A Proposed Method to Coordinate mmWave Beams Based on Coordinated Multi-Point in 5G Networks

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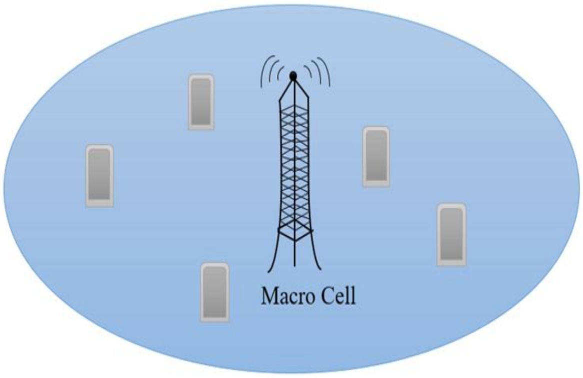
Abstract**—**5G overcame the severe shortage of cellular spectrum used by its predecessors by using millimeter-wave (mmWave) packets that provide broadband to 5G wireless networks. The problem of Inter User Interference (IUI) is also one of the most important and dangerous problems facing telecommunication networks. IUI is exacerbated, especially in the areas near the Tower as the narrow coverage area compared to the areas farthest from the Tower. As a result of this effect, our paper proposes a new model by taking a matrix of antennas at different heights and coordinating mmWave beams. Coordinated Multi-Point (CoMP) is the essential solution in 5G to improve throughput and coverage performance. As a result, millimeter wave technology was used in the proposed CoMP system. The new proposed system works to study the effect of the height of the antenna matrix on reducing IUI by calculating the peak capacity value on the user with different distances. In addition to the impact of the azimuth angle of arrival AoA ($\emptyset$) on capacity when implementing each scenario. Simulation results show that the proposed system scheme with different heights of the antenna matrix can get a large capacity than a traditional system. Choosing the best antenna matrix height reduces interference and improves capacity. The highest improvement obtained is 53%.

Index Terms**—**5G, Millimeter-wave, CoMP, antenna matrix, Beamforming, massive MIMO, azimuth angle of arrival.

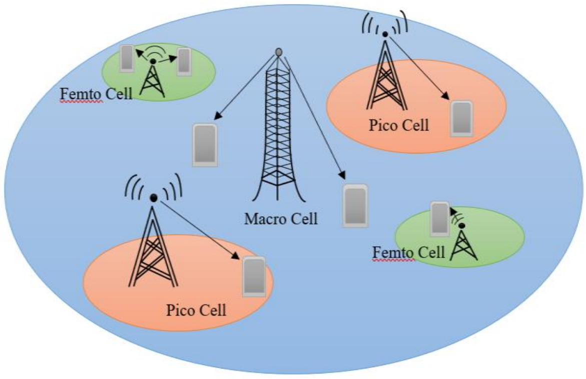
I. Introduction

The cell phone is considered one of the most important revolutions of the twentieth century and to this day. Cellular networks communicate with each other wirelessly using the radio frequency spectrum. Wireless networks have continued to advance since their advent. This has led to the emergence and use of new technologies and applications [1], [2]. The transition from the 1st generation to the 5th generation that most countries announced recently promises that communications will be on a promising path. The traffic continued to increase due to the heavy use of mobile devices in the 4th generation. This issue has been addressed in 5G systems [2], [3]. The most important technologies used in 5G are Beamforming, Massive MIMO, mmWave, Full Duplex, Small Cell, and non-orthogonal multiple access (NOMA) [2], [4].

5G system structures are divided into two main types: homogeneous and heterogeneous networks shown in Fig. 1(a, b). Homogeneous networks consist of a specified number of users within the same coverage area of a particular cell type. Heterogeneous networks use millimeter waves and consist of large cells such as (Macro) and small cells such as (femtocell, picocell, and microcell) [3], [5].



a.



b.

Fig. 1. (a, b): Homogenous and heterogenous network.

Millimeter-wave has an essential role in 5G communications and lies in the electromagnetic spectrum at the frequency range (30-300 GHz). It is called mmWave because it has a short wavelength (1-10 mm) [2]. The mmWave frequency range is extremely high frequency, and the frequency range from 3 to 30 GHz is super frequency [6].

