Wireless Personal Communications
https://doi.org/10.1007/s11277-021-08455-7

# Hybrid Beamforming for Massive MIMO Using Rectangular Antenna Array Model in 5G Wireless Networks

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Accepted: 28 March 2021



## Abstract

Fifth and future generation (5G and B5G) wireless networks aim to serve users with higher data rates and lower latency. Data traffic due to the rapid growth in communication has motivated the study of Multiple Input Multiple Output (MIMO) systems. They utilize multiple antennas in both transmitter and receiver sides. It is necessary to improve the existing technology to achieve fast and reliable communication. In this research work, a rectangular array antenna based hybrid beamforming in a massive MIMO model has been proposed to improve the spectral efficiency of the system. Thus channel capacity with small RF chains is used. To achieve the high signal strength in the main lobe, Chebyshev tapering has been used to suppress the side lobes signals. In this manner, the proposed Hybrid Beamforming for Massive Output MIMO has been realized with a small complexity and higher spectral efficiency. In this research work, the spectral efficiency of both proposed Hybrid and fully-digital beamforming with a different number of RF chains for a various number of antennas at the transmitter, the receiver side has been analyzed. From the simulation results, it has been observed that the proposed rectangular array antenna based Hybrid beamforming in a massive MIMO system reduces the computational complexity up to 99% as compared with conventional fully digital beamforming to achieve the same spectral efficiencies, which is a productive model for 5G wireless networks.


**Keywords** 5G Wireless networks · Massive MIMO · Hybrid beamforming · Rectangular antenna array · Spectral efficiency

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Published online: 05 April 2021

## 1 Introduction

Innovation is continuously changing the manner of communication with the world. As pushed ahead, new technologies such as connected vehicles, autonomous drones, three-dimensional (3D) media, artificial intelligence (AI), Blockchain, Internet of Everything (IoE) are escalating the network traffic as appeared by predicted statistics in [1], 2]. Taking a look at the next decade, the innovations have become unpredictable in the new wireless technologies, as the number of voice and data communications is exponentially growing in accordance with Cooper's law. This was explained by researcher Martin Cooper [3]. User needs have ever increased and the current mobile communications have minimal systems and have compelled the researchers to come up with more advanced and efficient technologies. The 3G network (Wideband-CDMA), which is termed as Mobile Broadband, with Code-Division Multiple Access (CDMA) Supported video conferencing, GPS, mobile TV, etc. The 4G network (Long-Term Evolution) with Ultra-Broadband internet service and CDMA. They concentrated on desegregating the terminals, networks, and applications, supported high-speed applications, wearable devices, mobile TV, interactive multimedia, etc.

The 5G network with a speed 10 × than 4G uses a scalable orthogonal frequency-division multiplexing (OFDM) framework and New Radio (NR) technology in millimeter-wave (mmWave) spectra to elevate over its predecessor [4], 5]. Along with that wireless world wide web internet service supports autonomous robotics in medical applications, autonomous unmanned vehicles and video streaming with high quality. The fifth-generation (5G) network was first globally launched by Verizon in April 2019. The 4G and 5G technologies have concentrated on increasing the speed and reducing the latency in personalized communication. A detailed comparison of 2G, 3G, 4G & 5G is given in Table 1. Moving further beyond 5G that is into B5G communication, it is supposed to be structured in such a way that it will move towards using the full potential of high-speed communication. Reducing latency is not only the constraints in mobile-to-mobile communication but also machine-to-machine communication [6], 7]. The 5G networks are employed now. There are possible improvements in present technologies to support the new challenges in future innovations. This is Beyond fifth-generation (B5G) [1]. Present 5G technologies face Coverage issues, Emerging applications challenges, D2D (Device to Device) communication and vulnerabilities, mobile edge computing issues, network orchestration, slicing, etc.

These issues are to be rectified by the development of Internet of Everything (IoE) services, future generation (B5G) wireless system with Network intelligence, fast spectrum reallocation, enhanced mobile broadband (eMBB), Ultra-reliable low latency communications (URLLC), peer-to-peer communication, security and privacy, enhanced senses where human senses improve the quality of interaction, battery duration, energy, etc. [8]

**Table 1** Comparison of various mobile network technology generations

| Generation | Maximum speed | Delay (ms) | Download time* | Bandwidth |
|---|---|---|---|---|
| 2G | 0.3 Mbps | 300–1000 | 35–40 min | 25 MHz |
| 3G | 42 Mbps | 50–100 | 45 s–1 min | 25 MHz |
| 4G | 1 Gbps | 20–30 | 5–8 s | 100 MHz |
| 5G | 10 Gbps | 1–10 | < 1 s | 30 GHz–300 GHz |

(*Average application file size being 38 Mb for IOS, 15 Mb for Android) by enabling higher frequency bands, communications with large intelligent surfaces, transceivers with integrated receiver bands, edge artificial intelligence(AI), integrated terrestrial, airborne and satellite networks [9]. In order to meet the requirements of the 5G networks mentioned above and to achieve the smooth functioning of future network traffic, massive MIMO mmWave technologies employed in Heterogeneous networks (HetNets) [7] are emerging. These core technologies provide a better quality of service (QoS) when compared with the existing communication technologies.

### 1.1 Motivation

Due to the technology development and increase in demand, fifth-generation networks (5G) are facing problems to provide the service for more number of users. Therefore, the 5G network service has to provide the service to mobile users with high data rates and low latency. This is the bottleneck of the existing wireless networks. This motivated the authors to do the present research work in a different direction. The area throughput of any wireless network is given by

$$Area\ throughput = B(\mathrm{Hz}) \times D\left(\mathrm{cells/km^2}\right) \times SE(\mathrm{bits/s/Hz/cell}) \tag{1}$$

where *B, D* and *SE* are bandwidth, mean cell density and spectral efficiency per cell respectively. Therefore from Eq. (1), it has been found that the average throughput is depending on the three metrics. Hence, the area throughput can be increased by optimizing the above mentioned three metrics to meet the requirement of future generation networks. Therefore, area throughput can be increased by either allocating more bandwidth or densifying the cellular network, or improving the spectral efficiency per cell. But due to the limitation in the frequency band, allocating more bandwidth is the bottleneck for the wireless industry. Also densifying the cell with more BSs will create a shadowing effect in the coverage. Therefore an optimal throughput demands an increase in the area by optimizing the spectral efficiency per cell.

Also, Shannon's channel capacity is defined by

$$C = B \times log_2\left(1 + \frac{S}{N}\right)\mathrm{bits/s} \tag{2}$$

where *S* and *N* are the signal and noise power respectively. Equation (2) also can be rewritten as

$$C = B \times SE \tag{3}$$

From Eqs. (2) and (3), it is observed that to increase and optimize the channel capacity as well as the spectral efficiency, the power of the transmitting signal (*S*) may be increased. But increasing the signal power beyond a certain limit will also increase the complexity in wireless networks. Hence, this motivated the present work to propose the rectangular antenna array-based Hybrid Beamforming for massive MIMO systems for increasing the channel capacity and spectral efficiency per cell without increasing the transmitted signal power.

The rest of the paper is structured as follows: The detailed literature has been reviewed in Sect. 2. Section 3 explains the system model and rectangular antenna array model for the proposed system. The experimental results and analysis have been investigated in Sect. 4. Section 5 concludes and directs for future research.

