Adaptive Cylindrical Antenna Array For Massive MIMO in 5G

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Summary
Massive capacity and connectivity are the main new emerged issues in the last wireless generations, especially for LTE-Advanced. The last cited topics, are the reason of a new wireless core network well known as 5G. There are different methods to deal with this fact, we propose in this paper an ingenious one which is the massive MIMO adaptive array antennas considering a millimetric wavelength small cell. Existing Array antennas geometry are even linear, circular, planar or in multidimensional grid that don't satisfy our increasing capacity and connectivity needs. Subsequently, creating a new geometric form based on cylindrical smart antennas have been developed using MATLAB software to scan the overall 3D space, improves the network capacity and edges the value of several tens of Giga bit per second (Gbps). The problem of energy scattering is solved by Beam Division Multiple Access (BDMA). Only service-requesting users are susceptible to be served. Otherwise, They are not considered by the access points (APs).

Key words:
5G, LTE-Adv., BDMA, APs, massive MIMO.

1. Introduction

Mobile information, including voice, data and internet might save further time and energy. The main issue is that older generations of wireless communication don't support growing capacities and connectivity.

Continuously increasing bit rate capacity either at transmission or at the reception's end besides the considerable intensification of interconnected networks build the basis of new paradigm emerging from a considerable need of several objects interconnection as machines, robots and vehicles …. The last cited paradigm is well recognized as 5G or internet of everything (IoE). The key ascertainments offered by IoE are unsignifying latency, high mobility moreover the massive connectivity and huge capacity are guaranteed this way.

The upcoming event of mobile communications is expected to be very dissimilar to today's use. Although, Demand for mobile broadband will continue to upsurge, basically driven by ultra-high definition video and 4K,8K,16K … screens, we have previously seen the rising influence of new interconnected things everywhere around us and the possibilities of new combinations for more connected things. The last cited objects are extending from robots, cars, applications for devices and vehicles, will be able to acquire
and shape themselves to fulfill the human requirements. Probably many not yet conceived, several Newfangled practices will appear and generate new supplies that communications networks ought to deal with the demanded cost efficiency and flexibly aiming to assist telecom operator effectiveness.

Basically, we are looking for how to support the changes of virtual mobility, real world mobility, the 4th industrial revolution and high-performance infrastructure. By now we have some indicators about these tendencies and disruptions.

They are not just remotely driven by telecommunication and Internet industry, several domains such as manufacturing and logistics, healthcare, rail network and automotive which need to upgrade themselves. As a result, every industry will be affected by the migration to the 5G telecom mobile. The network speeds will be as high as 10 Gbps and offering an extremely low latency. The overall obligations consist the driving force for new appliances that use huge broadband capabilities in many industries, extending from the information and telecommunication (IT) industry to cars, entertainment, agriculture and manufacturing. 5G will be able to connect the future's factory and help promoting a fully automated and flexible production chains.

We could assume that protection and business applications will be more promoted, which requires predictable and reliable service heights in terms of capacity, amount and latency. These levels will seriously surpass what we are using nowadays.

What is 5G?

Every decade, a new generation of mobile radio is born ... the scientific community is focusing on the 5G core structure and features and its offered performances. Why should we perform the migration? what should we update in difference to its precursor and its extent, scheduled for tomorrow in horizon 2020?

The main goals vised by 5G mobile network remain to achieve basically a large data rate over than 10 Gbps, guarantee as minimum data rate more than 100 Mbps, a traffic volume density, superior to 10 Tbps/Km², resolved massive estimated connectivity to 7 billion people and 7

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trillion things, A small radio latency not as much of 1ms and a smaller amount of 10 ms End to End (E2E) devices. The incorporated problems resolved by this new paradigm are essentially the response of; First, how to improve bandwidth? Second how to increase the flow rate to meet a satisfactory requested need in term of network user coverage. Third how to avoid saturation traffic in the period-zone, fourth how to sidestep static saturation of the spectrum allocated to the service, fifth how to self-immunize against all types of prevalence perturbation, sixth how to improve quality of service (QoS), the major concern of ensuring an expected service price. Finally, the scalability anxiety referred to already installed devices.