Millimeter waves provide new bands that have a higher data rate. So, increasing the security and privacy of mmWave in 5G, especially when using beamforming. The use of beams is to have the antenna broadcast in one direction instead of the omnidirectional formula used by the antenna for microwaves of previous generations [7],

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[8]. The mmWave has important determinants compared to microwave frequencies [9], [10].

1) Pathloss: Path losses for free space are proportional to the square of the carrier frequency, as stated by Friis's law (The transmission in all directions increases the possibility of blocking the carrier).
2) Diffraction and blockage: Diffraction causes omnidirectional propagation in the two contact types, LOS and NLOS. Microwaves penetrate solid materials and buildings more than mmWave signals.
3) Rain attenuation: The attenuation of millimeter waves from rain is more than microwaves by about 10 dB/km.
4) Atmospheric absorption: The mmWave is more likely to absorb oxygen at higher frequencies than microwaves.

Despite all these limitations, mmWave has already been implemented in 5G. When the physical aperture size is constant, the antenna gain value changes quadratically as the frequency increases. Accordingly, if the number of antennas within the same array area increases, the transmitted and received energy increases also in a given direction [6].

CoMP is a 4G network technology to support many varied user requirements. Also, this technology has been used in 5G. CoMP reduces interference by improving throughput with limited power consumption [11]. The improvement of a higher received signal strength indication (RSSI) is the result, and the value of this index indicates an effective channel quality index (CQI) as a higher SINR. The most difficult challenge is serving users at the cell boundary due to its distance from the base station and the effect of high interference on it due to signals coming from the adjacent sectors known as inter-cell interference (ICI), or reuse of the same frequency from neighboring cells, which is known as commodity channel indicator (CCI). Thus, CoMP gives better resolution and lower complexity for cell edge support [12], [13]. One of the CoMP types is inter-site, which reduces the value of overlap between cells by coordinating several Towers located in different areas. The second type is the intra-site which means coordination between several sectors in a single cell. Beam-COMP is characterized by the process of coordinating the packages of one Tower to serve one of the cell sectors [14]. The CoMP types are shown in Fig. (2) [15].

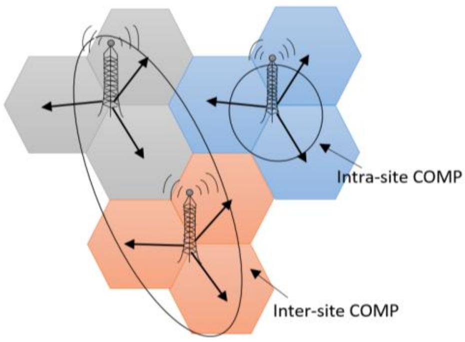


Fig. 2. CoMP type

II. Related Work

The emerging 5G networks announced recently by some countries will operate in mmWave frequency bands. The advantages of 5G networks in providing high speed, reducing power consumption, and reducing latency make them robust and with a bright future. These features were presented with a brief introduction to these networks discussed in [11]. Millimeter-wave communications have attracted much interest due to their broadband properties. The historical progress of 5G networks and the advantages and disadvantages of mmWave were studied, and most applications are used [2]. The challenges faced by the 5G network using millimeter waves in heterogeneous networks (HetNet) in the first part were also discussed [16]. The maximum gain is obtained by adjusting the antenna vector elements and the use beamforming technique in massive MIMO antennas. A comparison has been made between the two proposed methods for the future digital beamforming Grid of Beams (GOB) and Eigen Based Beamforming (EBB). In addition to clarifying the types of beamforming, all of this was reviewed in [3]. The number of beams required for massive MIMO is unclear in 5G networks. Monte Carlo simulation was used [17]. The optimum number of beams was reached to obtain the highest capacity per HPBW. In [18], the so-called beam switching is used and suppresses interference between but at the expense of complexity in mmWave systems. Another model suggests an algorithm called beam interference. The proposed algorithm reduces the computational complexity and solves the interference suppression problem. Path loss models were used for LOS and NLOS cases in rural Tokyo and at a frequency less than 6 GHz [19]. In [20], CoMP technology has proven to be one of the effective interference mitigation techniques through efficient resource allocation and interference management. As the throughput of the cell increases with the increase in the number of users. As a result of complexity increasing in inter-site CoMP systems and achieving low gains, and accordingly, the Beam-CoMP scheme was proposed in [14]. The proposed system coordinates the beams in the same sector. The proposed system proved its effectiveness by achieving higher throughput and less complexity compared to systems without the CoMP technique.

