# METHODOLOGIES FOR EFFICIENT AND OPTIMAL IMPLEMENTATION OF 5G MMWAVE NETWORKS

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***Abstract:*** The implementation of 5G mobile networks is going to completely transform our communication systems, providing a rich and uniform experience to up to thousand times of the existing users with the help of mmWave spectrum. The mmWave band, also known as millimeter band ensures errorfree delivery at the maximum capacity and helps to increase the performance. In typical scenarios where data congestion is a problem, mmWave spectrum will help by providing better coverage and ultra-high throughput. The available bandwidth of mmWave is in the range of 25 GHz to 100 GHz which is capable of supporting the requirements of today's world and hence is promising. These characteristics vary from that of microwave frequency bands in terms of attenuation, atmospheric absorption and the path loss that happens. So, for a point-to-point like mmWave systems have a larger overall loss in comparison to microwave systems. In this research paper we will discuss signal transmission and how connectivity can be established for a link level perspective of UE i.e., User Equipment and gNodeB i.e., radio network node for 5G in a more effective manner. By determining the signal loss in the practical environment via the pilot signal, we aim to reduce the noise by optimally positioning the minimum number of small cells. The purpose of the research is to find the optimum solution for faster and noiseless communication, most importantly in a cost-efficient manner.

## I. INTRODUCTION

In the last few years, mobile and wireless networks have made remarkable developments world- wide. Fifth-generation wireless (5G) is the latest iteration of cellular technology and an evolution from the current 4G LTE networks. The demands have been increasing substantially over the past few years. Global connectivity, where the world is being considered to be connected through modern telecommunications, requires a different kind of design. 5G in conjunction with existing 4G LTE Technology will provide a solution for this and will be then fully independent over the coming years. The current re-architecture 5G network delivers multi-Gbps peak data speeds along with ultra-low latency and massive network capacity. It also has increased availability and it therefore leverages several key technology trends. As with the solutions that 4G LTE network provided, 5G's promise is primarily about transitioning from single access service which is broadband connectivity to a richer collection of services and to even more devices, in the near future.

With the world progressing towards technologies like AR/VR, autonomous vehicles and Internet of Things (IoT), 5G has been predicted to give immersive user experience. Now, the mission-critical applications like public safety would be in a better place with the usage of 5G. It would not be restricted just to supporting humans accessing the global connectivity through the web from their mobile devices but rather range from home appliances to self-driving cars to robots and this list never ends.

While the potential applications of 5G technology listed above, there will be some uncertainties along with it too. To overcome these challenges, we will be finding some key solutions in the subsequent sections.

**Table 1**. Data Transfer Rates of 3G, 4G & 5G

| Network Speed | Average Download Speeds | Peak Download Speeds | Theoretical Download Speeds |
|---|---|---|---|
| 3G | 8 Mbps | ~20 Mbps | 42 Mbps |
| 4G | 32.5 Mbps | 90+ Mbps | 300 Mbps |
| 5G | 130-240 Mbps | 599+ Mbps | 10-15 Gbps |

**Table 2.** Comparison of 3G/4G and Latency Times

| Network Type | Milliseconds (ms) |
|---|---|
| 3G Network | 60 ms (Typical) |
| 4G Network | 50 ms (Typical) |
| 5G Network | 1 ms (Typical) |

The global adoption of 5G will be possible when several challenges are addressed and hence making the roll out in an efficient manner. The infrastructure for 5G will be expensive at an initial stage and therefore materializing things will take time. As discussed, the frequency of 5G mmWave signals requires the production and installation of many more cellular communications towers. Building out intermediate networks along with current 4G LTE networks will likely take some time to be accessible by all around the globe.