Over the last decade, there have been various works, describing migrations toward new mobile generations, treating especially antenna's topology, optimization methods, optimal dimensions and massive MIMO [1-9].

As proposed in the Ref. [10], in which authors have introduced a 2D pattern synthesis for cylindrical arrays.

They have conceived cylindrical arrays, by multiplying linear and circular characteristic array types. Consequently, the beam pattern has been obtained and the synthesis process

is divided into two individual 1D pattern syntheses of subarrays to obtain the desired sidelobe level.

Ref. [11] consists of a hybrid Linear and Circular Antenna Arrays. It could be concentric, circular, cylindrical, or coaxial cylindrical antenna arrays. the expressions

of their array factors are derived, their directivities and half

power beam widths (HPBW) for the three types of combinations are given and explicated.

Moreover, for Ref. [12] radiation properties program computing spherical and cylindrical rectangular microstrip patch antenna has been presented where the patch could be embedded in or placed on a general multilayer structure. This solution combines the advantage of spectral-domain and the spherical/cylindrical approaches showing the rigorous analysis of curved patch.

In Ref. [13] the authors present the pattern synthesis issue with cylindrical arrays topology. An ingenious transformation that allows the circular array to be treated similarly as a virtual linear array requires many elements and it is used to synthesize patterns with narrow beams and low side lobes. The cylindrical arrays offer an enhanced directivity property and the main beam was piloted in any space direction. A new pattern approach generation exhibits the desired pattern distribution. It consists of minimising the squared error between the desired and real patterns for a specific elevation of the cylindrical antenna array. Then, the directivity is promoted without the need of a very large number of elements.

However, in Ref. [14] authors treat the main weaknesses of the traditional particle swarm optimization (PSO) method, which adopts a global best perturbation, optimizing the pattern sidelobe level (SLL) suppression and null control in certain directions of cylindrical antenna array. The convergence speed, implementation, complexity and effectiveness of the algorithm have been improved using a multi-dimension and nonlinear problem correction. Moreover, A mathematical pattern and array formulation have been provided. Standard and improved Particle Swarm Optimization PSO algorithms are compared.

In Ref. [15] A proposed method based on iterated function minimization that includes imposed constraints is in every direction. An 8-element cylindrical antenna has been proposed for several beam configuration types. It consists of a new approach to synthesize controlled cylindrical antenna arrays using phase excitation to produce directive lobe and multilobe patterns with steered zero.

In the case of Ref. [16], four element cylindrical dielectric resonator antennas array using an annular shaped feed has been presented. The distance between the dielectric resonators is optimized by a DRA array design via microstrip feeding, 27% of the bandwidth has been achieved for the last cited DRA array in which an appreciable gain and better radiation at resonant frequencies have been fulfilled. The prototypes of antenna array have been fabricated according to optimized dimensions.

Ref. [17], presents an overview of the massive MIMO concept, historical development and a research update.

All these cited works have some weakness residing in the following points:

The space should be modelled in 3D which it's not the case for the Ref. [10] the authors opt for 2D. in Ref. [11] the number of antenna elements is insignificant to hold an acceptable or huge bit rate necessary for migrating to 5G. in Ref. [12] the disk shape is insufficient to scan all the space. Ref. [13] cylindrical uniform antennas is not sufficient to increase the bit rate. In Ref. [14] authors didn't have taken account of elementary electrical field in the computation of the overall antenna.

Nevertheless, in Ref. [15] the number of antenna elements is not flexible. For Ref. [16] the number of antenna and frequency didn't match the 5G operational requirements. For the last Ref. [17] the massive MIMO scenario is without explaining the mathematic demonstration and simulation.

Our novelty presented in this paper compared to already cited references is resumed in three main originalities:

First, A new cylindrical topology in which the number of elements is considerably enhanced, embedded in a massive MIMO. Second the frequency, raised up. And finally, cells dimension become slighter.

This paper is divided into 3 sections. The first section is an Introduction, the second section treats the mathematical modelling of the cylindrical antenna, the third aims to present performed simulation results and discussion.

Finally, we introduce the conclusion and the main perspectives.