In this paper, a new coordination system is proposed in 5G homogeneous networks for downlink transmission. The proposed coordination includes a group of antennas for different heights in the same Tower. Packages are coordinated to serve users located within different dimensions of the Tower. In addition, investigation of the effect of the user's distance from the Tower at different AoA angles. mmWave and beamforming technologies were used in the proposed new system. The rest of this paper is organized in the following sections: The section (II) made related works. Section (III) shows the most important technologies which used in 5G. The idea of the proposed system is presented in the (IV) section.

Simulation and discussion of the results are submitted in the (V) section. Finally, the (VI) section contains the conclusion and future work.

III. Some 5G Technolgies

A. Beamforming Technology

The beamforming of the array antennas is used to focus the signal towards a specific receiver. The use of this technology results in less interference between users. This technology can change the amplitude and phase signals to direct the beam towards the wanted direction. It is implemented by the array antennas to obtain an optimum gain by modifying the vector elements of the array [3], [21]. The beamforming types are divided into:

1) Analog beamforming. Fig. 3 shows the simplest type of analog beamforming. The analog signal changes occur in terms of change in amplitude and phase. Each phase-shifter is associated with an antenna, so the accuracy is very low. One of the advantages of analog beamforming is a minimum number of devices [3], [21].

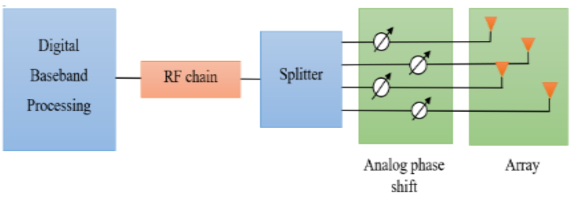


Fig. 3. Analog beamforming

2) Digital beamforming. Amplitude and phase changes are done in a digital baseband (precoder) before the RF chain is added to get very high accuracy. High spectral efficiency is achieved for high frequencies, i.e., before changing from digital to analog conversion. Fig. 4 shows this type [3], [6].

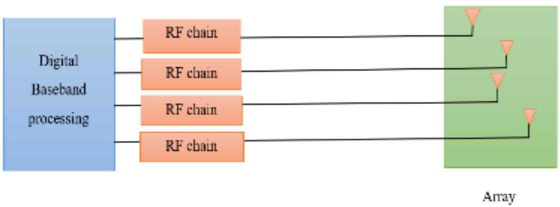


Fig. 4. Digital beamforming

3) Hybrid beamforming. It consists of two domains: analog and digital domains. The analog field is obtained from which different phases. The digital modulation of the packet can be obtained in the baseband field shown in Fig. 5 [3], [21].

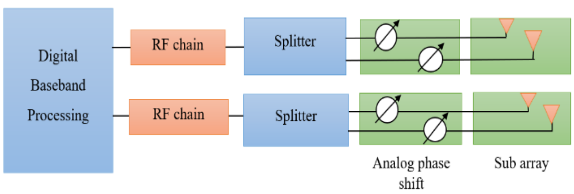


Fig. 5. Hybrid beamforming

B. Massive MIMO

A system that can serve dozens of users simultaneously using hundreds of antennas. It is also called Large-Scale MIMO (LS-MIMO). The Massive MIMO system with the antenna array can change both AoA and elevation angles. Adjusting the AoA and elevation angles propagates the beams in a three-dimensional space (3D MIMO). The system mitigates IUI due to the use of a very narrow beam [22], [23].

IV. Proposed System

A. System Model

There are different antenna arrays types (linear, planar, circular, and spherical). In this paper, a square planar matrix is used and located in alignment with the (x and y) axes with equal dimensions between elements. The square matrix consists of rows and columns (Nx and Ny) of the (x and y) axes, respectively. The space between elements is (dx and dy) of the (x and y) axes [24].

