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BEAMFORMING WITH MASSIVE MIMO SYSTEMS IN 5G - REDUCTION OF BEAMWIDTH AND SIDELOBES

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Abstract

Beamforming is the process of directing the beam towards the desired direction while suppressing the signals from other directions. Multiple Input Multiple Output systems along with beamforming has a major influence on the next-generation wireless communication system. Techniques like beamforming is increasing its use in cellular telecommunication and particularly in 5G. The work carried out is to reduce the beam width of the main lobe of the beam pattern. Reducing the beam-width ensures that more signals can be radiated in the serving area. By increasing the separation between array elements, the lobe width decreases or the array directivity improves. Reduction of side lobe level reduces noise and interference with other signals so that the receiver receives good quality signal. Also, the main lobe beam is made to reach the user equipment. The beam width of the main lobe becomes narrower with increase in the number of antennas of the uniform linear array.

Keywords:

Multiple Input Multiple Output Systems, Beamforming, 5G, Side-Lobes, Beam-Width

1. INTRODUCTION

A Mobile communication demand is increasing at a sustained rate with increase in the number of users served by each cell. The users expect higher data rates for applications like online high-resolution videos. To transfer these rising needs operators, adopt high frequency carriers currently located in the centimeter band and in the near future in the millimeter spectral region as well [1]. But as the carrier frequency increases the power loss on the base to mobile path increases as well. To compensate for this additional attenuation higher gain antennas are required. This can be resolved by concentrating the transmitting wave's power in a narrow path connecting the base station and the user equipment. This technology is called beamforming [2]. A unit antenna transmit signals in all directions i.e., it is omnidirectional as shown in Fig.1. Transmission of signals in the region where there are no users is waste of energy. Thus, it needs to be targeted in a specific direction. This can be attained by arranging multiple antennas closely [3], all sending the same signal with certain calculated time differences. The constructive interference [4] makes the signal strong in desired direction and undetecTable.in other areas. Thus, beamforming process can focus the antenna energy where it is desired using multiple antenna technology.

Antenna contains a radiating element that radiates electromagnetic energy in a particular direction. If we want radiation pointing towards a particular direction, multiple radiating elements are put next to each other and fed them with same signal, this is still called as one antenna but the signal will become more directive. For example, with two radiating elements we get twice of energy going forward and less energy going in other directions. To reach the user in a particular direction we need to feed the radiating elements with different signals (same signal with different phases) such that it forms constructive interference in the direction of interest. Number of inputs is same as number of antennas. So, if we feed radiating elements with different signals, it is similar to having many antennas [5].

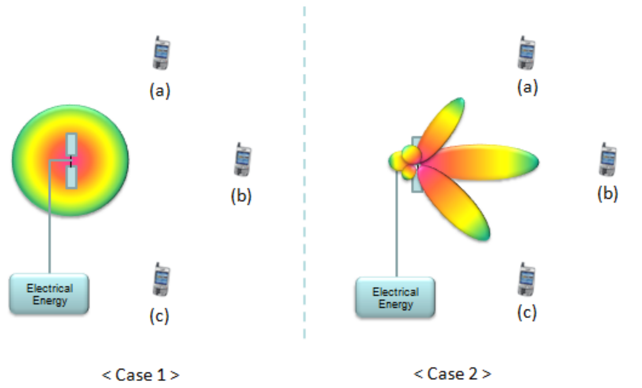


Fig.1. Antenna system radiating energy in all directions and radiating energy directed towards the user equipment.

Spatial multiplexing or Spatial Division Multiple Access (SDMA) is sending multiple beams at the same time [6], could be to the same user or to different users. We can multiplex as many signals as the antenna numbers. For example, if we have 4 antennas, we can choose between one strong beam, two weaker beams or 4 even weaker beams. However, the 4 beams will still be strong as with one radiating element [7]. If we have many radiating elements, it is expensive to feed each one with independent signal to generate and hence same signal is sent to every element by adding phase shifters. In this case we can only send one beam at a time. Beamforming using multiple antennas can control the direction of the wave by calculating appropriate weights to the phase and magnitude of individual antenna element signals in an array of multiple antennas [8].

In brief, major components of beamforming implementations include:

- Number of antennae in an array.
- Inter-element distance in the array
- Phase applied to each array element

The technique used in [9] is phase-manipulation. In this technique the beam-pattern is altered by varying the signal phase entering each antenna. The phase of signal for individual antenna port is varied differently to form a specific beam-pattern that best fits for unit or multiple User Equipment (UE). Beam-pattern can also be changed by switching on (or off) of antenna selectively from the antenna array system [10] [11]. An array of 64 antennae is a minimum for massive MIMO as shown in Fig.2 which increases the cell capacity.