## II. ADVANTAGES OF 5G

### 1. Enhanced Capacity

The enhanced capacity of 5G will deliver up to 1000x more capacity than the current 4G LTE networks. The development of fertile ground enabling 5G not only to mobile devices but also to robots requires capacity to be increased. The seamless communication around the globe and in cities, factories, schools, homes and offices will flourish in the near future. The large data transmission will be easy with a combination of increased speed and network capacity on 5G networks. The handling of current usage spikes for wireless communication will not be much better and smooth with the help of 5G's new architecture that is evolving now.

### 2. Latency

Lower latency is one of the major improvements from current 4G LTE networks. The processing is happening closer to the user now and thus eliminating the need to send data to the cloud and back. This round trip of data transmission will take less than five milliseconds. This will enable controlling real time devices.

Lower latency is one of the primary key features considering a wide range of applications in today's world. During the development of 5G, lower latency was also kept in mind because of self-driven cars that is one of the major applications for this. This kind of latency with high data speeds is never seen before in wireless communication.

### 3. Connected Devices

The number of connected devices is set to increase and the ability to incorporate a huge number to reach up to each other with a plus point of 100 times faster data rate as compared to 4G wireless network is one of the most important advantages for 5G network.

### 4. Multiple Radio Access Technologies

The 5G network is not meant to replace the current wireless networks. It will be built upon the existing wireless technologies and in subsequent releases will stand alone. 5G is envisioned to support a wide range of different use cases where orthogonal multiple access schemes will be beneficial.

### 5. Energy and Cost Efficiency

With exponentially increased data traffic, 5G wireless networks meet the date-consuming applications at a lower cost and higher energy efficiency. As we move ahead with 5G, and with the local 5G base stations installed now the increased transfer of computation from smartphone to the cloud is one step easy. Some recent studies have also shown that 5G has a 90% more energy efficient rate as compared to 4G LTE.

## III. KEY CHALLENGES IN IMPLEMENTATION

### 1. Availability of Spectrum and Implementation

5G will require some new as well as some existing spectrum bands. It operates on higher frequencies nearly up to 300 GHz and these bands have increased capacity allowing for ultra-fast data. It has been more than 20 times as compared to LTE networks theoretical speed. The operators still find availability and the price of spectrum a problem. Operators will need to bid for these higher spectrum bands as they continue to build and deploy 5G wireless networks.

### 2. Deploying Hybrid LTE-NR is Critical

The initial phase of 5G deployments is supported with current 4G LTE core and LTE access as the anchor for New Radio (NR). Control and excess user traffic above LTE traffic are administered by LTE eNB and 5G gNB. Configuration of hybrid LTE-NR using the macro-LTE layer is beneficial for the deployment of 5G in mmWave spectrum and thus increases its mobility in between the hotspots.

This mobility gained from mmWave works well at low speeds. Nevertheless, these benefits have evolved from the performance of the dual connectivity (EN-DC) and is very challenging to perform 5G network testing due to its complex nature. It definitely requires synchronisation between gNB and eNB for data transfer and signaling to the NR.

### 3. Deployment and Coverage

We know 5G is offering an enormous increase in speed and bandwidth, but its more limited range would require further infrastructure to be improved. Beamforming enables highly directional radio waves to be implemented and 5G will work on that.

Even with antennas and base stations getting smaller during this scenario, more of them got to be installed on buildings or homes. Cities will probably get to install extra repeaters to spread out the waves for extended range, while also maintaining consistent speeds in denser population areas. It's likely carriers will continue to use lower-frequency bands to cover wider areas until the 5G network matures.

### 4. Impact of Obstructions Reducing Connectivity

The frequency waves travel a shorter distance in 5G so the connectivity isn't great for a longer distance. Added to the present setback is the fact that 5G frequency is interrupted by physical obstructions such as buildings, towers, walls and trees. These will either block, disrupt or absorb the high-frequency signals from going from one destination to another. To counter this setback, the telecom industry is extending existing cell broadcast distance.