## 2 Literature Review

Massive MIMO is a large scale antenna system with radio antenna technology. This enhanced the number of antennas at transmitter and receivers by a few orders of magnitude more than conventional MIMO enabling multiple signal paths, thus increasing the array gain than before [10]. Going large from multi-user MIMO (MU-MIMO) originated massive MIMO, which offered vast degrees of freedom (DoF). It could be utilized by using beamforming techniques if channel state information (CSI) was available. The CSI was the signal propagation (transmitter to receiver) information [1]. The additional antennas could be used for minimal areas to bring a vast improvement in massive MIMO throughput and radiated energy efficiency. Beamforming was a technique used in massive MIMO which navigated the signals produced from an array of antennas in a particular required direction. The various channel parameters were extracted using the perturbation-aided opportunistic method. This had been utilized to generate the pre-coders for temporarily correlated mmWave MIMO systems [11]. A coherent combination of all received signals took place at the receivers by a diverging scale factor to enlarge the Signal-to-Noise Ratio, which was received. In mmWave massive MIMO, the issue of power consumption and cost due to mixed analog/digital signal components at each antenna could be overruled by designing different topologies of hybrid beamforming [12]. The hybrid beamforming topology had a reduced number of RF systems when compared with analog/digital beamforming techniques. This gave rise to multi-stream digital processing (Baseband). Also, following this, analog processing (Baseband or RF) took place. [13].

The error performance and average sum rate of the mmWave MU-MIMO might also be increased using a partially connected structure (PCS) hybrid beamforming mechanism [14]. The reported PCS mechanism was formed by combining the beam patterns using the information of azimuth and elevation angles. The mmWave communication was a favorable technology that could overcome the bandwidth shortage issue for the next generation wireless communication [15, 16]. The mmWave technology utilized a very high frequency between 30 and 300 GHz, the wavelength between 1 and 10 mm, and the maximum bandwidth of 252 GHz. Although mmWave frequencies experienced path loss and absorption issues when compared with normal frequency ranges, a large number of antennas was stacked within minimal areas. This increased the deployment of large scale antennas array systems at the transceivers, which could possibly deal with propagation issues of the channel [17]. Ultra-Dense Networks (UDN) was a crammed development of small cell base stations (SBS) within the limit of macrocell base stations (MBS). It was obvious that UDN was an adequate way to accelerate network capacity, throughput, SE, EE and coherent coverage for networks.

The combination of mmWave Technology, UDN and massive MIMO cooperatively produced HetNets architecture. The critical aspects of combined mmWave massive MIMO technology were by merging the feature of mmWave BW and antenna array gains of massive MIMO technology. This had become the central element of next-generation cellular networks such as 5G communication [18]. Antenna Pre-coding and array combining techniques could be used to utilize the array gain of the massive number of antennas of MIMO [19]. The deployment of devoted RF chain hardware was required for each antenna, which could increase the cost as well as power consumption peculiarly for mmWave technologies. Therefore, it was necessary to innovate in the antenna system design that would use the potential gain from a stack of low-cost antennas using a less amount of costly RF systems. [20]

Hu et al. [17] had explained the significant effect on Spectrum efficiency, channel capacity and energy efficiency in Massive MIMO systems. It was described that there was a higher requirement of Massive MIMO in the future due to its increased performance in many aspects. The different combinations, such as fully connected phase shifters and switching networks in massive MIMO had been elaborated [20]. Also, the optimal design of the pre-coder and the combiner was explained with the constraint of minimum mean square error (MSE). The authors had come up with different combinations of phase shifters and switches while increasing the number of both. The mathematical expression regarding the Greedy Ration Trace Maximization (GRTM) was also explained where each iteration was added with one RF chain that had an optimal combinational vector, which was added to the previously K selected vectors.

Ahmed et al. [21] had focused on the work on the hybrid beamforming application. Hybrid beam forming had been categorized into hybrid beamforming architecture, managing the available resources, various numbers of antennas on transmitter and receiver sides, the hybrid beamforming in HetNets and microcells. Future research problems, challenges and open issues had been listed. The impact of the downlink MU-MIMO system channel with hybrid beamforming had been explained [22]. They had demonstrated that by utilizing more RF chains and Analog-to-digital converters (ADCs), the performance of the MU-MIMO could be increased. Huang et al. [23] proposed the framework for optimizing the transmitting and receiving beamformers jointly by using the extreme learning machine mechanism for Millimeter-Wave Multi-User MIMO Systems.

The hybrid beamforming technique for different frequencies and only for a selective channel had been proposed [24], 25]. They had addressed the issue related to maximizing the spectral efficiency in SU-MIMO by utilizing a little feedback consideration. Initially, they had developed a hybrid analog–digital codebook design for mmWave systems and further, the pre-coding algorithm had been proposed based on Gram Schmidt orthogonalization. A generalized hybrid beamforming scheme for mmWave MIMO systems using singular value decomposition (SVD) to reduce the complexity and number of RF chains [26]. Also, the energy consumed by the mmWave massive MIMO could also be reduced by a fully complex Zero Forcing mechanism by reducing the number of RF chains [27]. Soleimani et al. [28] investigated the design of a simplified user clustering algorithm which was based on the DFT. In this proposed method mobile users available in the same and overlapping angular bins were grouped together as a single cluster to find the optimal solution for mmWave MIMO systems.

Molisch et al. [29] explained the usage of many hybrid-multiple antenna transceivers that combined large dimensional analog pre and post-processing. The study involved various structures of different combinations of transmitters and receivers. Second-order channel states were mainly used, which provide better SNR and interference ratio. The main difference between structures of different complexities had been explained and the design aspects for the operation of mmWave frequencies were listed as future problems. The difference between bit error rate (BER) performance of the hybrid pre-coding and the BER performance of the receiving beamforming of mmWave-massive MIMO systems had been explained [30]. A detailed analysis had been done on hybrid precoding technique as well as receiver combining technique for various configurations, and it had been concluded that processing played a vital role than diversity when flawless CSI was present at transmitter and receiver sides. When the number of antennas and users were equal, an unacceptable error performance had been found at high SNR rates also [31].

Noordin et al. [32] had proposed various uniform circular arrays (UCA) configurations implementation for hybrid beamforming. A detailed explanation of these arrays and a comparison had also been given. It shows the configuration which would be able to enable the phased antenna array to scan azimuthally with very few changes in its sidelobe levels and the widths of the beam. The Particle Swarm Optimization (PSO) method had been used to calculate the complex weights for the antennas to adapt to the changing environments which had been used to increase the information rate in hybrid pre-coding methods [33]. Busari et al. [34] had presented a framework for the design of Hybrid Beamforming (HBF) architecture which utilized the subarray spacing as a key parameter. The performance of the HDF architecture had been analyzed using the single-path terahertz (THz) channel model.

### 2.1 Research Contribution

Based on the above literature survey, it has been observed that still a lot of opportunities are there to improve the spectral efficiency of the massive MIMO which can be used in 5G wireless networks by increasing the channel capacity and area throughput. Hence in this research work, the following contribution has been done:

1. A rectangular antenna array-based hybrid beamforming model for a massive MIMO system has been introduced as a system model.
2. The rectangular array antenna geometry has been analyzed and also the practical antenna has been introduced.
3. The spectral efficiency analysis has been carried out for different array sizes to conclude the impact of RF chains in hybrid beamforming as compared with conventional fully digital beamforming.
4. Bit Error Rate (BER) has been computed for various SNR to prove the superiority of the proposed rectangular array antenna based MIMO system.

## 3 System and Channel Model

The system model considered in this proposed work is illustrated in Fig. 1. The massive MIMO system has been considered. It is a multi-user system with multiple streams whose downlink is equipped with 3-D $\mathrm{N_t}$ antenna arrays with $\mathrm{N_t^{RF}}$ RF chains and uplink is equipped with 3-dimensional $\mathrm{N_r}$ antenna arrays and $\mathrm{N_r^{RF}}$ RF chains. Let $\mathrm{N_r}$ denote the number of streams received at each receiver. The proposed hybrid MIMO system model has been configured such that $N_t^{RF} < N_t$ and $N_r^{RF} < N_r$.