2. mathematical modeling of the cylindrical antenna

$$E_{total} = E_{single\ element\ at\ reference\ point} * AF \quad (1)$$

The overall electrical field is the single element reference point field multiplied by the array factor.

$$F_{total}(\theta,\varphi) = F_{element}(\theta,\varphi) * AF_{array}(\theta,\varphi) \quad (2)$$

Where θ is the elevation angle and φ is the azimuth angle.

2.1 Single element at reference point E

Represent the magnitude of the fields
The free-space wavenumber

$$K = \frac{2\pi}{\lambda} \quad (3)$$

The patch Microstrip: length L, width W,
where $W = L = \frac{\lambda}{2}$

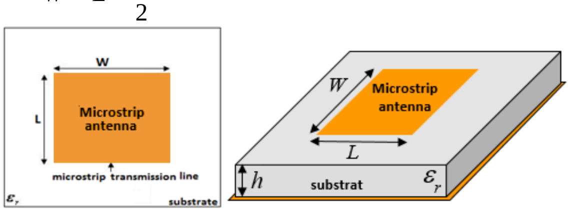

Fig. 1 Microstrip element model.

The magnitude of the fields, given by:

$$f(\theta,\varphi) = \sqrt{E_\theta^2 + E_\varphi^2} \quad (4)$$

$$E_\theta = \frac{\sin\left(\frac{KW\sin\theta\cos\varphi}{2}\right)}{\frac{KW\sin\theta\cos\varphi}{2}} \cos\left(\frac{KL\sin\theta\cos\varphi}{2}\right)\cos\varphi \quad (5)$$

$$E_\varphi = \frac{\sin\left(\frac{KW\sin\theta\cos\varphi}{2}\right)}{\frac{KW\sin\theta\cos\varphi}{2}} \cos\left(\frac{KL\sin\theta\cos\varphi}{2}\right)\cos\theta\sin\varphi \quad (6)$$

2.2 Array factor

- Vertical

The array factor of M linear element array is given by equation (7)

$$AF_{linear}(\theta,\varphi) = \sum_{m=1}^{M} b_m e^{j(m-1)(K d \cos\theta + \beta)} \quad (7)$$

$$K = \frac{2\pi}{\lambda}.$$

b_m are the excitation coefficients.
m number of vertical antennas elements [1to10].
d the distances between the elements.
θ theta is the angle in the z-y plane [elevation].
β beta is the excitation phase.

- Horizontal

The array factor of an N element circular array is given by equation (8) hereunder:

$$AF_{Circular}(\theta,\varphi) = \sum_{n=1}^{N} I_n e^{j(\mathrm{K} r \sin\theta\cos(\varphi-\varphi_n)+\alpha_n)} \quad (8)$$

I_n are the excitation coefficients.
n is the number of horizonal antennas elements [1to16].
r is the radius between the origin and the terminal (receiver).
θ is the angle in the z-y plane [elevation].
φ is the angle in the x-y plane [azimuth].
φ_n is the angle in the x-y plane between the x-axis and the nth element.
α_n is the excitation phases ponderation.

2.3 Global Array Factor

The overall expression defining the total array factor is subsequently:

$$AF_{total}(\theta,\varphi) = \sum_{m=1}^{M} b_m e^{j(m-1)(\mathrm{K} d\cos\theta+\beta)} \sum_{n=1}^{N} I_n e^{j(\mathrm{K} r\sin\theta\cos(\varphi-\varphi_n)+\alpha_n)} \quad (9)$$

Thus, the overall expression defining the total field magnitude is:

$$F_{total}(\theta,\varphi) = \sqrt{E_\theta^2 + E_\varphi^2} * \sum_{m=1}^{M} b_m e^{j(m-1)(\mathrm{K} d\cos\theta+\beta)} * \sum_{n=1}^{N} I_n e^{j(\mathrm{K} r\sin\theta\cos(\varphi-\varphi_n)+\alpha_n)} \quad (10)$$

3. simulation results and discussion of Massive MIMO and mmWave Cylindrical Antenna Arrays

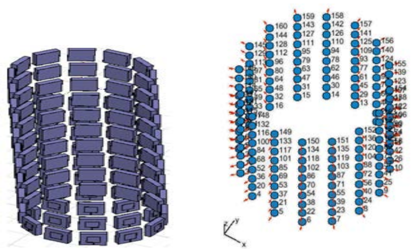

Fig. 2 Antena topology and disposition.

