiners $W_{rf}W_{bb}$ can be designed to minimise the mean-squared-error (MSE) between the transmitted and processed received signals by using the linear minimum mean square error (MMSE) receiver if the hybrid precoders $F_{rf}F_{bb}$ are assumed to be fixed.

The first step of Algorithm 1i.e OMP is to identify the array response vector at(φ^{t}_{il}, θ^{t}_{il}) along which the best precoder has the greatest projection. Following that, step 6 shows how Algorithm 1 concatenates that chosen column vector into the RF precoder F_{rf}. The baseband precoder F_{bb} is then solved using least squares, and the residual precoding matrix Fres is produced to account for the contribution of the chosen vector. Once all RF chains have been used, the computer keeps looking for the column along which Fres has the largest projection. In the general case of Ns>=1, the transmit power constraint is satisfied at step 10, which is appropriate.

To create quick approximation OMP algorithms that use less storage, this paper addresses optimization schemes based on gradient, conjugate gradient, and approximate conjugate gradient approaches, and suggests enhancements to greedy strategies utilizing directional pursuit methods. The gradient pursuit (GP) method is presented as a cutting-edge approach to the optimization problem with performance comparable to OMP, lower cost consumption, and quicker processing. In contrast to OMP, which uses all of the selected atoms to achieve the best signal approximation, GP only uses one gradient direction, which eliminates the need to take into account all of the atoms and, as a result, reduces computing time.When GP is used, as is demonstrated in section IV, the computation time for large MIMO systems is significantly reduced. The same as with Algorithm 1, Algorithm 2 begins. The baseband precoder matrix F_{bb} is produced using an index set that is updated after each iteration, as shown in step 6. At each iteration, the gradient direction, which was indicated in step 8, is computed, and the step-size is explicitly defined using the gradient direction, as demonstrated in step 10. At the conclusion of the process, the RF precoder matrix F_{rf} and the baseband precoder matrix $F_{bb}$are obtained. At step 14, the transmit power constraint is met.

SIMULATION RESULTS

We will plot the hybrid precoder design's spectrum efficiency and energy efficiency metrics as outputs and contrast them with the ideal digital precoder and beam steering. In order to determine whether algorithm is more effective, we will plot these findings using both OMP and GP algorithmic methods and compare the outcomes. Nray = 10 and Ncl = 8 indicate that there are 10 rays for observation and a total of 8 clusters. Each cluster has an average power of 1, or _(i,i), of 1. The signal-to-noise ratio (SNR) is calculated using the formula $\frac{\rho}{\sigma_n^2}$. While beam steering simply utilises one RF chain at each ends, the ideal digital precoder uses Nt RF chains at the transmitter and Nr RF chains at the receiver.Four RF chains are used in hybrid precoding at both ends. The spectral efficiency versus SNR plot for the best digital precoding, hybrid precoding, and beam steering is displayed in Fig. 4.1. It has been found that hybrid precoding works better than beam steering while slightly underperforming ideal digital precoding. Additionally, it has been noted that the performance of OMP and GP solutions is comparable.

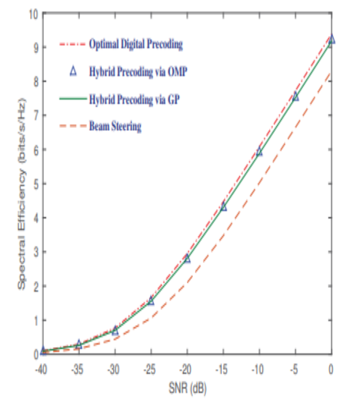
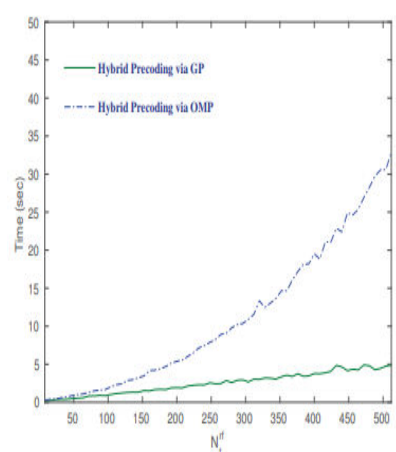