A transmitter is likely to be sectored to lesser the interference and increase the beamforming gain. The foremost thought of beamforming or large antenna arrays [35] is the excellent flexibility where the beam can be steered when there is a multiple user environment. Most beam steering flexibility comes with the fully digital MIMO beamforming technique, but the cost is high for this technique. The best outcome can be brought by combining the beamforming techniques of digital, analog system, and the RF domain, which has lower flexibility when compared to a fully digital MIMO system at a low cost.

In conventional (fully digital) MIMO systems, both the number of RF chains and the number of antennas are equal on the transmitter side for pre-coding and number of antennas on the receiver side for combining. The performance analysis of a conventional fully digital MIMO system is compared with the Hybrid MIMO system using hybrid pre-coding

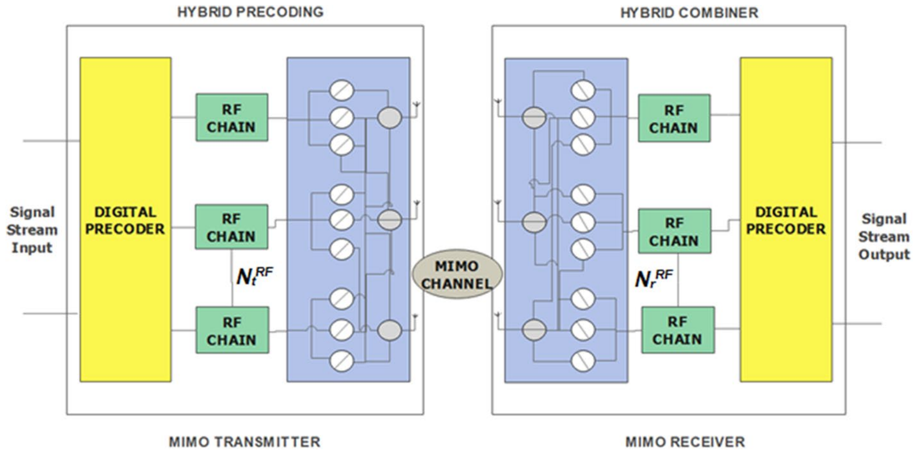



**Fig. 1** System model for massive MIMO system with hybrid beamforming

and combining. It depicts that there is a negligible loss in Hybrid MIMO when compared with fully digital conditions. Conventional fully digital beamforming technique demands a dedicated RF chain corresponding to a particular antenna. Hence it will be extremely costly and complex. Whereas, with a fewer number of RF chains, as shown in Fig. 1, the Hybrid beamforming techniques promise to reduce the complexity of the hardware and also cost. Their performance is analyzed and discussed in Sect. 4.

To reduce the complexity in hardware, a hybrid MIMO system with digital and analog pre- coding architecture has been considered (Fig. 1). The transmitted signal at the base station side is given by.

$$x = \boldsymbol{T_{RF}} \sum_{k=1}^{K} \boldsymbol{T_{BB_k}} S_k \tag{4}$$

where $\boldsymbol{T_{BB_k}} \in \mathbb{C}^{N_t \times N_t^{RF}}$ is denoted as the analog beamforming matrix and $\boldsymbol{T_{RF}} \in \mathbb{C}^{N_t^{RF} \times N_s}$ is denoted as the digital beamforming matrix. After the BS analog pre-coder where the signals go through analog phase shifters, the signals are processed digitally and then again up-converted to the carried frequency through RF chains and $S_k \in \mathbb{C}^{N_s \times T}$ denotes the data stream of the $k^{th}$ user.

The signal received for the *kth* user is given by

$$y_k = \sqrt{\rho} H_k x + n_k \tag{5}$$

where $H_k$ is the $N_t \times N_r$ channel matrix between the BS and *kth* user which can be represented as:

$$\boldsymbol{H_k} = \begin{bmatrix} \boldsymbol{H}_{11} & \boldsymbol{H}_{12} & \cdots & \boldsymbol{H}_{1N_t} \\ \boldsymbol{H}_{21} & \boldsymbol{H}_{22} & \cdots & \boldsymbol{H}_{2N_t} \\ \vdots & \vdots & \ddots & \vdots \\ \boldsymbol{H}_{N_r1} & \boldsymbol{H}_{N_r2} & \cdots & \boldsymbol{H}_{N_rN_t} \end{bmatrix} \tag{6}$$

For user k, where $\rho$ is the average received power and $n_k$ is the Additive White Gaussian Noise (AWGN) with zero mean and $\sigma^2$ covariance.

The finally processed discrete signal at the receiver side is given by

$$\tilde{S}_k = \boldsymbol{R}^*_{\boldsymbol{BB}_k} \boldsymbol{R}^*_{\boldsymbol{RF}_k} y_k \tag{7}$$

where $\boldsymbol{R}_{\boldsymbol{RF}_k} \in \mathbb{C}^{N_r \times N_r^{RF}}$ is denoted as the analog combiner matrix and $\boldsymbol{R}_{\boldsymbol{BB}_k} \in \mathbb{C}^{N_s \times N_r^{RF}}$ is denoted as digital combiner matrix. The received signal is processed first analog domain and then it has been processed in the digital domain and then down-converts the signal through RF chains. Equation (7) may be rewritten as

$$\tilde{S}_k = \sqrt{\rho} \boldsymbol{R}^*_{\boldsymbol{BB}_k} \boldsymbol{R}^*_{\boldsymbol{RF}_k} \boldsymbol{H}_k \boldsymbol{T}_{\boldsymbol{RF}} \boldsymbol{T}_{\boldsymbol{BB}_k} S_k + \boldsymbol{R}^*_{\boldsymbol{BB}_k} \boldsymbol{R}^*_{\boldsymbol{RF}_k} n_k \tag{8}$$

The spectral efficiency achieved by this proposed hybrid beamforming massive MIMO is given by

$$SE = \log_2 \left[ \det \left( I_{N_s} + \frac{\rho}{N_s} S_n^{-1} \boldsymbol{R}^*_{\boldsymbol{BB}_k} \boldsymbol{R}^*_{\boldsymbol{RF}_k} \boldsymbol{H}_k \boldsymbol{T}_{\boldsymbol{RF}} \boldsymbol{T}_{\boldsymbol{BB}_k} \boldsymbol{T}^*_{\boldsymbol{BB}_k} \boldsymbol{T}^*_{\boldsymbol{RF}_k} \boldsymbol{H}^*_k \boldsymbol{R}_{\boldsymbol{RF}_k} \boldsymbol{R}_{\boldsymbol{BB}_k} \right) \right] \tag{9}$$

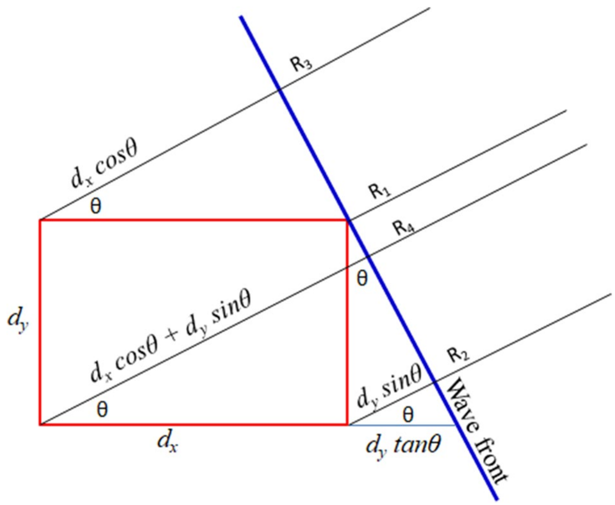
where $S_n = \sigma^2 \boldsymbol{R}^*_{\boldsymbol{BB}_k} \boldsymbol{R}^*_{\boldsymbol{RF}_k} \boldsymbol{R}_{\boldsymbol{RF}_k} \boldsymbol{R}_{\boldsymbol{BB}_k}$ is the noise covariance matrix of analog–digital combiner.