The radiation factor of Beam for planar array at a user in (x and y) direction is [24]

$$S(\theta_{ab},\varphi_{ab}) = S_{ax}(\theta_{ab},\varphi_{ab}).S_{ay}(\theta_{ab},\varphi_{ab}) \tag{1}$$

where:

$$S(\theta_{ab},\varphi_{ab}) = \left\{\sum_{m=0}^{Nx-1} I_m\ e^{J_m k d_x sin\theta_{ab} cos\varphi_{ab} + \alpha_x}\right\} * \left\{\sum_{n=0}^{Ny-1} I_n\ e^{J_n k d_y sin\theta_{ab} cos\varphi_{ab} + \alpha_y}\right\}$$

The matrix has N_X * Ny with spacing dx and dy equal 0.5λ. I_m and I_n are known current amplitude. k=2π/λ where λ is carrier wavelength.

In this paper, the current amplitude values are optimized to obtain the highest value for capacity. Fig. 6. shows the proposed current amplitude values.

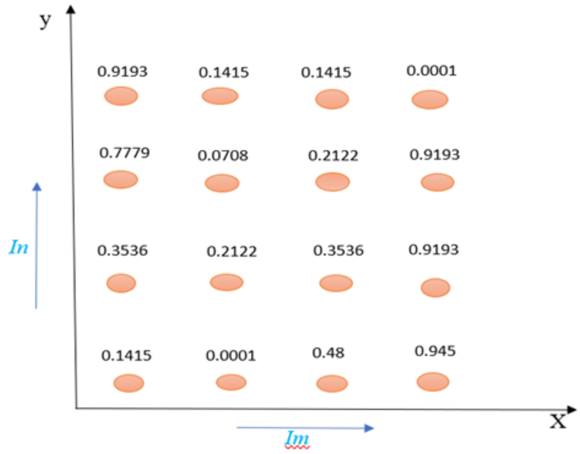


Fig. 6. Proposed current amplitude values.

$$\alpha_x = -kd_x \sin\theta_b \sin\varphi_b \tag{2}$$
$$\alpha_y = -kd_y \sin\theta_b \sin\varphi_b \tag{3}$$

α_x and α_y are current uniformly graded phase of Beam. To calculate the P_l in the case of LOS by following equation [14]:

$$P_l = \propto + 10\log 10(d) + X_\sigma \quad (4)$$

where d is path length between the Tower and the user in meter and calculated by equation $d=\sqrt{z^2+r^2}$ where z is height of antenna array and the transmitter is separated from the receiver by r, which is measured in meter. $\propto$ is floating intercept, β is a linear slope and X_σ is zero mean Gaussian random deviation in dB. Interference Power between beams by the following equation [14]:

$$P_I\,[dB]= P_t\,[dBm]+ G_t\,[dBi]+ G_r\,[dBi]- P_l\,[dB] \quad (5)$$

According to equation (5), G_t and G_r are transmitted and received gain. Where G_t calculated by $G_t = S^2_{normilized}\,G_{tmax}$. Received signal power of user is [25].

$$P_r(d)[dBm]=P_t[dBm]+G_t[dBi]+G_r[dBi]+10\log\left(\frac{\lambda}{4\pi d}\right)^2 \quad (6)$$

To calculate the signal to interference plus noise ratio by the following equation:

$$SINR= \frac{P_r[mW]}{N[mW]+P_I[mW]} \quad (7)$$

where N is noise power. The capacity of the user is calculated by Shannon formula [26]:

$$C=B\log_2(1+SINR) \quad (8)$$

where C in bit/sec, B is the Bandwidth in Hz.

B. Inter User Interference (IUI) Scenario

The proposed system includes placing several groups of antennas on one Tower at different heights. This method was proposed to solve or reduce the interference problem. Fig. 7 shows interference occurs at the receiver site [21]. Wide beams in close areas cause high interference between users, especially users who are close to each other.

