Hybrid Beamforming Techniques for Massive Mimo Technique

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HYBRID BEAMFORMING TECHNIQUES FOR MASSIVE MIMO TECHNIQUE

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***Abstract*—Massive MIMO (Multiple Input Multiple Output) is a key technology in the evolution of 5G wireless networks. One of the key challenges in Massive MIMO is the design of the beamforming vectors, which determines the transmission direction and the quality of the received signals. Hybrid beamforming is a promising solution to address this challenge by combining the benefits of both analog and digital beamforming. This abstract summarizes the benefits and challenges of hybrid beamforming in Massive MIMO systems. The use of hybrid beamforming can reduce the number of RF chains and the hardware cost, while maintaining high spectral efficiency and low latency. The hybrid beamforming technique involves the precoding of digital signals in the baseband and the beamforming of analog signals in the RF domain. The digital precoding is performed by optimizing the beamforming weights to improve the signal quality, while the analog beamforming is performed by adjusting the phase shifters to control the transmission direction. The hybrid beamforming technique can effectively balance the trade-off between performance and cost, making it a promising solution for the implementation of Massive MIMO systems. However, the design of hybrid beamforming requires a careful optimization of the analog and digital beamforming vectors to achieve the desired performance.**

***Index Terms*—MIMO system.**

I. INTRODUCTION

The provision of zero latency high data rate services to mobile consumers is intrinsically linked with a comprehensive network redesign as the deployment of fifth-generation (5G) broadband wireless cellular networks approaches reality . In this regard, several cutting-edge technologies have been launched to serve the 5G vision, including massive multiple input multiple output (MIMO) de- signs , non-orthogonal multiple access (NOMA), and millimeter wave (mmWave) transmission. In the latter scenario, several antenna arrays are installed at cellular orientation base stations (BSs) to serve mobile stations (MSs) that are requiring high data rate services. The creation of highly directed beams that reduce multiple access interference allows for this (MAI).

Along with fifth-generation (5G) networks, the sixth-generation (6G) age of technology is on the horizon and is expected to link everyone and everything. For multi-gigabit-per-second data throughput applications (i.e., 20 Gbps for downlink and 10 Gbps for uplink with latencies on the order of 1ms) to be enabled, the required 5G equipment to be converted to high frequency devices. It will be necessary for ultra-small communication devices to support these kinds of bandwidth-hungry operations. The future of 6G communications will thus be illuminated by the experience of the unique design and effective operation of mmWave antenna configurations in 5G communication technologies. The use of mmWave antennas in cellular systems can result in the design of powerful BSs in terms of flexible geometry and construction costs, it should be highlighted at this point. A multiplicity of adaptable BS installations are also made possible by the tiny size of mmWave antenna topologies, supporting changeable traffic and enhancing throughput overall.

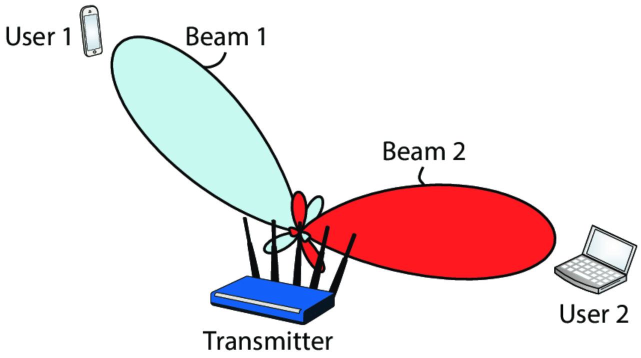

Fig. 1. **Visualisation of Beamforming**

Beamforming is a signal processing technique used in wireless communication systems to focus the transmitted signal towards a particular direction or a specific receiver, while minimizing the signal in other directions. It is achieved by combining the signal of multiple antennas in a way that maximizes the signal power in the desired direction and minimizes the interference from other direc- tions. Beamforming can be done using analog or digital techniques, and can improve signal strength, range, and reliability of wireless communication systems. Since the hybrid beamforming (HBF) approach combines the analog precoder in the RF domain with the digital precoder at baseband, the majority of related research in this area focuses on suboptimal beamforming algorithms based on this technique. Consequently, fewer RF chains are needed for implementation as a result of the low-dimensional digital precoder. Using massive MIMO mmWave multicellular orientations, the performance of a low-complexity HBF structure is assessed in this research.