### 3.1 Rectangular Antenna Array Model

The rectangular antenna array model is shown in Fig. 2. Let the source be in the far-field of the receive antenna array.

Assume that every element of the rectangular antenna array is having either isotropic or omnidirectional radiation pattern. The received signals due to the far-field source of the four array elements can be obtained using the expressions given below.

**Fig. 2** Rectangular antenna array geometry



$$R_1 = 1 \tag{10}$$

$$R_2 = e^{-j2\pi d_y sin\theta/\lambda} \tag{11}$$

$$R_3 = e^{-j2\pi d_x \cos\theta/\lambda} \tag{12}$$

$$R_4 = e^{-j2\pi\left(d_y \sin\theta + d_x \cos\theta\right)/\lambda} \tag{13}$$

It is observed that as per the vector geometry, the resultant signal is depending upon the relative phase of the above four vector components. Therefore the resultant field received at the rectangular antenna array due to the far-filed source is given by

$$R = R_1 + R_2 + R_3 + R_4 \tag{14}$$

However in the proposed Hybrid Beamforming for Massive MIMO using Rectangular Antenna Array Model, $N_t$ *x* $N_r$ rectangular array antenna is considered. The resultant signal can be written as

$$R_T = \sum_{n=0}^{N_t-1} \sum_{m=0}^{N_r-1} e^{-j2\pi\left(md_y sin\theta + nd_x cos\theta\right)/\lambda} \tag{15}$$

The range of *n* and *m* is 0 to $N_t - 1$ and 0 to $N_r - 1$ respectively.

### 3.2 Bit Error Rate, Spectral Efficiency and Channel Capacity

The proposed system model has been analyzed by computing spectral efficiency, channel capacity and BER over SNR for a different combination of transmitter and receiver antennas is very important for MIMO systems.

SNR is a ratio of the strength of the received signal to the strength of noise in the operating frequency range. Noise commonly includes unwanted signals, environmental noises, which end up as interference. SNR is generally used as an indicator to assess the quality of the communication channel. The relationship between BER and SNR is inversely related, i.e., high SNR causes low BER and SNR is measured in decibels(dB) The SNR and BER formulae are given by:

$$SNR = 10 \times log_{10} \frac{Signal\,Power}{Noise\,Power} \mathrm{dB} \tag{16}$$

$$BER = \frac{Bits\,in\,Error}{Total\,bits\,received} \tag{17}$$

The channel matrix $h_{ji}$ of the massive MIMO channel matrix can be represented as (6), where it is a complex Gaussian random variable that models fading gain between the *i*th transmitter and *jth* receiver antenna. And in terms of spectral efficiency, the spectral efficiency and the channel capacity of the various system can be calculated using Eqs. (19)–(24). The spectral efficiency and the channel capacity of the conventional system is given by

$$SE_{SISO} = log_2\left(1 + \frac{S}{N}\right)\text{bits/s/Hz/cell} \tag{18}$$

$$C_{SISO} = B * log_2\left(1 + \frac{S}{N}\right)\text{bit/s} \tag{19}$$

The spectral efficiency and the channel capacity of the SIMO as well as MISO system is given by

$$SE_{SIMO} = SE_{MISO} = log_2\left(1 + n\frac{S}{N}\right)\text{bits/s/Hz/cell} \tag{20}$$

$$C_{SIMO} = C_{MISO} = B * log_2\left(1 + n\frac{S}{N}\right)\text{bit/s} \tag{21}$$

where $n = N_r$ is the number of antennas on the receiver side for SIMO and $n = N_t$ is the number of antennas on the transmitter side for MISO.

The Spectral efficiency and the channel capacity for the MIMO is given by

$$SE_{MIMO} = log_2\left(1 + N_t * N_r * \frac{S}{N}\right)\text{bits/s/Hz/cell} \tag{22}$$

$$C_{MIMO} = B * log_2\left(1 + N_t * N_r * \frac{S}{N}\right)\text{bit/s} \tag{23}$$

It has been proven theoretically and practically that massive MIMO shows the highest spectral efficiency and channel capacity. Thus the average area throughput increases with the increased number of transmitting and receiving antennas.

## 4 Experimental Results and Discussions

This section deals with the practical antenna configuration and the results obtained for the proposed rectangular antenna array based Hybrid Beamforming for massive MIMO systems.

### 4.1 Rectangular Antenna Array Structure

Figure 3 represents a developed Rectangular antenna array with a 4X4 antenna array structure using polyhedron material.

There are a total of 12 planar arrays that transmit an equal amount of power individually and each of these is connected to a single receiving antenna placed in a device. The proposed array antenna is capable of forming the radiation beams in all directions in a 3D manner. This is done to maximize the efficiency and serve User Equipment (UE) with higher data rates and low latency. The average size of the receiving antenna device is considered to be from 0.9 to 1.5 m.

The developed Rectangular Antenna Array-based Hybrid Beamforming model for massive MIMO has been simulated and verified using MATLAB R2019b. The parameters assumed for the simulation are tabulated in Table 2. First, the radiation pattern and azimuth pattern without and with Chebyshev Tapering for various rectangular array size

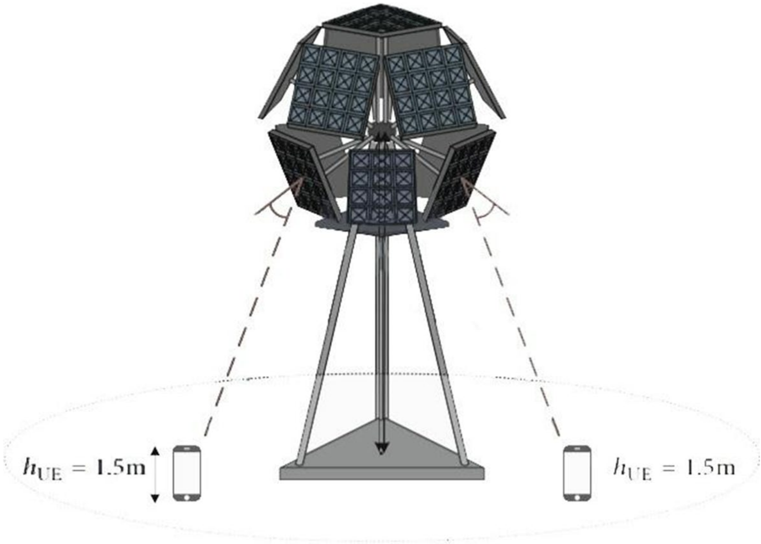



**Fig. 3** Rectangular antenna array structure

**Table 2** Parameters assumed for simulation

| Parameters | Range |
|---|---|
| Radius of the cell | 400 m |
| Number of Transmitting Antenna Array | Upto 256×256 |
| Number of Receiving Antenna | Upto 65 |
| Arrangement of Antenna | Rectangular Polarization Array |
| Separation distance between Antenna (mm) | λ/2 |
| SNR | 20 dB |

for the developed model has been simulated using the parameter shown in Table 2. After that, the spectral efficiency improvement using the developed Rectangular Antenna Array based Hybrid Beamforming in massive MIMO for 5G has been simulated for various data streams and compared with conventional fully digital beamforming technique. At last, the BER performance versus SNR has been analyzed.

### 4.2 3D Radiation and Azimuth Patterns

In this subsection, the simulation and an analysis of radiation and azimuth patterns for various rectangular antennas array has been carried out. Different types of patterns with different array sizes are considered and analysis of their spectral efficiency, BER vs SNR performance has been done.