### 5. Limitations of Rural Access

While 5G brings real connectivity in urban areas, but within the rural settings it wouldn't necessarily benefit from this wireless connection. As it stands, many remote areas countrywide are not able to access any form of cellular connectivity. So, the 5G carriers are going to target big cities with larger populations, eventually working their way into the outer areas. They will start with installation of towers to those places where the usage and availability of resources is much higher and thus not all the population will benefit from this.

## IV. SOLUTIONS FOR THE ABOVE CHALLENGES

### 1. Increased Power

We propose a solution by using smart antennas to increase the signal power which in turn would reduce the bit error rate. In order to observe the effects of rainfall, we need to find a method to differentiate between any impact in the absence of precipitation and the impact that is caused by the precipitation. Because of this we are required to calibrate the system which can be done by measuring the RSL data in conditions of no rainfall for the calculation of the reference RSL level that consists of the impact of all sources of attenuation except the rain. After calculating the reference level, all the measured RSL values must be normalized as shown by the equation

$$RSL_n = \frac{RSL_m}{RSL_{nr}}$$

where:
$RSL_n$ stands for normalised RSL
$RSL_m$ stands for measured RSL
$RSL_{nr}$ stands for average RSL measured in no-rain conditions

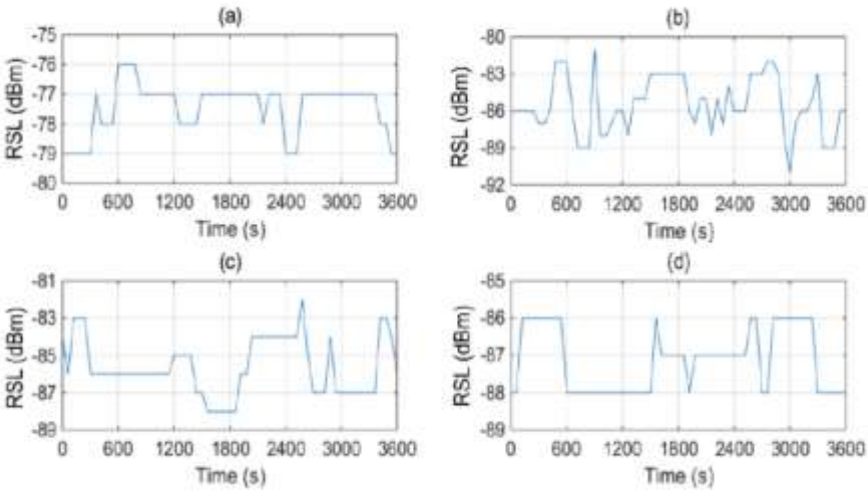


**Figure 1**. Different rainfall conditions: (a) No rain, (b) weak, (c) moderate and (d) heavy rain conditions for 1 hour [1]

### 2. Heterogeneous Network

In future, there is a possibility that modems and Wi-Fi routers could be replaced with 5G small cells or some other equipment to make 5G connections available for homes and businesses, thus replacing the wired internet connections which are extensively used today. Introducing 5G in rural areas would still be a big challenge as it happened during LTE launch.