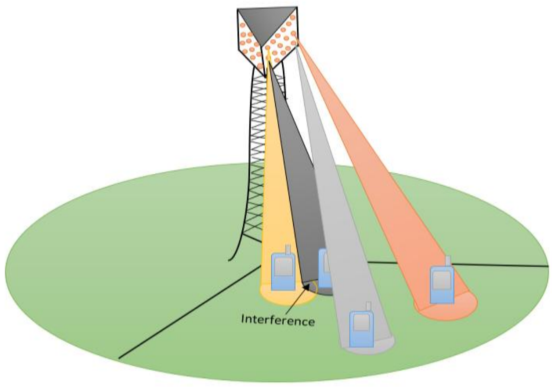


Fig. 7. IUI scenario

C. IUI Mitigation Using Proposed CoMP System

In this paper, three sets of antennas were selected at heights (5, 15, and 50 m) shown in Fig. 8 [21]. Through the highest throughput value for each user, the appropriate antenna height is selected within the proposed system.

The process of selecting the appropriate antenna in this paper is done according to the user's distance and angle of location. According to the coordination between the antenna groups, the interference of mmWave beams is reduced. Reduce interference, i.e., increase the SINR ratio, which increases throughput.

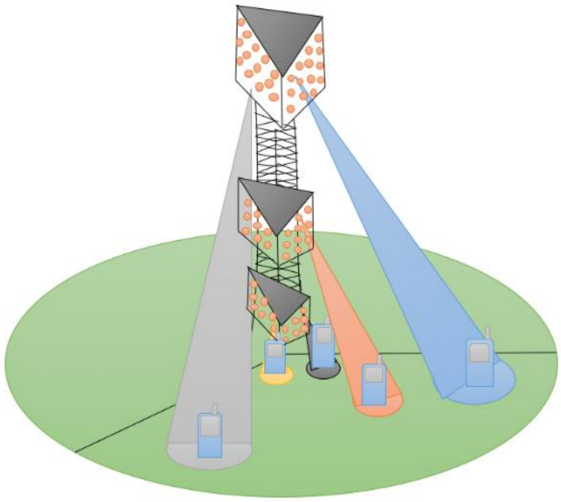


Fig 8. Proposed system model

V. Simulations and Result

A. Simulation Parameters

MATLAB simulator is used to demonstrate the performance of the beams-Coordinate algorithm between antenna matrixes. The interference effect is suppressed through antenna matrix height in the mmWave downlink system. Three antenna groups heights are proposed in one Tower, and users are located at different distances from the Tower with the same angles for azimuth AoA (It is the angle between the millimeter wave beam and the main sector axis). The optimized capacity is applied to each user then the appropriate height of the antenna array is selected for transmitting data to the user. All users are located in the same horizontal plane in the cells. The beamforming operation is a line of sight (LOS) situation for each employer. The detailed simulation parameters used in the proposed model are shown in Table I [1].

TABLE I: THE SIMULATION PARAMETERS USED

Simulation Parameters used	The value
Number of users	2 to 20
Hight of antenna array	5, 15, and 50m
Sector radius	50 m
Carrier Frequency	28 GHz
Bandwidth	500 MHz
Antenna array Transmit Power	22 dBm
Antenna array Gain	27 dBi
User Antenna Gain	0 dBi
Pathloss Model	Line of Sight (LOS)
Noise Temperature	298 k

B. Impact of Antenna Matrixes Height on The Capacity

At an azimuth AoA angle of 90°, 8 users were placed at different distances from the Tower. The effect of antenna array height is studied according to users' locations. Fig. 9 shows the relationship between the antenna matrix height and the user's distance from the Tower.

A significant improvement in capacity is observed for users located in the areas far locations from Tower. 20% of the coverage area in remote areas from the Tower saw an increase of 18.354% in 50 m antenna matrix height compared to the 2 m height. This proves that high altitude antenna matrix is better for users in remote locations from Tower. The results also show that the peak capacity value is obtained when the antenna matrix height equals the user's distance from the Tower.