The simulated beam pattern and azimuth pattern without and with Chebyshev tapering for different rectangular array sizes of 4 × 4, 8 × 8, 12 × 12 and 16 × 16 have been illustrated in Figs. 4, 5, 6 and 7 respectively. From the simulation, it has been observed that there is a clear distinction in radiation as well as azimuth patterns without and with

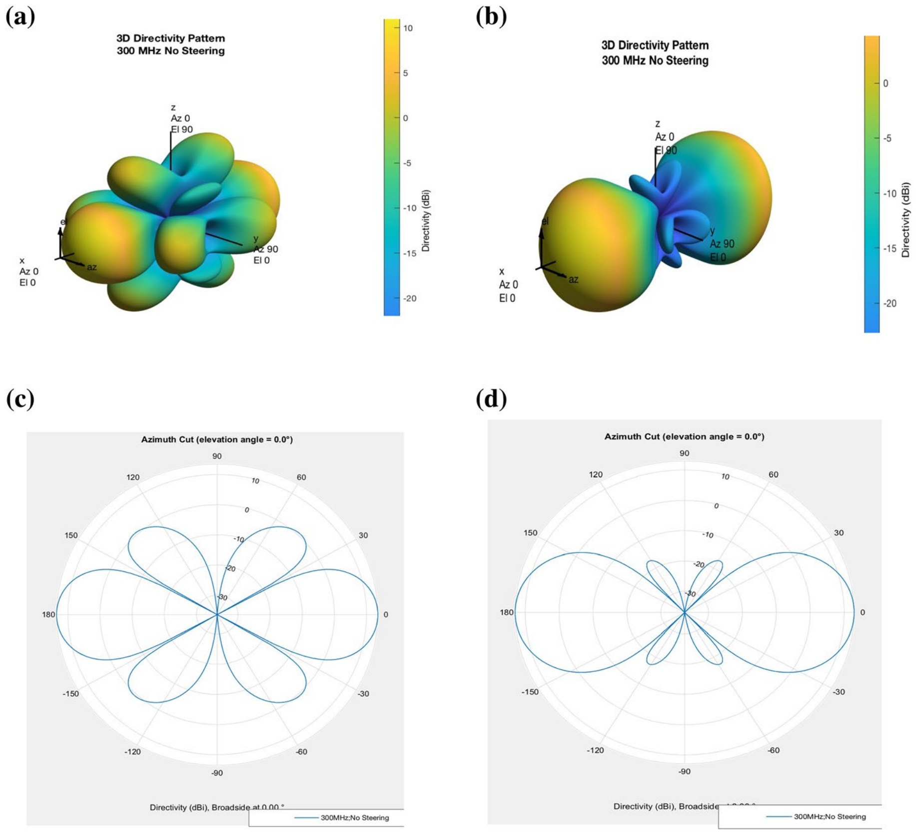



**Fig. 4** Beam patterns—4×4 rectangular array **a** 3D Pattern without Tapering **b** 3D Pattern with Chebyshev Tapering **c** Azimuth Pattern without Tapering **d** Azimuth Pattern with Chebyshev Tapering

Chebyshev tapering. For the basic design parameters, the number of antennas taken for Fig. 4 are $N_{row}=4$, $N_{col}=4$ (4 × 4) and an element spacing of ƛ = [0.5 0.5]. The lattice structure used is rectangular in nature and an amplitude taper is applied in the antenna structure. The element used is an isotropic antenna with a propagation speed of $3\times10^8$ (m/s) and a signal frequency of 300 MHz without any steering. The usage of a 2D-Azimuth pattern is done with a polar coordinate system into consideration.

The main problem that arose is that the formation of Side lobes that were present in the radiation pattern. These are unwanted ones and they lead to reception or transmission of energy in directions that are not required. Amplitude Taper/Amplitude Weighting can be used to reduce the side lobes' directivity in different array sizing. Amplitude taper is used from the centre of the array to the end of the array to control the minor lobe levels. These arrays are non-uniformly excited. The improved main beams can be achieved in the desired direction by controlling the side lobes on the linear array using amplitude tapering. This is nothing but a steerable antenna array and this can achieve the desired results.

In Fig. 4, where a 4 × 4 antenna array is considered, there are many side lobes and one main lobe. But since the antenna array number is very small i.e. only 16 antennas compared to other antenna array configurations considered which has a higher number of antennas.

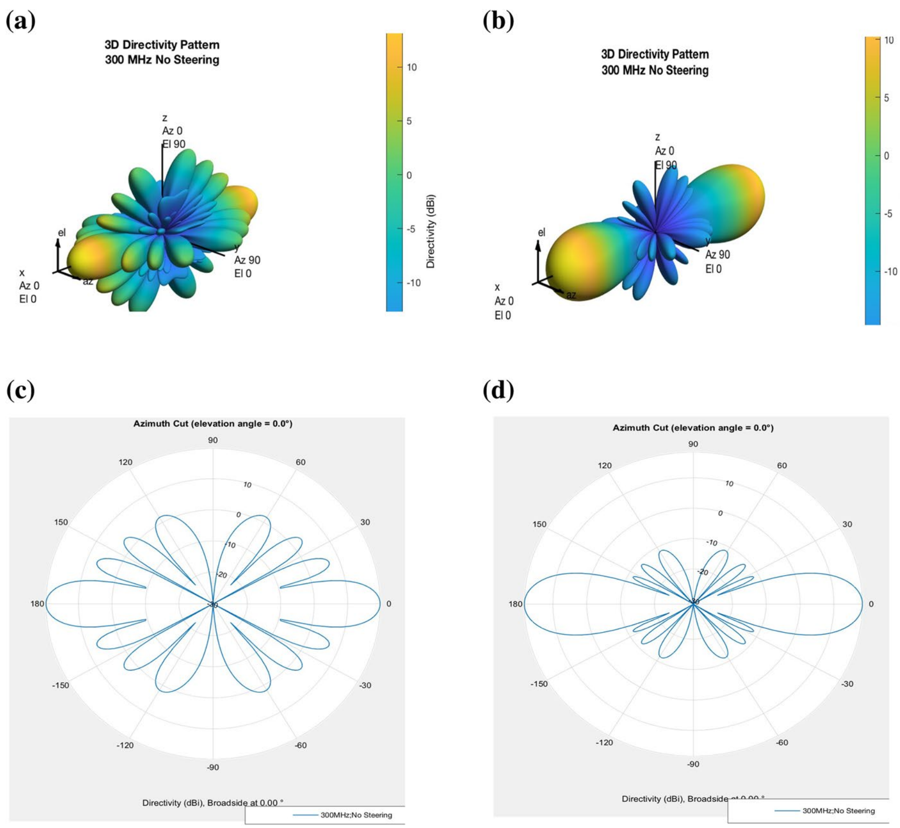



**Fig. 5** Beam patterns—8 × 8 rectangular array **a** 3D Pattern without Tapering **b** 3D Pattern with Chebyshev Tapering **c** Azimuth Pattern without Tapering **d** Azimuth Pattern with Chebyshev Tapering

It is observed that too many side lobes are present in it that can act as the main lobe also. It means that the signal power of the antenna is very small but it covers more area which is not a required feature. By increasing the antenna size of 64, where it is an 8 × 8 antenna array, form Fig. 5, it is observed that the number of side lobes have increased but are not as functional as the main lobe and the directional power of the 8X8 antenna array increased with the increase in the number of antennas and the signal power is increased in a specific direction.