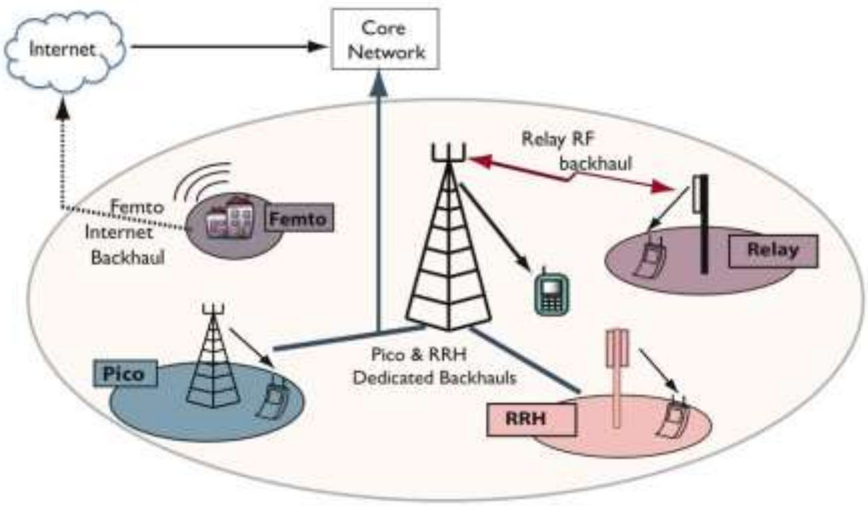


**Figure 2**. Representation of Heterogeneous Network [2]

## 3. Device to Device Communication

Device to Device (D2D) communications is a proposed method in which terminals in close range discover themselves automatically and communicate with one another without the need of a base-station. This approach is very efficient from a power control standpoint and may also reduce the unwanted noise due to interference in frequency bands which are unlicensed. Conventional cellular architecture does not grant authorization to user equipment (UEs) for exchanging data directly. However, when the devices are close by, this approach can be very much inefficient and Device to Device communication can be especially used in machine-type-communication (MTC) processes where there are a number of devices operating closely with one another.

D2D when considered together with the very fact that it will be coordinated with base-stations can provide several benefits to the cellular architecture in terms of energy efficiency and spectral efficiency. In the current state, D2D is evolving within 3GPP. D2D is promising because it is employed to make ultra-low latency communication possible.

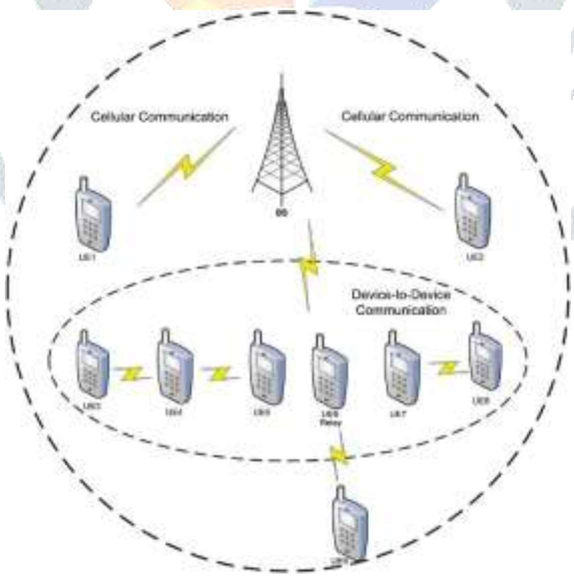


**Figure 3.** Architecture of D2D Communication networks [3]

## 4. Adaptive Beam Switching

In antenna arrays which work on the concept of beamforming, signals received by each element of the antenna array are adaptively built up which enhances the efficiency of the wireless communication system. The signals discovered at the different antennas on the gNodeB pass through multiplication processes involving complex weights. Summation of modified weights is then performed. In adaptive beamforming antenna arrays, according to the Direction of Arrival (DOA), the estimation beam can be steered to the direction of the required signal, and nullification is applied to unwanted signal directions.

The DOA of incoming signals and the direction of interfering signals can be effectively estimated by smart antennas. The generalized equation for adaptive array output $y(t)$ is given by