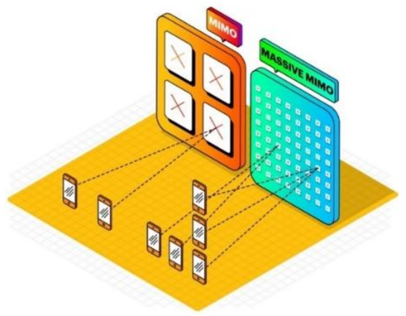


Fig.2. Capacity comparison of MIMO and massive MIMO

The paper work undertaken is organized in the sequence as follows: A brief introduction to the work is presented in section 1. Literature review is presented in section 2, followed by the Methodology in section 3. The detailed results are discussed in section 4. Finally concluded in section 5.

2. LITERATURE REVIEW

The progression rate of wireless communication technologies has been exponential and is bound to reach unprecedented level with the upcoming 5G. The upcoming generations of wireless communication will demand wider bandwidth and greater channel capacity to keep up with the increasing data rates [1]. The most popular or sort out solution is the use of multiple antennas to achieve higher antenna gain thereby enhancing the data rate. The spectral efficiency of a system was found to be increased to a high value by the use of

MIMO (Multiple Input Multiple Output) technology, that is, the presence of multiple antennas at the transmitter and the receiver [15].

Later came Single-User MIMO and Multi User MIMO techniques, which were discussed in [3] and a conclusion was drawn that the efficiency of the system can be greatly improved by increasing the number of antennas at transmitters and receiver systems. Massive MIMO, use of tens to hundreds of antennas at transmitter and receiver, resulted in high data rates and also eliminates small scale fading thereby reducing the energy required at the transmitter [16]. The authors in [17] also describes the Massive MIMO systems to play an important role in enabling the key features of the fifth-generation networks. Millimetre wave bands will be exploited by the future generation of cellular networks to produce the desired data rates. However, the coverage area of mm Waves is limited due to various penetration and propagation difficulties of mm Waves. In [8] the subsequent improvement in range and capacity of wireless systems by the use of multi beam and adaptive antenna arrays is discussed.

The advantages of antenna array in a mobile communications system is presented in [12] and the betterments that are possible by using multiple antennas instead of a single antenna in a system and the details of the feasibility of antenna arrays for mobile communications applications is outlined. Beamforming is seen as key enabling technology for the use of mm Wave bands in cellular communication [2]. Beamforming uses weights at the transmission and the reception end, forming the antennas' beam patterns in a way as to optimize a specific design criterion, like mean square error (MSE) and signal-to-noise ratio (SNR).

3. METHODOLOGY

Beamforming with massive MIMO systems in 5G can be achieved by (i) sending directed signal in the direction of user equipment (ii) making beam-width of the main lobe narrow (iii) reducing the side-lobe level of the beam and (iv) steering the main lobe beam towards the user position. To fulfill these objectives the following methods are employed:

- Directed signal towards desired UE is obtained by changing the array parameters.
- The beam-width of the main-lobe is decreased by increasing the number of antenna elements in the uniform linear array (ULA) [12]. This helps to serve more users in the serving area. Beams using the same frequency is reused. This is the concept of frequency reuse.
- Side lobe levels should be minimum to concentrate the energy towards the direction of the user [13]. If side lobe levels increase, the energy is deviated from the desired direction and goes in vain. The side lobes are minimized by choosing appropriate value of the inter-element distance in the ULA.
- Since the user equipment is mobile, the beam generated has to latch on to the moving user, this technique is called beam steering [14]. Here we chose the position of the user and make the beam to reach to that position.

A mathematical approach to achieve the proposed methodology is discussed next.