II. LITERATURE SURVEY

Y. Xu, G. Gui, H. Gacanin and F. Adachi [1]et.al.said that , Different service needs of diverse communication contexts are anticipated to be met by the fifth-generation (5G) mobile communication system. Heterogeneous network (HetNet) has been researched recently as a novel evolution network structure. HetNets, which evolve tiny cells into the coverage of macrocells, might increase the possi- bility of geographic resource reuse and improve users' quality of service in comparison to homogenous networks. However, effective resource allocation (RA) algorithms are crucial to reducing the mutual interference and achieving spectrum sharing in HetNets due to the mutual interference between various users and the restricted spectrum resource. The RA in HetNets for 5G communications is thoroughly surveyed in this article.

A. N. Uwaechia and N. M. Mahyuddin [2]et.al.propsed that, The underused, high-bandwidth millimeter-wave (mmWave) frequency spectrum, which has the potential for high-capacity wireless transmission of several gigabits per second (Gbps) data rates, is where fifth-generation (5G) cellular networks will almost definitely operate. Although mmWave signal transmissions have a huge poten- tial for accessible bandwidth, they are plagued by fundamental technological problems because of their short wavelengths, including substantial route loss, susceptibility to obstruction, directivity, and small beamwidth. Accurate channel modeling that takes into account various 5G technologies and scenarios is crucial to supporting system design and deployment properly. This survey offers a thor- ough overview of several cutting-edge technologies for 5G systems, including cell-free massive MIMO, simultaneous wireless information and power transfer (SWIPT), hybrid analog-digital precoding and combining, massive multiple-input multiple-output (MIMO).

A. V. Lopez, A. Chervyakov, G. Chance, S. Verma and Y. Tang [3]et.al. explained about thier existing communications technology has to be improved from both a network infrastructure and user equipment (UE) standpoint if they are to realize a seamless, completely linked society. These requirements are directly influenced by customer expectations, application needs, and frequency band saturation in the existing spectrum. Similar to what 4G Long Term Evolution (LTE) achieved a decade ago, millimeter-wave (mmWave) New Radio (NR), a component of the fifth generation (5G) of mobile communication networks, intends to allow this future with ultra-low-latency, ultra-wideband services.

B. Makki, K. Chitti, A. Behravan and M. -S. Alouini [4]et.al.stated that a research item in the 3GPP for the 5G new radio has been non-orthogonal multiple access (NOMA) (NR). It was ultimately decided, nevertheless, to leave it for potential usage after 5G rather than continue with it as a work item. In this essay, they examine the debates that led to the chosen conclusion first. They evaluate the Welch-bound equality spread multiple access (WSMA)-based NOMA and multi- user multiple-input-multiple-output (MU-MIMO) in particular. The results show that there is less potential improvement for WSMA-based NOMA compared to MU-MIMO. In order to increase the effectiveness of NOMA-based transmission, they describe the 3GPP debates on the topic and sug- gest a variety of strategies to lessen implementation complexity and delay for both uplink (UL) and downlink (DL) NOMA-based transmission.

N. Nomikos, E. T. Michailidis, P. Trakadas, D. Vouyioukas, T. Zahariadis and I. Krikidis, [5] et.al. demonstrated that The ability to support demanding services with high connectivity needs, such as Internet of Things (IoT) nodes, mobile devices, or unmanned aerial vehicles, is essential for the success of fifth generation (5G) mobile networks and their long-term evolution (LTE) (UAVs). In order to do this, numerous users and devices can interact utilizing the same spectral and tempo- ral resources thanks to non-orthogonal multiple access (NOMA) techniques. Through more variety, buffer-aided (BA) relay selection can considerably improve the quality and dependability of communi- cation in this situation. Due to the coexistence of users and devices and the need for access to wireless resources, they adopt BA relay selection in this study in the uplink of NOMA networks.

S. Rangan, T. S. Rappaport and E. Erkip [6]et.al.explained that Millimeter-wave (mmW) frequencies between 30 and 300 GHz are a new frontier for cellular communication that offers the promise of orders of magnitude greater bandwidths combined with further gains via beamforming and spatial multiplexing from multielement antenna arrays. This paper surveys measurements and capacity stud- ies to assess this technology with a focus on small cell deployments in urban environ- ments.To address these challenges, the paper discusses how various technologies including adaptive beamforming, mul- tihop relaying, heterogeneous network architectures, and carrier aggregation can be leveraged in the mmW context.