Fig. 4.1 Spectral efficiency for several precoding solutions for 64 × 16 fully connected mmWave system

The Time evaluation in relation to the number of RF chains is shown in Fig. 4.2. It has been noted that hybrid precoding using GP has a significantly shorter run time than OMP. GP has a shorter runtime and offers comparable performance to OMP. As a result, GP is a more effective solution than OMP, and we use GP as a solution for hybrid precoding for the remaining graphs.



g. 4.2 Time evaluation with respect to number of RF chains for OMP and GP for 512 × 512 mmWave

International Journal For Recent Developments in Science & Technology
2581-4575
Crossref
A Peer Reviewed Research Journal

The spectrum efficiency characteristics of the best digital precoder, the hybrid precoder, and beam steering are plotted in Fig. 4.3 with respect to the quantity of RF chains. It has been noted that hybrid precoding initially had difficulties, but over time, it gradually approximates the output of ideal digital precoding and outperforms beam steering.

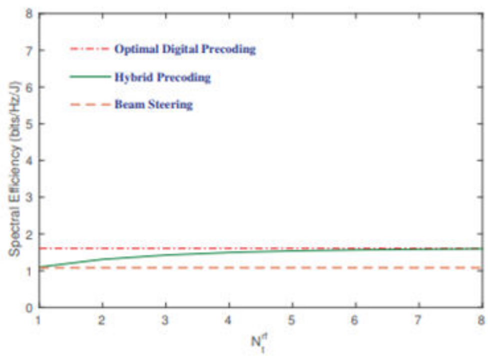
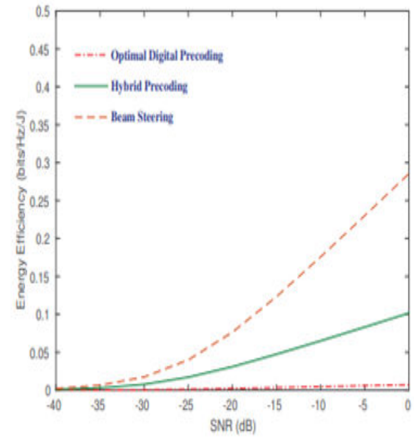


Fig. 4.3 Spectral efficiency for several fully-connected precoder designs

For both small and large MIMO systems, the run time for GP is shorter than the run time for OMP. The run time parameters for a large 512 512 mmWave system are shown in Fig. 4.2 with respect to the number of RF chains for both GP and OMP. The fact that the two algorithmic solutions take very different amounts of time to complete demonstrates that GP is a better practical option and more effective than OMP for designing a hybrid precoder.

The energy efficiency of the precoding solutions in relation to SNR is shown in Fig. 4.4. Since just one RF chain is used in beam steering, it uses less energy than the other two. Beam steering performs better than the other two precoding techniques in terms of energy efficiency. The parameters in (10), along with the other necessary parameters, are set as shown in Table I to produce Fig. 4.1.



;. 4.4 Energy efficiency for several precoding solutions for 64 × 16 fully connected mmWave system

As the SNR rises, it appears that the hybrid precoder performs more energy efficiently than the ideal digital precoder. However, because only one RF chain is employed in that system, which significantly lowers the energy consumption, the beam steering approach performs better in terms of energy efficiency. The energy usage will dramatically rise with regard to N^{rf}_t because N_{ps} scales linearly with $N^{rf}{}_t$ and N_t. For the same reason, when the number of RF chains increases for a specific SNR (such as 25 dB), beam steering beats hybrid precoding and optimal digital precoding. 4.5 With the employment of a single RF chain, the hybrid precoding performs exactly the same as beam steering in terms of energy efficiency.It should be noted that the hybrid precoder method might be a better course of action to take in order to get a considerable spectral efficiency gain while accepting an increase in energy usage. For example, the hybrid precoder will have 0.11 bits/Hz/J poorer energy efficiency than beam steering at SNR = 10 dB in order to achieve a gain of 1 bits/s/Hz over the beam steering approach. and Fig. 4.1 and Fig 4.4