The output of the uniform linear array is the beam response $s(t)$ which is the algebraic sum of antenna outputs of the individual array elements considering the phase shifts as shown in Fig.3

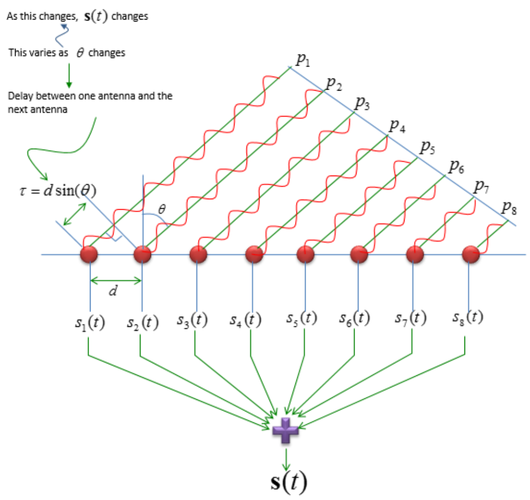


Fig.3. Illustration of the travel path difference and angle between antenna array axis

Parameters:

- Operational frequency f = 28 GHz
- Operational Wavelength thus calculated as,

$$\lambda = c/f = (3*10^8)/(28*10^9) = 0.0107\text{m}$$

- Wavenumber

$$k = 2\pi/\omega = (2*3.14)/0.0107 = 586.9159/\text{m}$$

- Time Period

$$T = 1/f = 1/(28*10^9) = 35.7*10^{-12}\ \text{s}$$

- Angular Frequency

$$\omega = 2\pi f = 2*3.14*28*10^9 = 175.84*10^9\ \text{Hz}$$

Set limits of spatial extent (R) and angular extent θ R varies from 0 to N λ, in steps of ds, where ds is the spatial discretization. Discretization is process of transferring continuous variables or functions or equations into discrete counterparts.

- Create a variable for the phase shift, delta
- Generate the domains for *x* and *y* planes to place antennas where

$$x = R\cos\theta \text{ and } y = R\sin\theta$$

- Positioning array (ULA) along the *x*-axis on both +*x* and -*x* axes.
- Initialize the antenna array separation value, *d* which is the inter element distance and is a multiple of the wavelength of the EM wave i.e., $d = n\lambda$
- Set amplitudes of each array antenna to unity
- Calculate electric fields for individual antennas

$$E_1(i_x,i_y) = \cos(\omega*(t*it) - K*R_1 + (-3*delta))$$

where *ix* = length (*R*), *iy* = length (θ)

$$R_1 = \sqrt{\{x[ix,iy]-r_1x\}^2 + \{y[ix,iy]-r_1y\}^2}$$

Here, r_1y=0, r_1x=-3*d*, $d=\lambda/2$ where r_1x, r_1y are the coordinates of the position of the first antenna when number of antenna *N*=7.

Calculate the total electric field (algebraic sum)

Total electric field is the sum of all individual electric fields

$$E = E_1 + E_2 + E_3 + \ldots$$

If *N* = 7

$$E = E_1 + \ldots + E_7.$$

If *N* = 15

$$E = E_1 + \ldots E_{15}.$$

If *N* = 64

$$E = E_1 + \ldots + E_{64}$$

This total electric filed is beam response *S*(*t*).

4. RESULTS AND DISCUSSIONS

The time taken by the software tool to display the results depends on the antenna number in the ULA. If the antennas used are more, then the run time is increased. In the following beam patterns, dots represented the antennas. The results are summarized below.

1. Increasing the separation between array elements the lobe width decreases or the array directivity improves. However, secondary lobes appear increasing the array directivity towards unwanted directions. As the inter-element distance increases, the maximum array gain does not change. Here, d is the inter-element distance of the ULA. λ is the wavelength of the EM wave. The Fig.4 represents variation of the beam-pattern with respect to variation of inter-element distance.

$d = 0.1\lambda$

$d = 0.5\lambda$

$d = \lambda$

$d = 1.5\lambda$

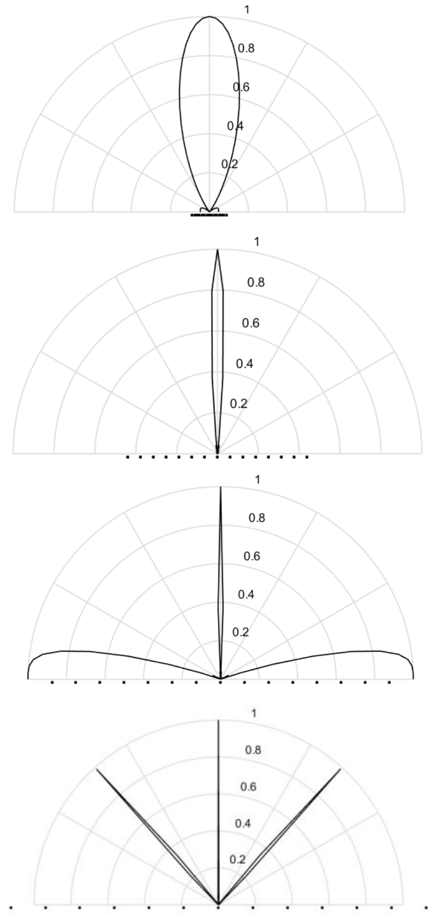
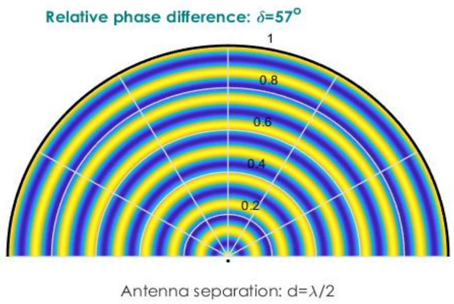