Loading circular array arranged one above the other, using the same separation distance between them will lead to draw the cylindrical array in which the antenna elements form a vertical surface line are equivalent to a linear array of antenna. Moreover, those implanted in the transversal plan section create the circular array as shown in Figure. 2.

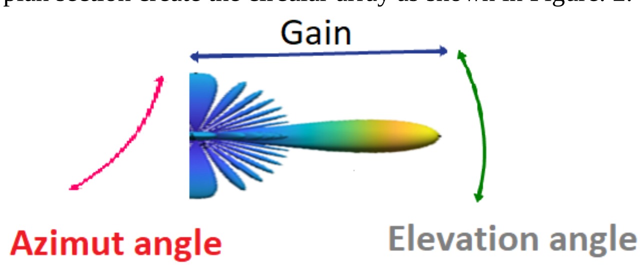

Fig. 3 Narrow beam width power.

In Figure 3. The beam direction is commanded by azimuth and elevation angle. The power is defined by the distance between the user and the antenna modeled by the beam width.

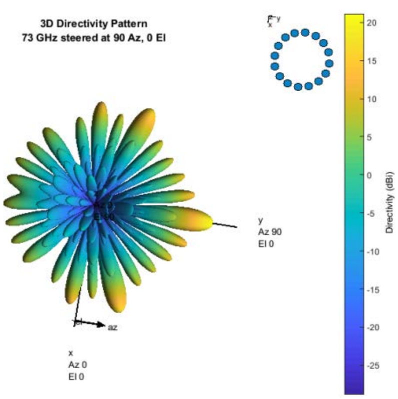

Fig. 4 Pattern power in 3D.

In figure 4. A three dimensional top view of array directivity at 90° azimuth angle and 0° elevation operating at 73Ghz frequency demonstrating that the beams are devided between users. The yellow color matches 20 dBi directivity the assisted users is situated.

Table 1: Array Caracteristics

Array directivity	23.76 dBi at 90Az,0 El
Array Span	X=0m, y=48.21 mm, z=80.36 mm
Number of elements	160

The Table 1 illustrates the array directivity, array span and the number of deployed antennas on our mentioned topology.

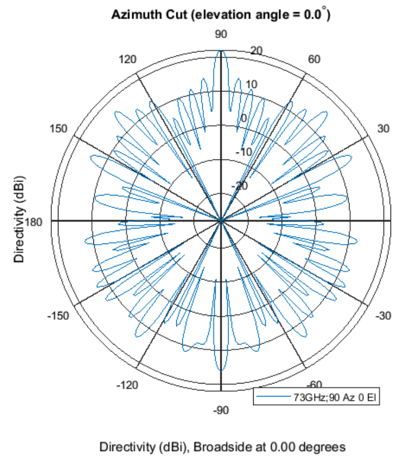

Fig. 5 Azimuth cut elevation angle.

Figure 5 described a cutted section of the overall directivity pattern at the same azimuth related to 0°elevation angle.

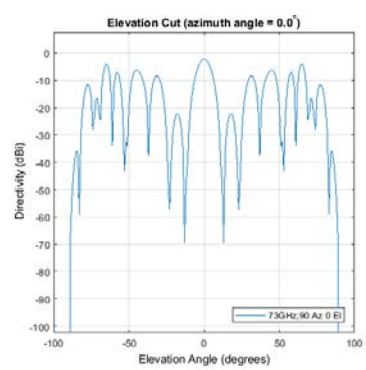

Fig. 6 Elevation cut angle.

Figure. 6 Using the proposed system antenna, as given in the design; the excitation coefficients, inter element arrangement, magnitude and phase, and angular separations are changed in a way to obtain the wanted pattern in term of directivity intensification, side lobe decreasing, pattern nulling and pattern shaping.