O. El Ayach, S. Rajagopal, S. Abu-Surra, Z. Pi and R. W. Heath [7]et.al. explained that Beam- forming with multiple data streams, known as precoding, can be used to further improve mmWave spectral efficiency. Both beamforming and precoding are done digitally at baseband in traditional multi-antenna systems. The high cost and power consumption of mixed-signal devices in mmWave systems, however, make analog processing in the RF domain more attractive. This hardware limita- tion restricts the feasible set of precoders and combiners that can be applied by practical mmWave transceivers. Also exploit the spatial structure of mmWave channels to formulate the precoding/com- bining problem as a sparse reconstruction problem.Using the principle of basis pursuit, they develop algorithms that accurately approximate optimal unconstrained precoders and combiners such that they can be implemented in low-cost RF hardware. They present numerical results on the performance of the proposed algorithms and show that they allow mmWave systems to approach their uncon- strained performance limits, even when transceiver hardware constraints are considered.

III. PROPOSED MODEL

The studied hybrid beamforming approach, the set denotes the active radiating elements of the array geometry deployed in the bth BS and the corresponding angles of the generated adaptive beams (notation a:b indicates all elements from a to b with step 1). Moreover, each entry indicating the channel matrix of the k th MS relevant to its serving sector for the s th PRB is calculated.

IV. METHODOLOGY

The studied hybrid beamforming approach, the set denotes the active radiating elements of the array geometry deployed in the bth BS and the corresponding angles of the generated adaptive beams (notation a:b indicates all elements from a to b with step 1). Moreover, each entry indicating the channel matrix of the k th MS relevant to its serving sector for the s th PRB is calculated.

An arbitrary BS is assumed to use a FGoB in the initial state, with three active sectors separated by 120 degrees spatially. In order to do this, the deployed geometry is specified in accor- dance with the angle of the first MS that is utilized by this BS. In order to achieve the required 120o spacing in the deployed beams, two more arrays—vo + [v/3] and vo+2[v/3]—must also be activated in this scenario, assuming that the vertical array vo is already active. When a possible (new) MS seeks to join the network and requests Rk PRBs, it is checked to see if the geometry already in place can supply the minimal amount of transmission power necessary for good QoS without experiencing a power loss.

According to the angular position of the prospective new MS, this is accomplished by acti- vating a different vertical array.Note that in this instance, the whole array's radiating components are turned on. However, if there is a power loss in at least one of the MSs previously covered by this BS, all radiating elements in the first vertical arrays (specified in line 1) can be activated, creating a grid of beams with higher gain.

In each of the aforementioned situations where the antenna radiation pattern is altered, it is determined if the proposed changes to the radiation diagram would cause a link outage for another MS that the bth BS already serves.The reject flag (rf) is set to 1 and the procedure is repeated for the next candidate MS if this is the case, even though all radiating elements for each vertical array are active.Otherwise, updates are made to corresponding sets (i.e., b and b).

Hybrid beamforming can include both fixed and adaptive grid of beams to optimize the beamforming performance. In this approach, a fixed grid of beams can be used to provide an initial beamforming solution, followed by an adaptive grid of beams for further optimization. The fixed grid of beams can be designed based on the spatial properties of the communication environment, while the adaptive grid of beams can adjust the beamforming vectors in real-time to compensate for changes in the channel conditions. The fixed grid of beams can be generated by using a predefined set of beamforming vectors, which can be calculated based on the number of antennas and the spatial dimensions of the environment. The adaptive grid of beams can be implemented using an optimization algorithm, such as the gradient descent method, to adjust the beamforming vectors based on the channel conditions.