Fig.4. Beam-pattern with varying inter-element distance

2. The beam width of the main lobe becomes narrower with increase in the number of antennas of the uniform linear array. For massive MIMO with 64 antennas we can see a pencil beam directed towards the desired direction. *N* = 1 implies a single antenna which radiates in all directions. i.e., it is similar to an omnidirectional antenna. The Fig.5 represents reduction of beam-width of main lobe with increase in the antenna numbers, *N* and relative phase difference delta (δ) =57°.
3. Relative phase difference delta is given in radians. The value of delta varies from 0 to 6.3 radians. i.e., 0 to 360 degrees. The beam is steered to the user position by varying the weights given to the input of array elements.



N = 1

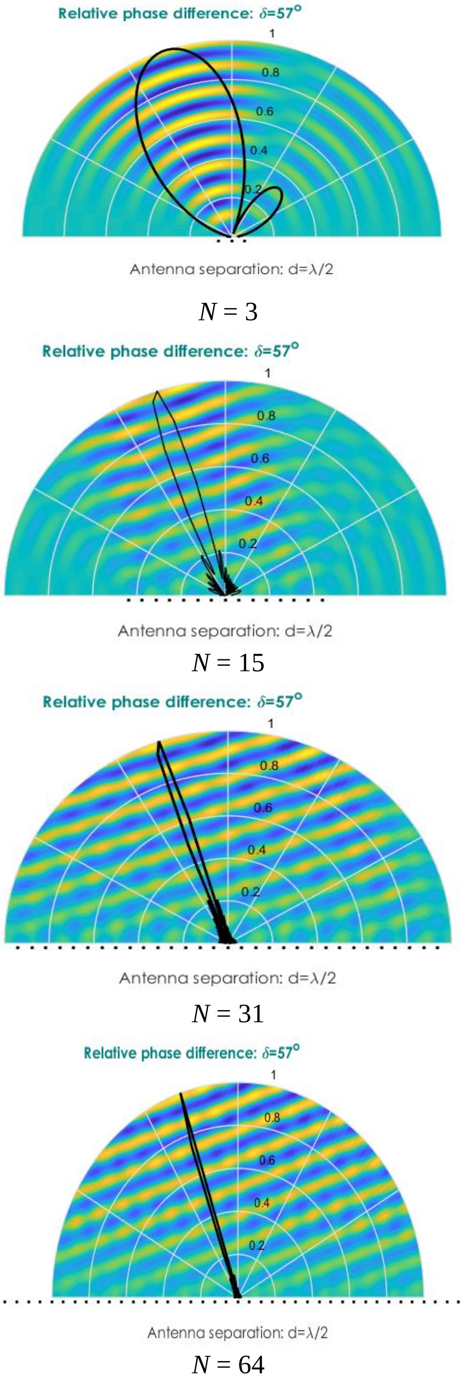


Fig.5. Reduction of beam-width of main lobe with increase in the antenna numbers, N

Thus, by changing the value of delta i.e., the user positions, we can direct the beam towards that polar coordinates. The beam steers left from the vertical axis which is considered as zero degrees. Fig.6 represents the tilting of the beam for various phase differences.