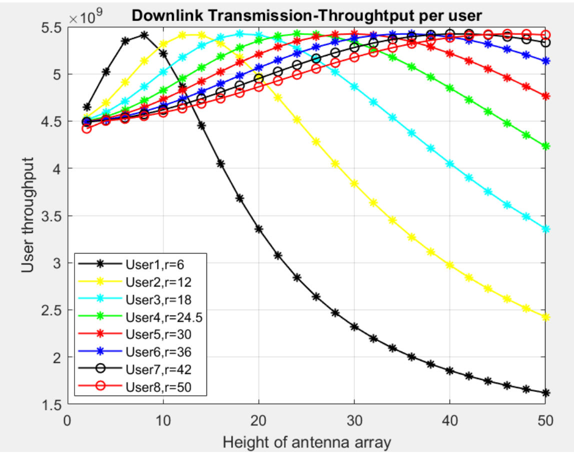


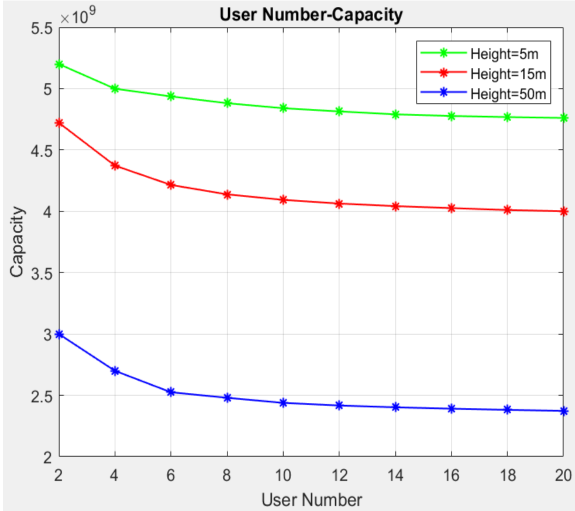
Fig. 9. The relation between users' throughput and antenna matrix height at azimuth AoA= 90°

C. Proposed CoMP System Simulation

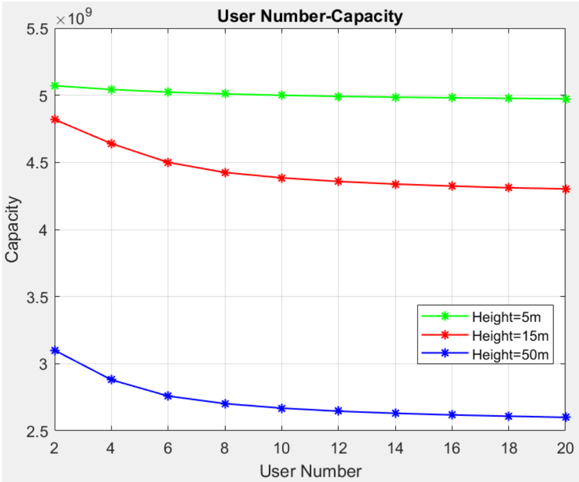
According to the results obtained from the previous paragraph, it proposed three heights of antennas in one Tower. Users are located at different distances from the Tower and at the same angles of azimuth AoA for each scenario. According to the peak capacity value for each user, the appropriate height of the antenna matrix is selected for transmitting data to the user. All users are located in the same horizontal plane in the cells. The beamforming operation in the LOS situation for each user. The simulation results are divided into three categories:

The first category contains simulated results of increasing the number of users located at different distances from the Tower with the throughput. Three different heights of the antenna array (5, 15, and 50 m) were assumed with azimuth AoA angles 20° and 70°. This relationship is represented in the following curves in Fig. 10.

The curves in Fig. 10 demonstrate an increase in capacity when the number of users located at different distances from the Tower increases. The antenna matrix with a height of 5 m has the highest value of a capacity in scenarios (a and b) due to the narrow beam of this height, which reduces the Inter User Interference (IUI). Reducing the interference value improves the SINR for each user and thus the highest value for the CQI. According to Shannon's law, higher capacity can be obtained. A high CQI indicates that the highest mode of coding, modulation, and the highest SE can be used.