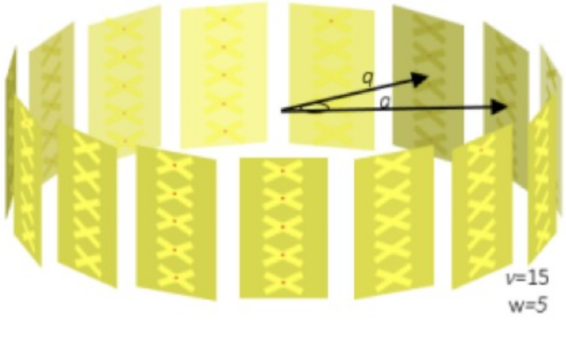

Fig. 2. **Circular array**

The Method of Moments (MoM) was used to conduct an electromagnetic analysis of the circular array shown in Fig. 2. In this situation, the parameters w, q, v, and a uniquely describe each research. Note that the current simulations have taken into account the significant effects of mutual coupling among all radiating elements (vw2). In order to achieve this, our 3D computational model has taken into account changes in the radiation pattern and input impedance of the array

V. BLOCK DIAGRAM

The block diagram shows the overall architecture of a massive MIMO system that employs hybrid beamforming technique at the transmit end using both analog and digital beamforming. At the input, there is a data source that generates the digital data to be transmitted over the wireless channel.

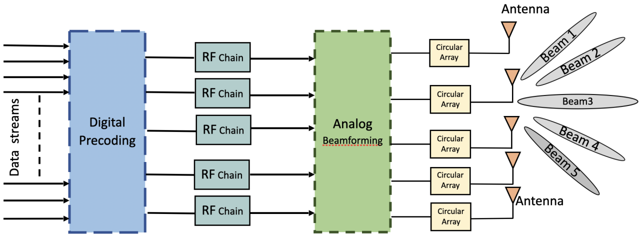

Fig. 3. **Block diagram**

As shown in the figure "fig.3.", the digital data is passed through the digital beamforming block, which processes the data using a digital precoder. The precoded data is then sent to the RF chains, which convert the digital signals to analog signals. The analog signals are then passed through the analog beamforming block, which processes the signals using an analog precoder.

The analog precoded signals are then passed to the antennas, which transmit the signals over the wireless channel to the receiving end. At the receiving end, the signals are received by the antennas, and the analog signals are converted to digital signals by the RF chains. The digital signals are then passed through the digital beamforming block, which processes the signals using a digital equalizer.

VI. PROCEDURE

A. *Data Source*

The data source is the initial component of the system. It refers to the source from where the data is generated for transmission. In a massive MIMO system, this data can come from various sources such as sensors, cameras, microphones, or any other devices that generate data. The data source can be analog or digital, depending on the type of data generated. In the case of digital data, it needs to be converted from analog to digital format using an analog-to-digital converter (ADC). The ADC samples the analog signal at regular intervals and quantizes it to produce a digital representation of the signal.The data generated by the source can be in the form of bits or symbols. The bits can be used to represent digital data such as text, images, audio, or video. The symbols can be used for modulation purposes to represent the data in the form of waveforms.

B. *Digital Precoding*

The digital precoding block takes as input the data symbols to be transmitted and the chan- nel state information (CSI), which provides information about the wireless channel between the base station and the user equipment. The CSI can be estimated using pilot signals transmitted by the base station and feedback from the user equipment. Using the data symbols and the CSI, the digital precoding block computes the precoding matrix, which maps the data symbols to the transmit anten- nas in such a way that the signal power is maximized at the receiver. The precoding matrix is then transmitted to the analog precoding block for implementation in the analog domain.

C. *RF Chains*

The exact implementation of the RF chains can vary depending on the specific system design and hardware constraints. For example, in some systems, the RF chains may be implemented using separate hardware components for each antenna element, while in others, a smaller number of RF chains may be used in conjunction with additional signal processing techniques to achieve the desired performance. RF chains play a critical role in the hybrid beamforming employed at the transmit end of a massive MIMO communications system, as they are responsible for converting the digital signals generated by the precoding module into analog signals that can be transmitted through the antenna array.

D. *Analog Beamforing*

The analog beamforming block also contains a beamforming weight matrix, which is used to adjust the phase and amplitude of the signals transmitted from each antenna element in order to generate a desired radiation pattern. The beamforming weight matrix is calculated using the digital precoding matrix and the channel state information. The digital precoding matrix is used to precode the signal before it is transmitted through the analog beamforming block. The analog beamforming block plays a critical role in the hybrid beamforming technique by allowing for the generation of the desired radiation pattern with high energy efficiency and low complexity.