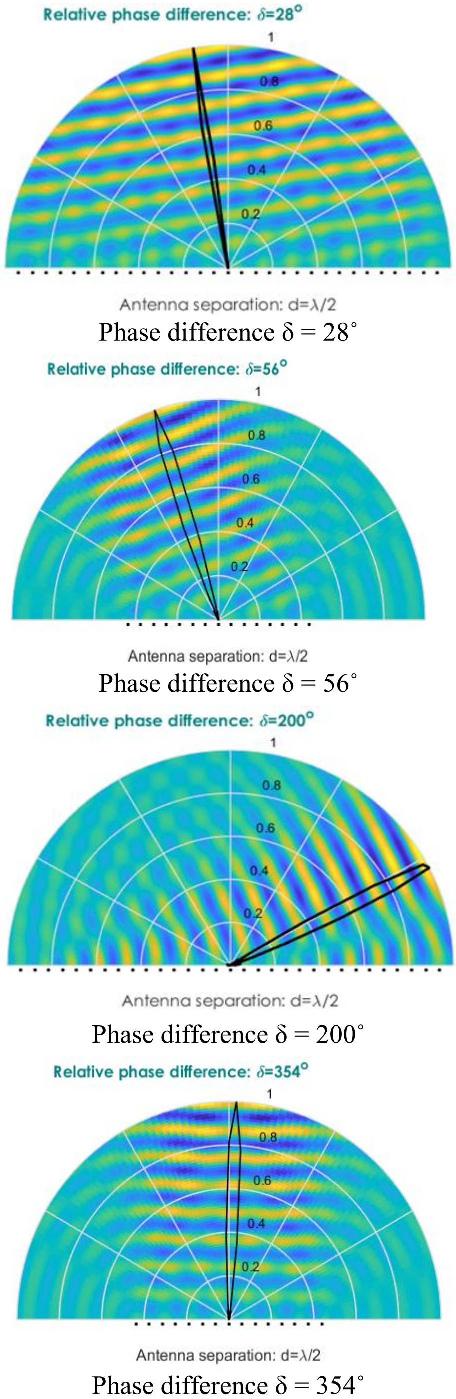


Fig.6. Tilting of the beam for various phase differences.

4. We also tried to formulate the results with the uniform rectangular array (URA) of 8*8, i.e., an array of 64 antennae, a minimum for massive MIMO. The three-dimensional response pattern for power in decibels, electric field plot and directivity are shown in Fig.7, Fig.8, Fig.9 respectively. It is observed that the side lobe level is much higher than expected.

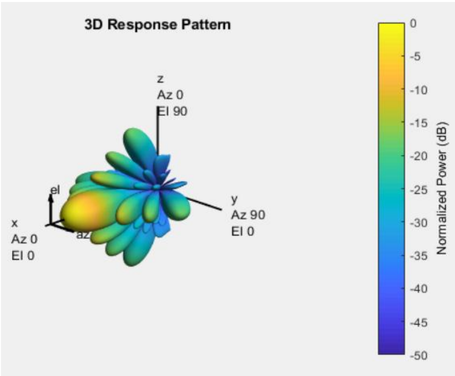


Fig.7. 3D plot of power in decibels for beamforming

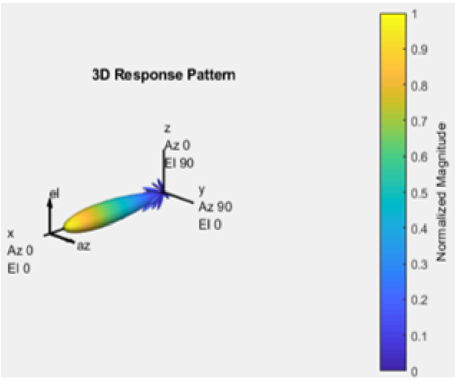


Fig.8. 3D plot of electric field for beamforming

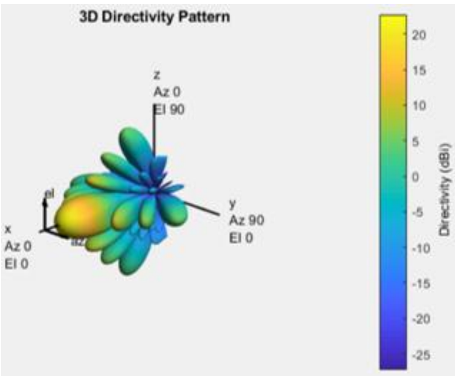


Fig.9. 3D plot of directivity for beamforming

From the above observations we found that a lot of improvements have to be made in the calculations to obtain a better directed beam with reduced side lobe level in case of 3D beamforming with URA. The array element positions, number of array elements etc. have to be taken care for further investigations. The power in decibel plot for different antenna array sizes of URA is tabulated in Fig.10.