The process of beamforming and beam steering is gradually increased with the increase in the number of antennas. The radiation pattern and azimuth pattern of the 12 × 12 antenna array configuration have been computed and illustrated in Fig. 6. It is observed that as compared with the 4 × 4 and 8 × 8 array antenna, even though the number of side lobes is higher, the directivity of the side lobes is decreased. After incorporating Chebyshev Tapering, the directivity of the side lobes is reduced further for providing better directivity for the main lobe. The antenna array configuration of 16 × 16 has been simulated and shown in Fig. 7. The main difference between normal 3D patterns and 3D patterns with Chebyshev tapering is that the number of side lobes formed in the 3D patterns with Chebyshev tapering will be very small. In the 3D patterning with Chebyshev tapering, it is observed that the patterns formed have a small number of side lobes even in 4 × 4 antenna array size

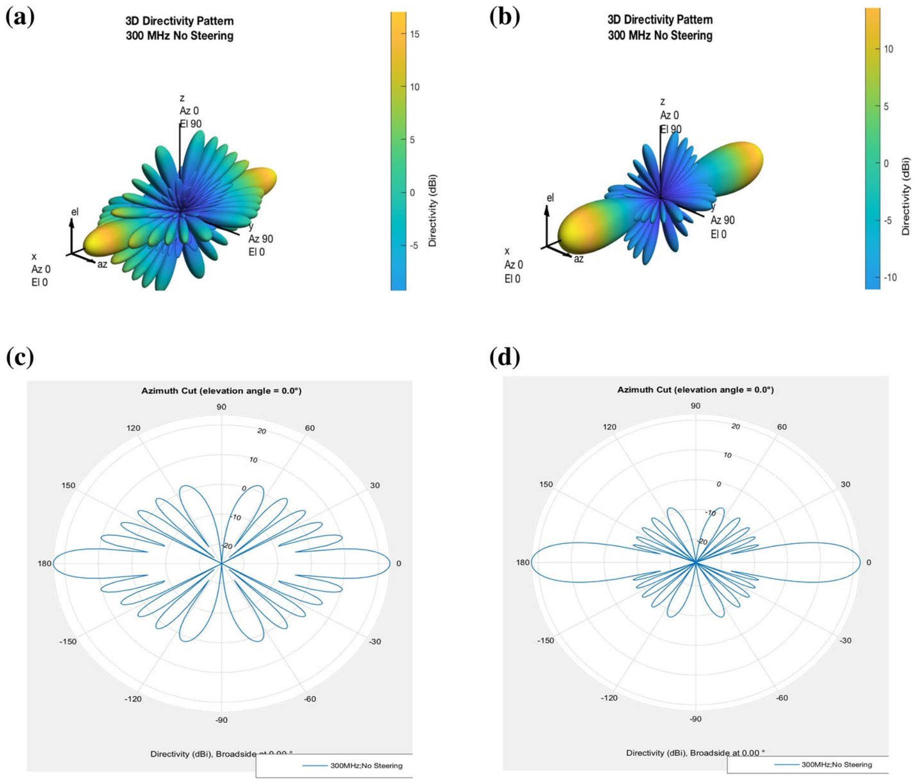



**Fig. 6** Beam patterns—12 × 12 rectangular array **a** 3D Pattern without Tapering **b** 3D Pattern with Chebyshev Tapering **c** Azimuth Pattern without Tapering **d** Azimuth Pattern with Chebyshev Tapering

compared to that of a 3D pattern formed without tapering. The reduction of sidelobe signal gain is due to the change in excitation amplitude done by Chebyshev amplitude tapering**.**

In the previous generation of wireless communication systems, the signal that is dissipated is bidirectional and the amount of power that will be received by each user is low. On observing the azimuth pattern in Fig. 7, it is observed that the number of side lobes is formed with less intensity/directivity and the directivity of the main lobe is very high. From the above illustrations, it has been observed that if the antenna is configured with rectangular array geometry with Chebyshev amplitude tapering then the signal strength achieved is higher with lower side lobes such that the signal can be focused in a required single direction.

### 4.3 Spectral Efficiency for Different Rectangular Array Antennas

In this subsection, the performance of the proposed Rectangular Antenna Array-based Hybrid Beamforming model for massive MIMO has been analyzed by computing the spectral efficiency. The spectral efficiency has been computed for the proposed hybrid beamforming and fully conventional digital beamforming. It has been generated with a different number of antenna and RF chains. The spectral efficiency has been simulated for a different number of data streams with various SNR ranging from −40s to 20 dB. The simulated

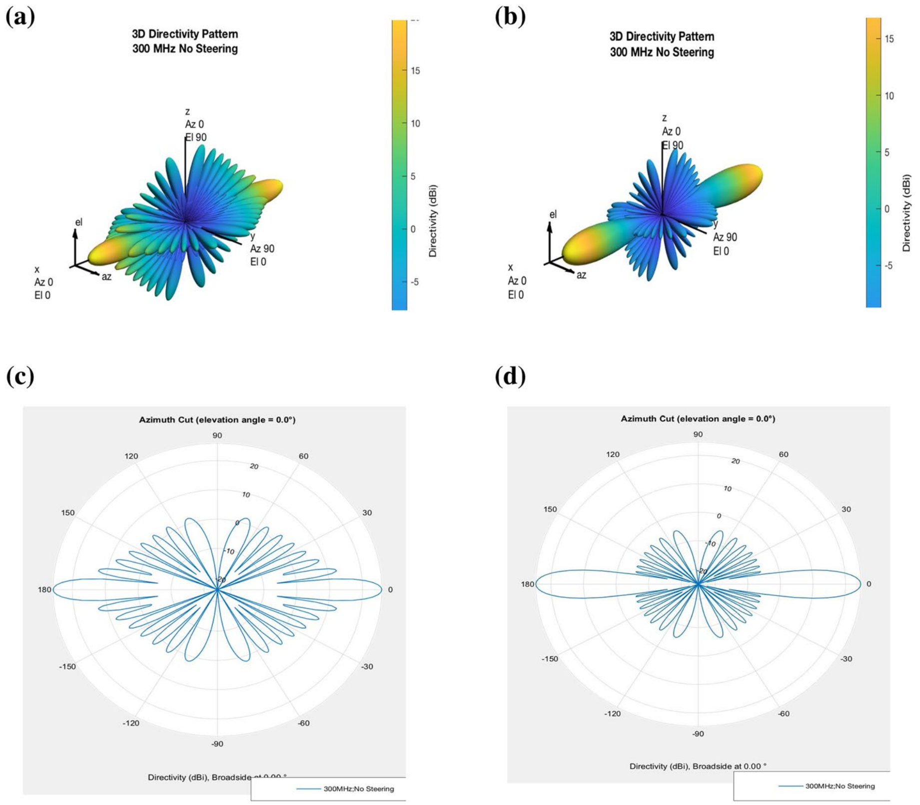



**Fig. 7** Beam patterns—16 × 16 rectangular array **a** 3D Pattern without Tapering **b** 3D Pattern with Chebyshev Tapering **c** Azimuth Pattern without Tapering **d** Azimuth Pattern with Chebyshev Tapering

spectral efficiency for the various number of the rectangular antenna array is shown in Figs. 8, 9, 10, 11 and 12.

Initially, 36 × 4 massive MIMO system is considered with rectangular planar arrays at transmitter and receiver, and the number of RF chains at each end is $N_{rf} = 4$. The spectral efficiency of the proposed rectangular array antenna based Hybrid beamforming of 36 × 4 massive MIMO systems for various numbers of data streams $N_s$ has been simulated and shown in Fig. 8. It has been observed that instead of fully digital beamforming, the number of base stations required is 4 or 36 whereas the same spectral efficiency has been achieved by the proposed Hybrid beamforming with 16 RF chains with different data streams. Figure 9 shows the spectral efficiency achieved in a 64 × 16 massive MIMO Hybrid beamforming model with $N_{rf} = 4$ at both ends for various transmitting data streams $N_s = 1$, 2 and 3. It has been observed that, that instead of 1024 RF chains in conventional fully digital beamforming, the proposed rectangular array antenna based Hybrid Beamforming with 256 RF chains can achieve almost the same spectral efficiency.