$$y(t) = w^H x(t)$$

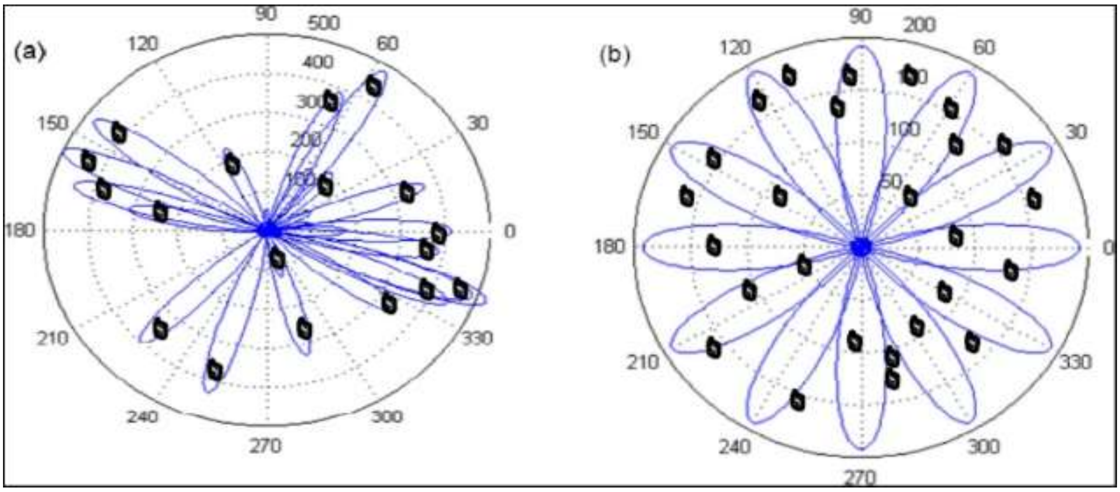


**Figure 4**. (a) Adaptive beamforming and (b) Switched beamforming [4]

## 5. Positioning of 5G Antenna

The relation between cell tower and location of customers depends on the final signal strength. Using this argument, we can get the relation between each gNodeB node and each selected area. Here, we have assumed that each gNodeB node is configured optimally according to the given position in order to cover as many locations as possible. Further, this prediction will vary as it depends on the deployment scenario (urban, suburban, rural area).

For urban/suburban areas the suitable path loss prediction models are
(i) Okumura-Hata Model
(ii) Stanford University Interim (SUI) Model
(iii) Cost 231 Hata Model [5]

For 5G and beyond deployments (in urban and suburban areas) the SUI Model seems promising for frequencies ranging from 2 to 11 GHz. This model is expressed by the following formula:

$$PL = A + 10\gamma.\log_{10}\left(\frac{d}{d_0}\right) + X_f + X_h + s$$

where d is the distance between the gNodeB node and the receiving antenna, $d_0 = 100$, $\gamma$ is the path-loss exponent, Xf is the correction for frequency above 2 GHz, Xh is the correction for receiving antenna height, s is the correction for shadow fading due to trees and other clutter and $\lambda$ is the wavelength. The other parameters are defined as:

$$A = 20\log_{10}\left(\frac{4\pi d_0}{\lambda}\right)$$

$$\gamma = a - bh_b - \frac{c}{h_b}$$

where $h_b$ is the gNodeB node height above ground in meters and a, b, c are constants that vary with terrain.

## V. RESULTS AND DISCUSSION

The solutions discovered above are simulated and verified in a practical environment with the help of MATLAB.

## 1. Massive MIMO

We know 5G is to be assisted by technologies that help to achieve significant rectification in cell throughput and for that Massive Multiple Input Multiple Output (MIMO) systems can be the gamechangers. They are much more practical and are currently being used in 4G LTE communications. They are MIMO systems containing numbers of precoders or detectors with the help of a large number of antennas which enable very high spectral efficiency and also maintain energy efficiency. To further enhance their quality of service, smart antennas can be used in them. Smart antennas are the centric location of many antenna elements at base stations (BSs) and gNodeB links, where signals are properly managed with the aim of enhancing the wireless mobile link and increasing the performance of the system.