a. ϕ =20°



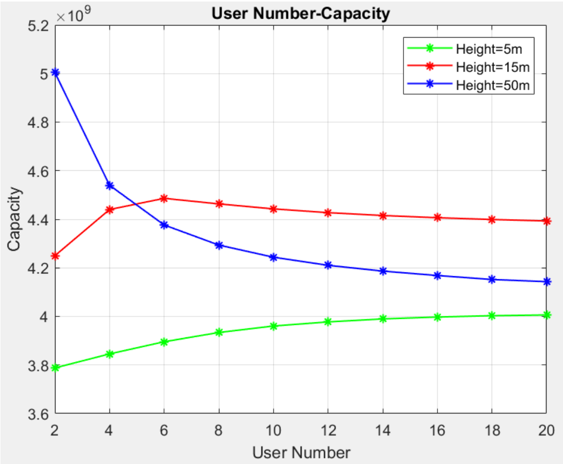
b. ϕ =70°

Fig. 10. The capacity with a varying number of users at azimuth AoA (20° and 70°)

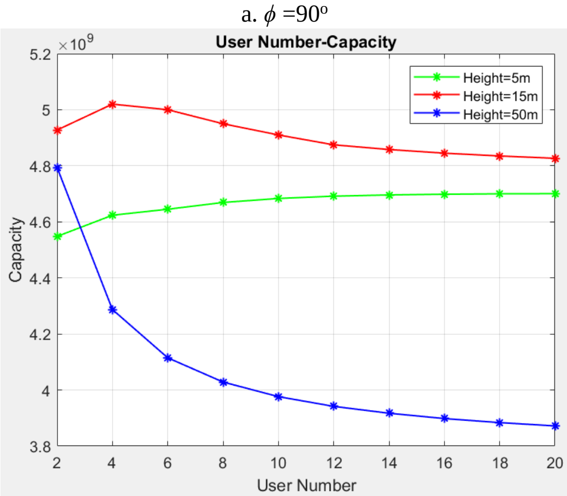
The 15 m matrix antenna height has wider beams. So, the interference ratio is higher at these angles of azimuth AoA, which reduces the capacity compared to the 5 m matrix antenna. The 50 m matrix antenna height has the widest for the beam. So, the capacity values are lower at the other matrix antenna heights. The sector capacity values at the antenna matrix height of 5 m are greater than the capacity values at the antenna matrix height of 15 and 50 m by 21.543% and 53.37 %, respectively.

The second category takes the same parameters as the first one. But when azimuth AoA angles equal to 90 ° and 100 ° are shown in Fig. 11.

It shown that the distances begin to converge between subscribers when the azimuth AoA and the number of subscribers increase, which leads to an increase in IUI at the height of two groups of antennas equal to 5 and 50 m. In other words, the antennas set at a height equal to 15 m reduce this interference and increase the capacity value.



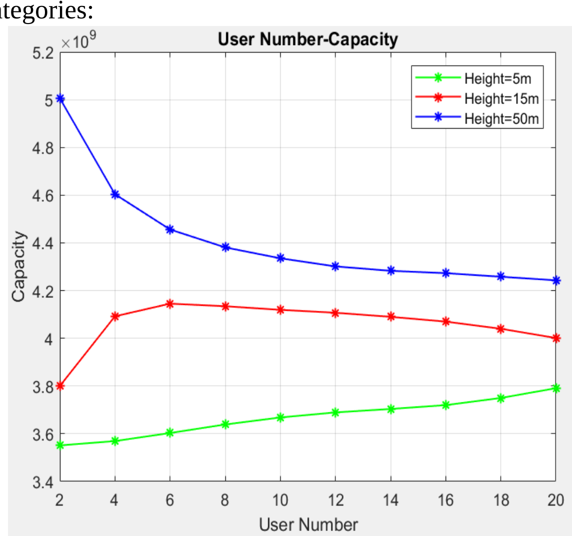
a. ϕ =90º



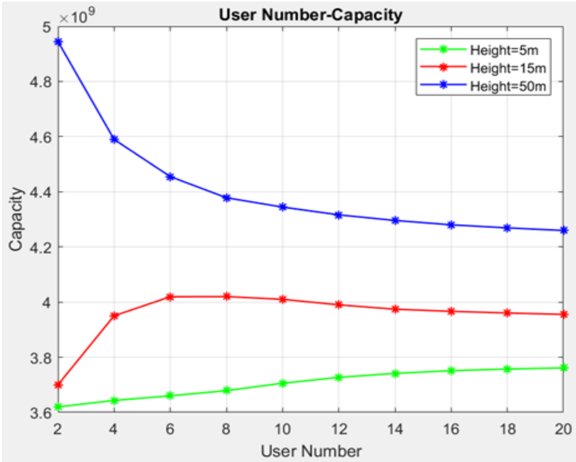
b. ϕ =100º

Fig. 11. The capacity with a varying number of users at azimuth AoA (90º and 100º)