E. *Circular Array*

A circular array consists of multiple antenna elements arranged in a circular shape. The circular shape is advantageous as it provides a uniform radiation pattern in all directions, making it suitable for mobile communication systems where the orientation of the antenna with respect to the user is unknown. The circular array can also provide a constant aperture, which is the area through which electromagnetic waves pass to reach the receiver. This allows for a uniform gain over the entire azimuth angle. The low correlation between the antennas in a circular array also makes it suitable for beamforming, where the antenna array is used to steer the radiation pattern towards a particular direction.

F. Antenna

The ”Antennas” block represents the physical antennas used for transmission and reception in the massive MIMO system. The number of antennas used in the system depends on various fac- tors, such as the channel characteristics, system requirements, and available resources. In general, the more antennas used in the system, the better the performance in terms of signal quality, coverage, and capacity. However, the use of more antennas also requires more resources, such as RF chains and processing power, which can increase the system complexity and cost.

VII. SOFTWARE SPECIFICATIONS

- The MATLAB Language - This is a high-level matrix/array language with control flow state- ments, functions, data structures, input/output, and object-oriented programming features. It allows both ”programming in the small” to rapidly create quick and dirty throw-away programs, and ”pro- gramming in the large” to create complete large and complex application programs.
- Analog and digital modulation strategies encode the facts circulation into a sign this is appropriate for transmission. Communications System Toolbox presents some of modulation and corresponding demodulation abilities.
- Communications System Toolbox affords source and channel coding talents that can help you develop and compare communications architectures fast, enabling you to discover what-if eventualities and avoid the need to create coding competencies from scratch.
- Source coding, also referred to as quantization or signal formatting, is a manner of processing facts a good way to lessen redundancy or prepare it for later processing.
- The gadget toolbox offers application functions for developing your personal channel coding.
- Graphical tool for evaluating the simulated bit mistakes rate of a machine with analytical outcomes.
- Communications System Toolbox lets you discover equalization and synchronization strate- gies. These techniques are usually adaptive in nature and tough to design and symbolize. The machine toolbox affords algorithms and tools that will let you swiftly select the proper approach on your com- munications machine.
- The device toolbox provides algorithms for each service segment synchronization and timing phase .

VIII. HYBRID BEAMFORMING AT MM-WAVE

The challenges associated with implementing hybrid beamforming architectures and algo- rithms in the context of mm-wave frequencies. These frequencies are much higher than those used in traditional cellular networks and offer several advantages, such as increased bandwidth and data transfer rates. However, the propagation channel and RF hardware aspects are significantly different in these bands, and novel hybrid beamforming techniques are needed to address these differences.At mm-wave frequencies, the multipath channel experiences higher propagation loss, which means that the signal strength decreases more rapidly as it travels through the air. To compensate for this loss, gain from antenna arrays at the transmitter (TX), receiver (RX), or both is needed. These antenna arrays are typically composed of multiple radiating elements that can be used to focus the transmission or reception of radio waves in a specific direction.

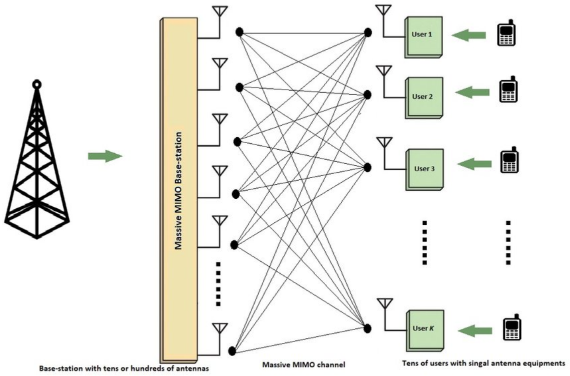

Fig. 4. **MIMO architecture with Hybrid beamforming**

However, implementing fully-digital beamforming solutions at mm-wave frequencies becomes infeasible due to power- and cost-related RF hardware constraints. This means that it is not practical to use a separate RF chain for each radiating element, as this would require a significant amount of power and increase the cost of the system. As a result, hybrid beamforming becomes harder, as it is necessary to strike a balance between hardware complexity and performance.