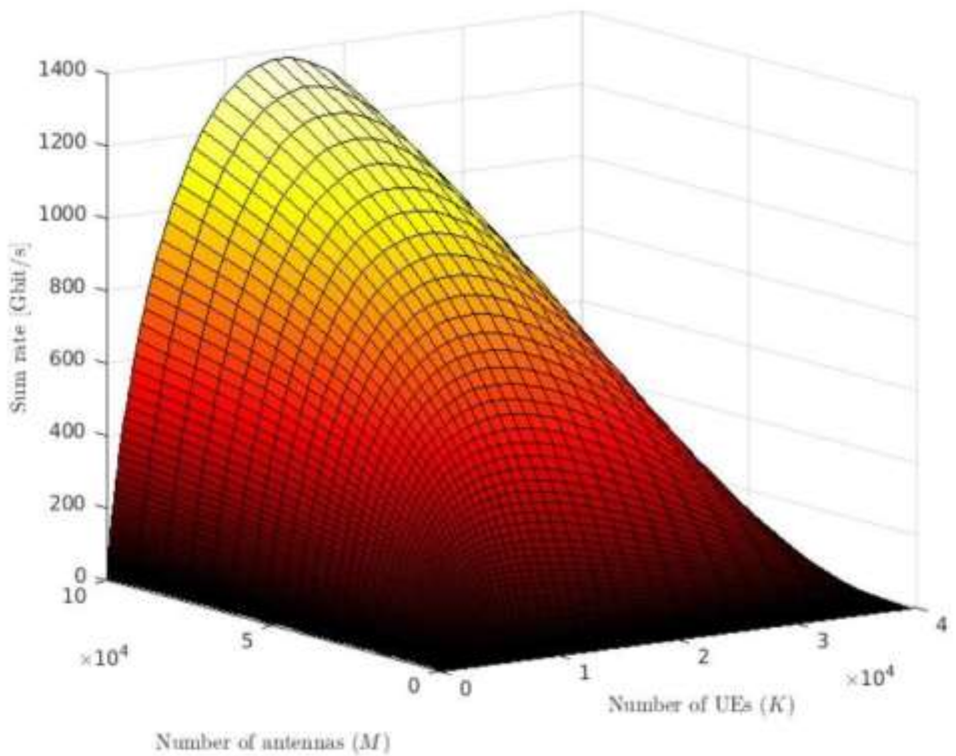


**Figure 5**. Massive MIMO caters to a significantly large number of UEs with no compromise on data rates.

## 2. OFDM

5G is based on OFDM (Orthogonal frequency-division multiplexing), a way of modulating a digital signal across several different channels to scale back interference. 5G uses the 5G NR air interface alongside OFDM principles and wider bandwidth technologies like sub-6 GHz and mmWave. Like 4G LTE, 5G OFDM operates supported equivalent mobile networking principles. However, the new 5G NR air interface can further enhance OFDM to deliver a way higher degree of flexibility and scalability. This could provide more 5G access to more people and things for a variety of different use cases. This could provide more 5G access to more people and things for a variety of different use cases.

## *3.* Small Cells

Small cells are low-powered radio access nodes which are used to meet the ever-increasing demands of a continuously expanding user base, therefore strengthening the infrastructure required for the implementation of truly 5G networks. They help to boost the performance for the mobile communication network while keeping infrastructure and power costs in control.

They can also be a key to solving the data loss and poor connectivity of UE because of the lower penetration power of the high frequency mmWave.

**Table 3.** Theoretical vs Actual number of gNodeBs deployed on different Terrains.

| Terrain | Theoretical Number of Locations to Deploy gNodeB | Number of UEs | Net Coverage Area [$km^2$] | Optimal Number of gNodeB that can be Deployed |
|---|---|---|---|---|
| Urban | 83 | 8000 | 3 | 20 |
| Sub Urban | 425 | 8000 | 19.25 | 23 |
| Rural | 491 | 8000 | 77 | 19 |