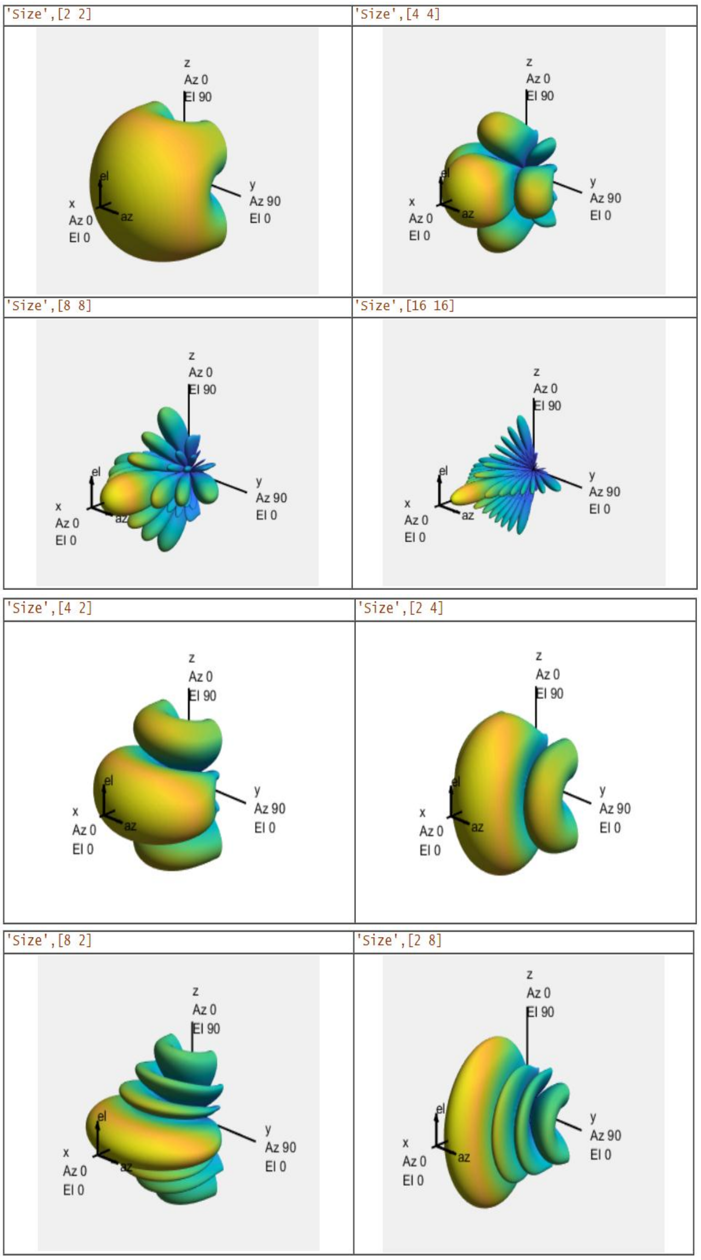


Fig.10. Power in dB plot for different antenna array sizes

From Fig.10, we observe that, a simple 2*2 URA shows a wide beam with least directivity, but the side lobes of the plot is at minimum. Considering a plot of 4*4 URA the directivity is improved compared to the 2*2 URA but a lot of side lobes are arraised. Likewise the results for 8*8 and 16*16 URA's are followed and the same observations can be made. As the number of antennas are increased we can see a high increase in the side lobes.

5. CONCLUSIONS AND FUTURE SCOPE

A phased array antenna is designed using uniform linear array and antenna array separation is a significant factor which is a multiple of the wavelength of the electromagnetic wave. This antenna array also is steerable. Introduction of a specific time delay at each element of the antenna array achieves steering. The number of antennae is increased to enable better steering to required angles and also to lower the beam width. The main lobe beam is formed by the constructive interference of antenna outputs. Narrow beam width helps utilization of more beams of same frequencies in the same cell area which is the concept of frequency reuse. The higher frequencies and bandwidth limitations causes the directivity and gain to decrease. This also is compensated by increasing the antenna numbers in the array. The phase-shift given to each antenna of the array is the value of delta, by changing which steering to particular angle (position of the UE) can be achieved. The total electric field is the sum of individual electric fields of each antenna element. In addition to the conventional 2D beam forming technique, 3D beamforming technique (full dimension MIMO) or tilt angle adaptation can be an improvement over the 2D beamforming techniques. Exploration on the array geometry may provide better results additionally. ULA is a basic array configurations. Uniform circular array (UCA) or concentric ring array (CRA) configurations can be used to improve the beam former performances. Beam former weights can be calculated using different adaptive or hybrid algorithms which is a challenging research topic.

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