IX. OUTPUTS

A. OUTPUTS IN ADAPTIVE GRID OF BEAMS

- In the figure ”fig.5.”, x-axis is Blocking probability number and y-axis is Throughput in Mbps. The graph represents Blocking probability number versus Throughput in Mbps for Adaptive grid of beams configuration.

- In the figure ”fig.6.”, x-axis is Blocking probability number and y-axis is Transmitting power. The graph represents Blocking probability number versus Transmitting power for Adaptive grid of beams configuration.

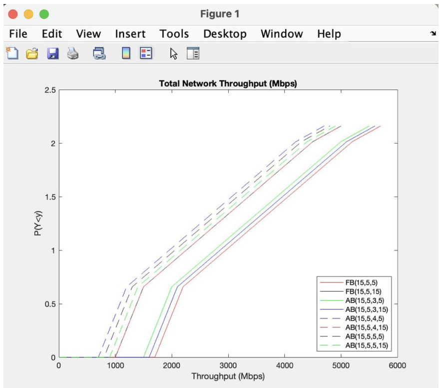

Fig. 5. **Total Network Throughput(Mbps)**

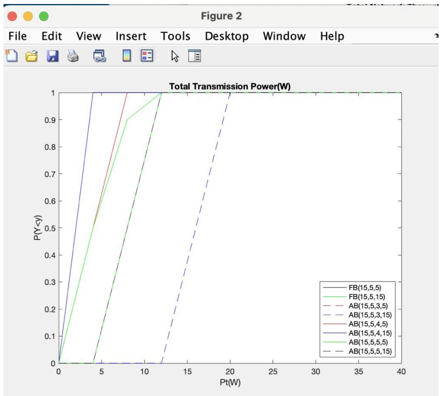

Fig. 6. **Total Transmission Power**

- In the figure ”fig.7.”, x-axis is Blocking probability number and y-axis is Blocking Prob- ability Percentage. The graph represents Blocking probability number versus Blocking Probability Percentage for Adaptive grid of beams configuration.

- In the figure ”fig.8.”, x-axis is Blocking probability number and y-axis is Radiating Element. The graph represents Blocking probability number versus Radiating Element for Adaptive grid of beams configuration.

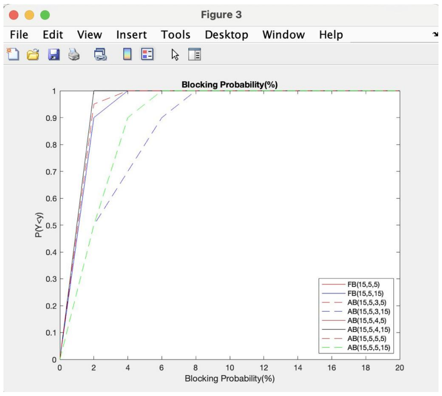

Fig. 7. **Blocking Probability**

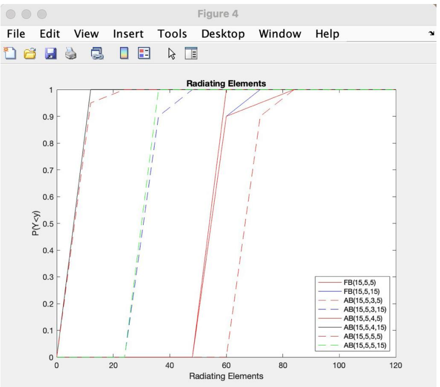

Fig. 8. **Radiating Element**

B. OUTPUTS IN FIXED GRID OF BEAMS

- In the figure ”fig.9.”, x-axis is Blocking probability number and y-axis is Throughput in Mbps. The graph represents Blocking probability number versus Throughput in Mbp for Fixed grid of beams configuration.