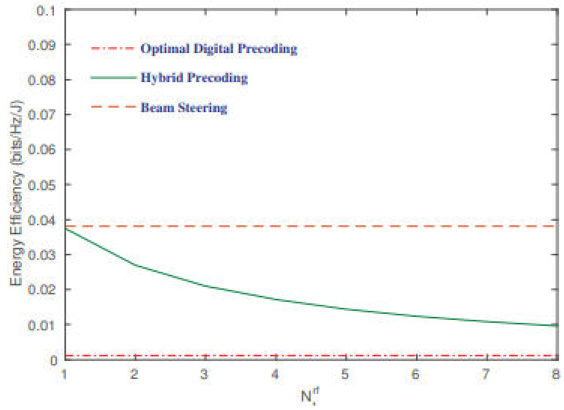


Fig. 4.5 Energy efficiency for several fully-connected precoder designs

CONCLUSION

In order to create high capacity and low energy hybrid mmWave communication systems, this research focuses on assessing the spectrum efficiency and energy efficiency characteristics of a hybrid precoder. It is compared to simplified beam steering systems and optimal digital precoding (with one RF chain per antenna) in terms of spectrum efficiency and energy efficiency. It can be seen that the hybrid precoder design offers spectral efficiency that is nearly optimal and greatly beats the ideal digital precoder in terms of energy efficiency. The hybrid precoder exhibits a significant improvement in performance when compared to the traditional beam steering method in terms of spectral efficiency. However, in terms of energy economy with respect to SNR and number of RF chains, beam steering exceeds hybrid precoding.We offer the gradient pursuit (GP) method as a novel algorithmic approach to the optimization problem. While the GP algorithm is suggested as a quick and inexpensive approximation solution, the orthogonal matching pursuit (OMP) approach seems to offer a high performance solution to the issue. The performance of GP is comparable to that of OMP, but it runs faster in both small- and large-MIMO configurations.By optimising the baseband and RF precoder matrices as well as the number of RF chains, this research will be expanded to design an energy-efficient hybrid precoder with a fully-connected architecture. The energy performance of the fully optimised hybrid precoder will be compared to the hybrid precoder without optimization, the ideal digital precoder, and the simplified beam steering system.

REFERENCES

[1] Li, X., Gani, A., Salleh, R., and Zakaria, O.: 'The future of mobile wirelesscommunication networks', IEEE Intern. Conf. Commun. Softwareand Networks, Macau, Feb. 2009, pp. 554-557.

[2] NGMN 5G White Paper, v.1.0, Feb. 2015, pp. 1-125.

[3] 2020 Networld White Paper for Research Beyond 5G, v.1.0, Oct. 2015,pp. 1-43.

[4] Rappaport, T. S., Shu, S., Mayzus, R., Hang, Z., Azar, Y., Wang, K.,Wong, G. N., Schulz, J. K., Samimi, M., and Gutierrez: 'Millimeter wavemobile communications for 5G cellular: It will work!', IEEE Access,2013, 1, pp. 335-349.

[5] Pi, Z., and Khan, F.: 'An introduction to millimeter-wave mobile broadbandsystems', IEEE Commun. Mag., 2011, 49, (6), pp. 101-107.

[6] Hur, S., Kim, T., Love, D. J., Krogmeier, J. V., Thomas, T. A., andGhosh, A.: 'Millimeter wave beamforming for wireless backhaul andaccess in small cell networks', IEEE Trans. Commun., 2013, 61, (10),pp, 4391-4403, .

[7]Rangan, S., Rappaport, T. S., and Erkip, E.: 'Millimeter-wave cellular wireless networks: potentials and challenges', Proc. IEEE, 2014, 102, (3), pp. 366-385.

[8]Biglarbegian, B., Fakharzadeh, M., Busuioc,

D., Nezhad-Ahmadi, M.- R., and Safavi-Naeini, S.: 'Optimized microstrip antenna arrays for emerging millimeter-wave wireless applications', IEEE Trans. Antenn. and Propag., 2011, 59, (5), pp. 1742-1747.
[9] Zhang, J. A., Huang, X., Dyadyuk, V., and Guo, Y. J.: 'Massive hybrid antenna array for millimeter-wave cellular communications', IEEE Wireless Commun., 2015, 22, (1), pp. 79-87,
[10] Rappaport, T. S., Heath, R. W., Daniels, R. C., and Murdock, J. N.: 'Millimeter wave wireless communications' (Prentice-Hall, Sept. 2014).