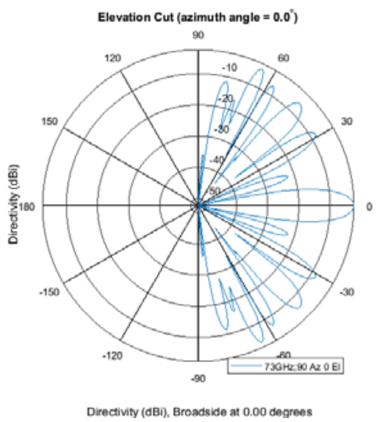

Fig. 7 Elevation cut Azimuth angle.

Figure 7 defines a cutted section of the overall directivity plan at the elevation cut for azimuth angle 0°. The main assisted user is at 0° azimuth as we visualize the maximum received power is axed to the cibled point in concordance with cylindrical coordinates in the space.

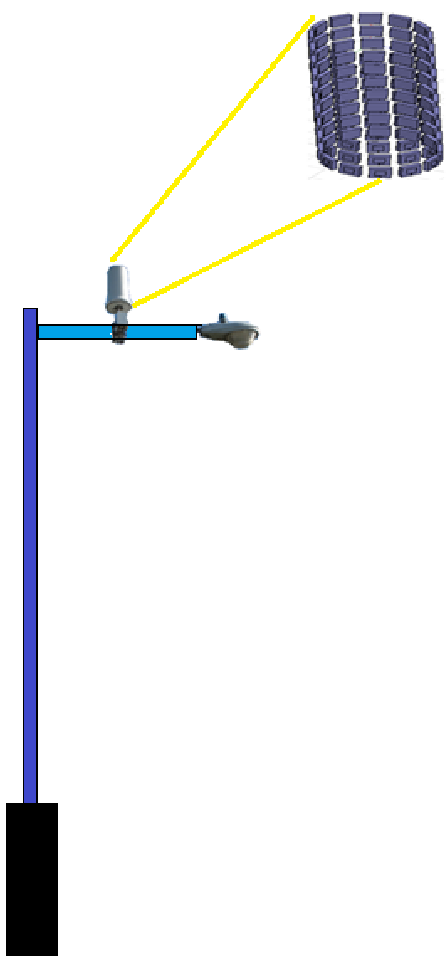

Fig. 8 Exemple of small cells on Lamposts.

Figure 8 demonstrates a case of prototype disposition attached to lampposts of the cylindrical antenna array.

Table 2: Summary of MATLAB values

F=73 GHz	***160 antennas (massive MIMO)***					
φ (azimuth): (-180° to +180°)	0	30	60	90	120	180
θ (elevation): (-90° to 90°)	0	15	30	45	60	90
Pr [dBi]	21.13	21.73	21.34	21.05	21.74	20.42

- Link 73GHz Cylindrical properties:
- F=73GHz.
- $\lambda = 4 \times 10^{-3}$m=4mm.
- d=$\lambda/2 = 2 \times 10^{-3}$m=2mm.
- R=10×10^{-3}m =1cm (16ant.)
- H=40×10^{-3}m=4cm (10ant.)

Table 2 represents the numerical simulation values in MATLAB. Depending on the user placement the cylindrical antenna array in 3D satisfy users demand with maximal power of 20 dBi thanks to the considerable number of adaptive antenna elements. Thus, beams are far more directive and narrow P (r, θ, φ).
An antenna matrix in the base station BS (2x2,3x3,4x4 …) blades the power only to the demanding user. By this manner the power is optimized because exclusively demanding users are served. Subsequently services price falls down for both parties, even operators or customers in addition to the suppression of electromagnetic pollution.

4. Conclusion

Designs with high directivity, narrow beams and low side lobes were gained with cylindrical arrays. A renovation proposed with circular arrays was obtained and its benefits were exhausted using cylindrical arrays. It allowed us to obtain the wanted patterns with the main beam pointing in any space direction. The conception of the antenna array in massive MIMO with the cylindrical shape aims to scan all around the space in 3D, to offer a considerable bit rate over than 10 Gbps implicitly a large bandwidth incites to deploy a high frequency of 73 GHz. This frequency implies a millimeter wave length (mm-Wave) and subsequently small cells, which depose the 5G mobile generation. In spite of the effectiveness of this ingenious design method there is just one limit concerning the top or the bottom of the cylinder. They cannot be seen by this structure. As a future work we propose to solve this issue.

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