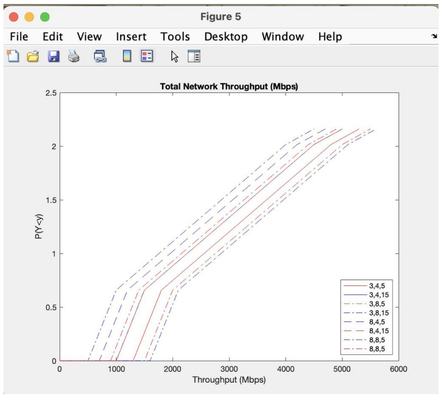

Fig. 9. **Total Network Throughput (Mbps)**

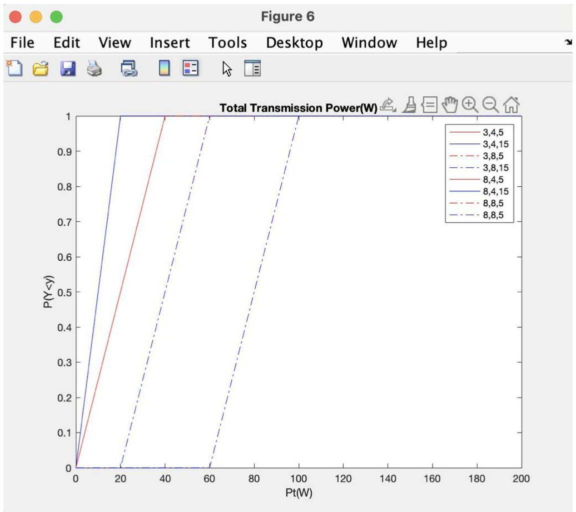

Fig. 10. **Total Transmission Power(W)**

- In the figure ”fig.10.”,x-axis is Blocking probability number and y-axis is Transmitting power. The graph represents Blocking probability number versus Transmitting power for Fixed grid of beams configuration.

- In the figure ”fig.11.”,x-axis is Blocking probability number and y-axis is Blocking Probability Percentage. The graph represents Blocking probability number versus Blocking Probability Percentage for Fixed grid of beams configuration.

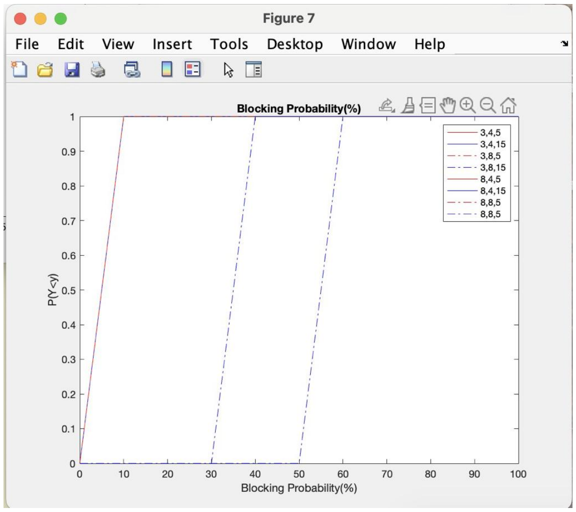

Fig. 11. **Blocking Probability**

X. FUTURE SCOPE

- Further work on developing advanced algorithms for channel estimation that can improve the accuracy and efficiency of hybrid beamforming.

- Developing new algorithms and techniques to mitigate interference in hybrid beamforming systems, such as multi-user detection, interference cancellation, and adaptive beamforming.

- The improvement in the more efficient hardware architectures for hybrid beamforming systems that can reduce power consumption and cost.

- Optimize the performance of distributed massive MIMO systems, such as joint precoding and coordinated beamforming.

XI. CONCLUSION

The hybrid beamforming approach involves activating a different set of radiating antenna elements in each vertical antenna array to generate the radiation pattern, which allows for more efficient use of the available bandwidth and increased data transfer rates. The results of the assessment show that the hybrid beamforming approach can improve a number of key performance indicators (KPIs) of the cellular orientation. For example, the total downlink transmission power can be improved when all radiating elements per vertical antenna array are activated, and the blocking probability can be reduced. However, it should be noted that hardware complexity reduction (expressed via the number of active radiating antenna elements) comes at the expense of increased transmission power.

The suggested hybrid beamforming technique is based on flawless channel state information (CSI) at base stations (BSs), which means that the BSs have accurate knowledge of the channel conditions. This is essential for optimizing the beamforming weights and achieving the desired radiation pattern. However, the method can be readily adapted to situations where the analog stage uses codebook searching to prevent channel estimate of the analog channel with huge dimensions. This is a technique used to reduce the hardware complexity of the system and improve its practical implementation. Overall, the results of the assessment demonstrate the potential benefits of the hybrid beamforming approach for improving the performance of cellular orientation in 5G mmWave cellular networks. The technique can be adapted to different channel conditions and hardware configurations to achieve optimal results.

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