The spectral efficiency achieved for 64 × 16 massive MIMO Hybrid beamforming system with $N_{rf} = 8$ for different data streams has been illustrated in Fig. 10. It has been found that, that instead of 1024 RF chains in conventional fully digital beamforming, Hybrid Beamforming with 512 RF chains can achieve the same spectral efficiency. From Figs. 9

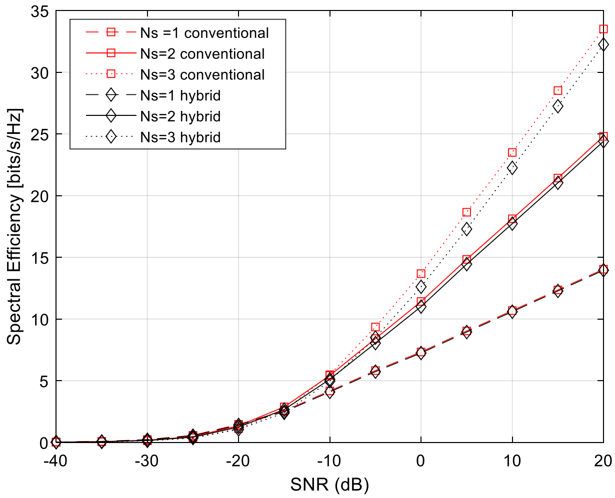



**Fig. 8** Spectral efficiency of fully conventional digital and proposed rectangular array antenna based Hybrid beamforming massive MIMO systems with $N_t = 36$, $N_r = 4$ and $N_{rf} = 4$

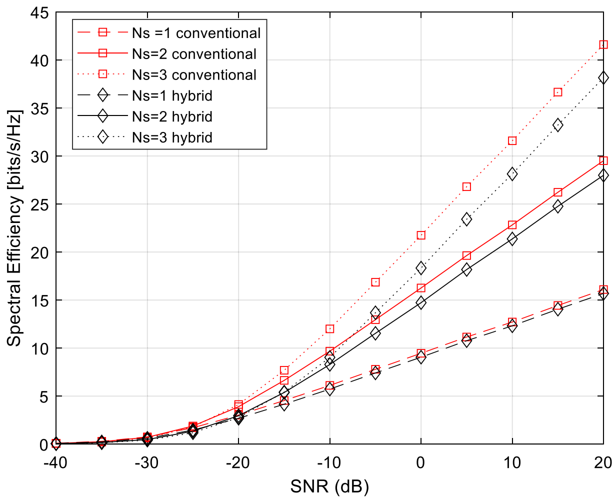



**Fig. 9** Spectral efficiency of fully conventional digital and proposed rectangular array antenna based Hybrid beamforming massive MIMO systems with $N_t = 64$, $N_r = 16$ and $N_{rf} = 4$

and 10 it has been observed that with an increase in the number of RF chains with the same number of antennas, the spectral efficiency can be increased to meet out the spectral efficiency of the conventional fully digital beamforming. More data streams can be transmitted simultaneously at large SNRs by activating additional RF chains due to the improved spectral efficiency. Thus, an increase in RF chains improves spectral efficiency. The difference in spectral efficiency between the system using 4RF & 8RF chains is very minimal and thus hybrid MIMO systems with fewer RF chains can be preferred for the efficient transmission of signals with lower complexity.

To explore the performance of larger antenna arrays, Fig. 11 plots the spectral efficiency achieved for 256 × 64 rectangular array antenna based hybrid beamforming MIMO system with $N_{rf} = 8$ at both ends where spectral efficiency is almost the same with a very minimal deviation in a fully digital system and hybrid system. The spectral efficiency achieved for the 256 × 64 massive MIMO Hybrid beamforming system with $N_{rf} = 8$ and $N_{rf} = 16$ for different data streams has been illustrated in Figs. 11 and 12 respectively. It can be observed

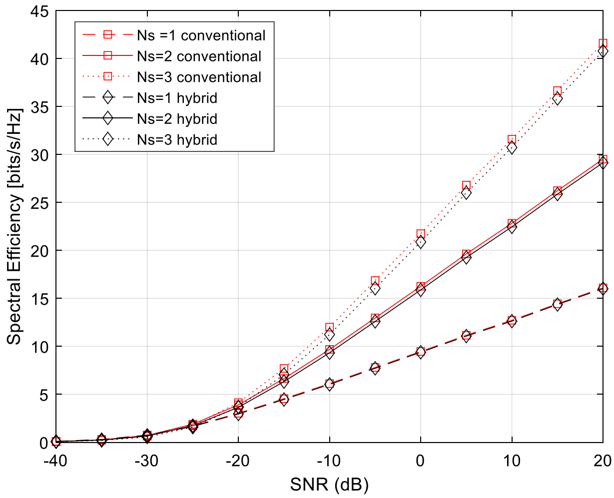



**Fig. 10** Spectral efficiency of fully conventional digital and proposed rectangular array antenna based Hybrid beamforming massive MIMO systems with $N_t = 64$, $N_r = 16$ and $N_{rf} = 8$

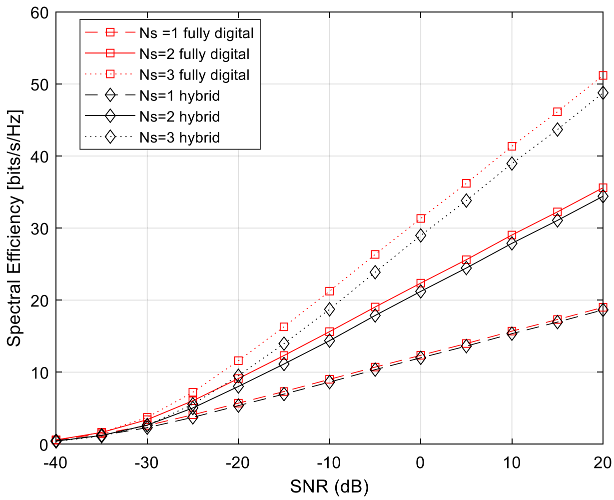



**Fig. 11** Spectral efficiency of fully conventional digital and proposed rectangular array antenna based Hybrid beamforming massive MIMO systems with $N_t = 256$, $N_r = 64$ and $N_{rf} = 8$

that the spectral efficiency of the hybrid beamforming in a massive MIMO system perfectly matches with the spectral efficiency of a fully digital MIMO system when the RF chains are increased from $N_{rf} = 8$ to $N_{rf} = 16$ in the hybrid MIMO system. From the above analysis, it has been proved that a larger rectangular antenna array with hybrid beamforming techniques matches the spectral efficiency nearly equal to the fully digital beamforming techniques with less number of antennas as well as RF chains. This will lead to low computational complexity and enhance the performance of the system thus showing an advantage over conventional fully digital MIMO systems.