The capacity improvement ratio for the 90o and 100 o angles when the antennas group used with a height of 15 m to the capacity value of the antennas group used with a height of 5 m are 3.33% and 4.7%, respectively, while the capacity improvements for the antennas group used with a height of 50 m are 19.37% and 9.433%, respectively categories:



a. ϕ =110º



b. ϕ =120º

Fig. 12. The capacity with a varying number of users at azimuth AoA (110º and 120º)

Fig. 12 shows the third category of 50 m antenna matrix that achieves the highest capacity at angles azimuth AoA 110º and 120º due to the possibility of separating the beams at this height, which reduces the interference from other users in the same sector or other users from the adjacent sector. Also, the width of the beam compared to the large area of the cell sector no longer has a significant impact on the IUI. Antenna array beams suffer more interference with an altitude of 15 m leading to a lower capacity value. In other words, within the 5 m antenna matrix, the interference is high, which leads to a significant decrease in the capacity value.

The capacity improvement ratio for the 110º and 120º angles when the antennas group used with a height of 50 m to the capacity value of the antennas group used with a height of 15 m are 4.322% and 7.497%, respectively, while the capacity improvements for the antennas group used with a height of 5 m are 4.7% and 12.917%, respectively.

The following has been proven by conducting a comprehensive study of all the sector areas. The users are located at different distances from the Tower within approximately 58.33% of the sector area. The capacity value at 5m height is higher than its value at other heights due to the small coverage area. At the lower antenna matrix height, the wide beam of mmWave decreases, so the interference reduces and increases capacity. In studying about 83.33% of the area of the sector, the antenna matrix height of 15 m proved superior to other antenna group heights of 50 m and then a height of 5 m. The area Increasing reduces the possibility of interference between users and the possibility of increasing the antenna array height. When studying the entire sector, the 50 m height stands out from the other heights. The larger the area covered, the higher the antenna matrix can be.

This confirms the idea of this paper that a given dimension of users' location for each domain contains a set of antennas operating based on a beamforming technique that provides them with the best capacity. The coordination process between these three proposed heights in the same sector is a new method added to the well-known CoMP types.

VI. Conclusions and Future Work

A new model of CoMP using millimeter wave technology is proposed. The new model for downlink was implemented using mmWave, and beamforming technologies. A new proposed system is implemented by three sets of antenna matrices in the same Tower at different heights (5, 15, and 50 m). This is accomplished by installing users to the same azimuth of arrival (AoA) and changing the distance between users' locations from the Tower. The cell capacity of different antenna matrix heights is analyzed and simulated with an accurate proposed system model. Simulation results show a significant capacity improvement for different antenna matrixes heights and at different AoA angles. Each antenna array height is suitable for users in a private sector area. Changing the antenna height solves the problem of IUI and increases the capacity. So, it reduces dangerous interference in overlapping regions between users and coordinates it. The results also showed that the height of 50 m achieves the highest capacity of the system when studying the entire sector. The 15 m height of the antenna matrix gets the maximum capacity value when reducing the sector area. It is worth noting that the proposed CoMP technology was used to coordinate mmWave beams for the three matrices to choose the best capacity for each user. The number of antenna matrices can also be increased to more than three in the future. Deep learning can also be used in place of the proposed CoMP to determine the appropriate matrix of antennas for the user's dimension to apply this proposal in the future.

Conflict of Interest

R. A. Abed, and S. A. Ayoob declare no conflict of interest with anyone.

Author Contributions

R. A. Abed designs the models. Simulations of these models and executions of all computations related to the results and the conclusions. All of these processes were verified and supervised by S. A. Ayoob. The authors participated in preparing the manuscript and the answer to the Reviewers.

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