The computed spectral efficiencies for both fully digital conventional beamforming and the proposed rectangular antenna array based hybrid beamforming in massive MIMO system with a different number of RF chains at SNR = 20 dB are compared and tabulated in Table 3. It is observed that for 64 × 16 massive MIMO system, almost the same spectral efficiency of that fully digital beamforming has been achieved if the number of RF chain has been varied from 64 to 16. This will decrease the % of reduction of

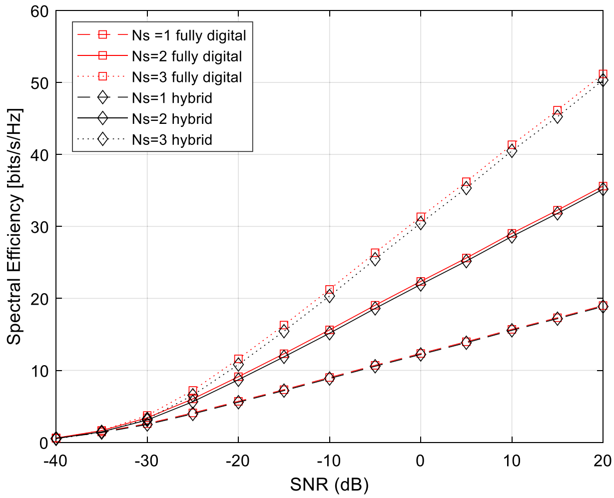



**Fig. 12** Spectral efficiency of fully conventional digital and proposed rectangular array antenna based Hybrid beamforming massive MIMO systems with $N_t = 256$, $N_r = 64$ and $N_{rf} = 16$

**Table 3** Spectral efficiencies of fully conventional digital and proposed Hybrid beamforming massive MIMO systems at SNR = 20 for different rectangular antenna array structures and RF chains

| Number of data streams $N_s$ | Spectral efficiency (bits/s/Hz) | | % of reduction in number RF chains |
|---|---|---|---|
| | Fully digital | Hybrid | |
| 36 × 4 Antennas | | | 88.89% |
| | 36 × 4 RF chains | 4 × 4 RF chains | |
| 1 | 14.04 | 13.95 | |
| 2 | 24.8 | 24.4 | |
| 3 | 33.5 | 32.24 | |
| 64 × 16 Antennas | | | 98.45% |
| | 64 × 16 RF chains | 4 × 4 RF chains | |
| 1 | 16.1 | 15.69 | |
| 2 | 29.51 | 27.99 | |
| 3 | 41.6 | 38.15 | |
| 64 × 16 Antennas | | | 93.75% |
| | 64 × 16 RF chains | 8 × 8 RF chains | |
| 1 | 16.1 | 16.01 | |
| 2 | 29.51 | 29.14 | |
| 3 | 41.6 | 40.77 | |
| 256 × 64 Antennas | | | 99.60% |
| | 256 × 64 RF chains | 8 × 8 RF chains | |
| 1 | 19 | 18.64 | |
| 2 | 35.6 | 34.42 | |
| 3 | 51.19 | 48.77 | |
| 256 × 64 Antennas | | | 98.44% |
| | 256 × 64 RF chains | 16 × 16 RF chains | |
| 1 | 19 | 18.87 | |
| 2 | 35.6 | 35.17 | |
| 3 | 51.19 | 50.33 | |

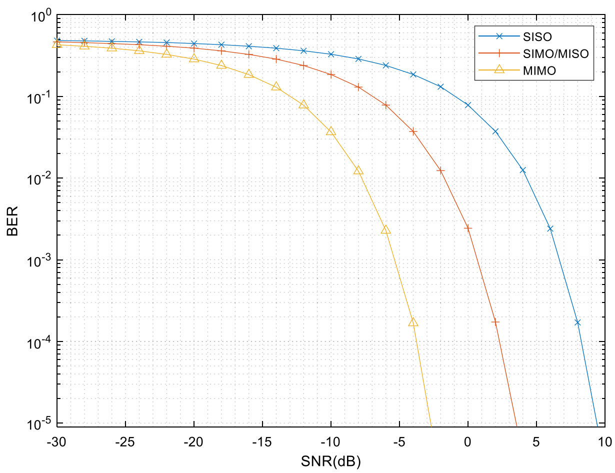
RF chains from 93.75 to 98.45%. Similarly, for the 256 × 64 massive MIMO system, the same spectral efficiency of that fully digital beamforming has been achieved if the number of RF chains has been varied from 256 to 64. This will decrease the % of reduction of RF chains from 98.44 to 99.60%. From Table 3, it has been observed that rectangular array antenna-based Hybrid beamforming in a massive MIMO system reduces the computational complexity up to 99.60% as compared with conventional fully digital beamforming to achieve the almost same spectral efficiencies.

### 4.4 BER Analysis vs SNR

The BER performance metrics with different SNR for different rectangular antenna array size of SISO, SIMO, MISO and MIMO has been simulated and compared. An upgraded SNR suggests a shrunk BER which is nothing but a reduced error rate leading to better performance. The BER has been computed for different SNR ranging from − 30 to 10 dB. The simulated BER with various SNR for 4 × 4 antenna array configuration is shown in Fig. 13. It shows that there is a total gain of around 12 dB in MIMO over the SISO. Also, there is around 6 dB gain in MIMO over the MISO/ SISO for the same BER. Also, it has been observed that a massive MIMO array attains the same BER as compared with SISO, SIMO, MISO at lower SNR. This will make the massive MIMO more suitable for the noisy environments also.

For the 8 × 8 rectangular array configuration, the BER has been computed for various SNR and illustrated in Fig. 14. From Fig. 14, it is found that there is a total gain of 24 dB in MIMO over the SISO and 12 dB gain over the MISO/SISO with the same BER. It has been depicted by comparing Figs. 13 and 14 that by increasing the number of array antenna elements from 4 × 4 to 8 × 8 for a MIMO system, it is possible to increase the antenna gain of 7 dB. Thus, by increasing the number of antennas on the transmitter and receiver side, array gain can be increased and thus the performance can be escalated. From the above simulation, it is observed that the MIMO is more suitable for a noisy environments and also if the number of array elements of the antenna is increased.

**Fig. 13** BER vs SNR—4 × 4 array configuration in SISO, SIMO/MISO, MIMO systems



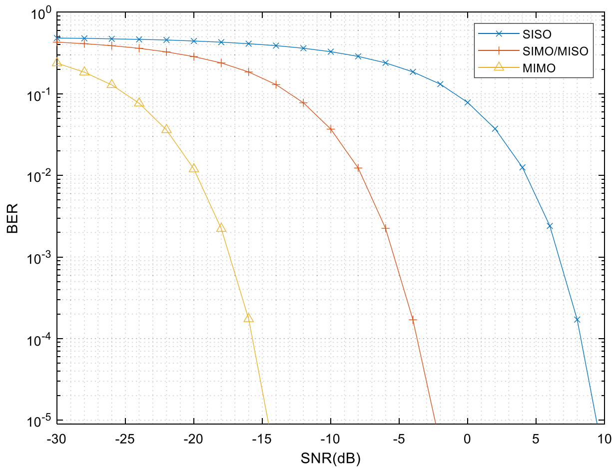



**Fig. 14** BER vs SNR—8 × 8 array configuration in SISO, SIMO/MISO, MIMO system

## 5 Conclusion

In this research work, a rectangular array antenna based Hybrid beamforming model in massive MIMO for 5G mobile network has been proposed. In order to increase the main lobe signal strength and also to suppress the side lobes, Chebyshev tapering has been used. The proposed rectangular antenna array model has been simulated for various array elements such as 4×4, 8×8, 12×12 and 16×16. The radiation pattern and Azimuth patterns have been generated with and without Chebyshev tapering. Also the BER of the proposed MU-MIMO for various antenna arrays has been simulated and compared with existing methods. From the spectral efficiency metric evaluation, it has been observed that the proposed rectangular array antenna based Hybrid beamforming in a massive MIMO system reduces the computational complexity up to 99% as compared with conventional fully digital beamforming to achieve the same spectral efficiencies. Therefore, the proposed method may solve the challenges faced by 5G wireless technology. While reducing the cost, the number of RF chains, hybrid beamforming carried out an outstanding performance. Thus, rectangular antenna array-based hybrid beamforming in massive MIMO indicate excellent performance and lesser cost when compared to conventional fully digital beamforming. Further, the spectral efficiency can be increased by utilizing the 3-D rectangular array antenna model in the future. Also, the proposed rectangular array antenna based Hybrid beamforming in a massive MIMO system can be designed and deployed in future work.

**Funding** NA

**Declarations**

**Conflict of interests** The authors declare that there is no conflict of interest regarding the publication of this paper and that the work presented in this article is not supported by any funding agency.

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