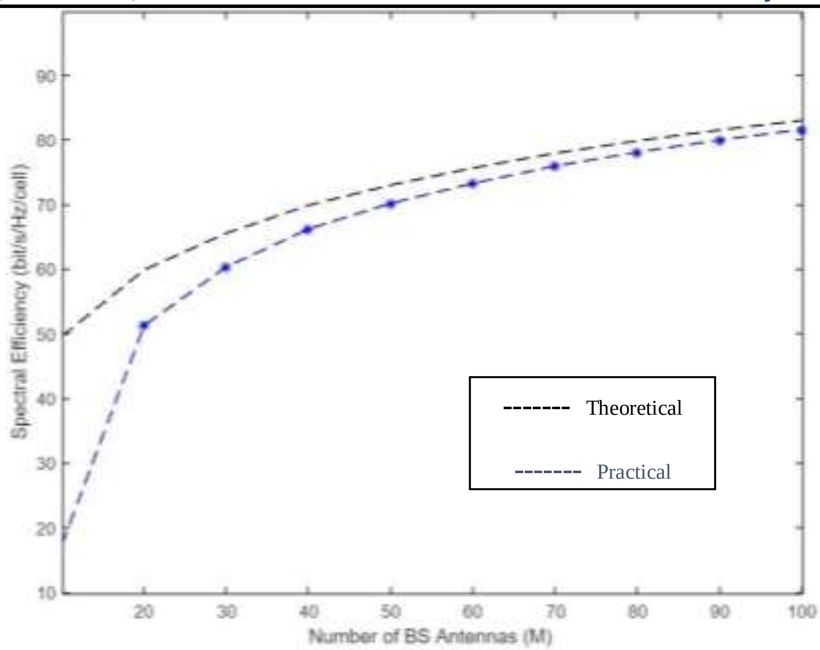


**Figure 6.** Simulation of achieving required spectral efficiency with optimal number of small cells.

### *4.* MmWave

The spectrum ranging from 30 GHz to 300 GHz bands is known as Millimeter wave spectrum. Wedged between microwave and infrared waves, this spectrum is often used for high-speed wireless communications as seen with the newest 802.11ad Wi-Fi standard (operating at 60 GHz). It is a reassuring way to implement 5G by allocating more bandwidth to transfer high quality videos and other multimedia content and services at significantly higher speeds.

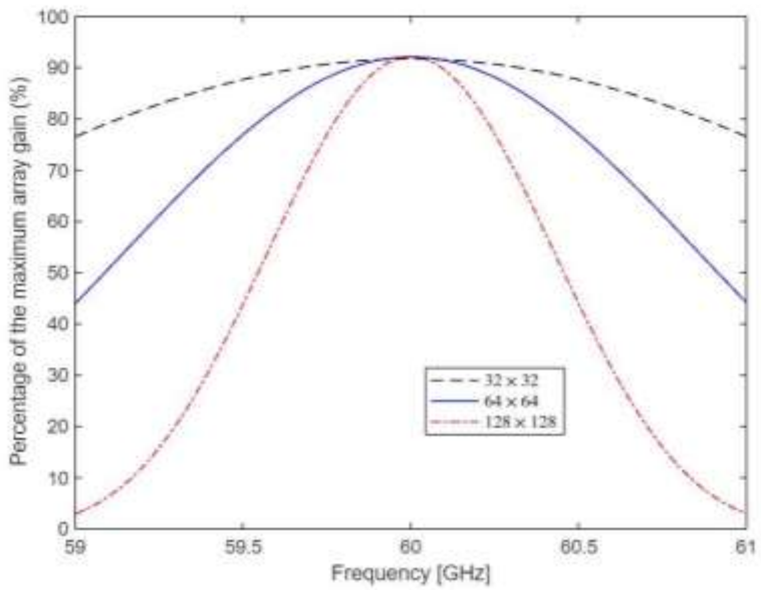


**Figure 7.** Percentage of maximum array gain (%) vs Spectrum Frequency (GHz)

### 5. Positioning of 5G Antenna

Based on AOA (Angle of Arrival) and the corresponding AOD (Angle of Departure) and the varying frequency channel, we tried to find the most suitable location for positioning of the 5G gNB.

This helps in finding the optimal signal strength and thus increases the data rate and harnessing the full potential of the 5G network.

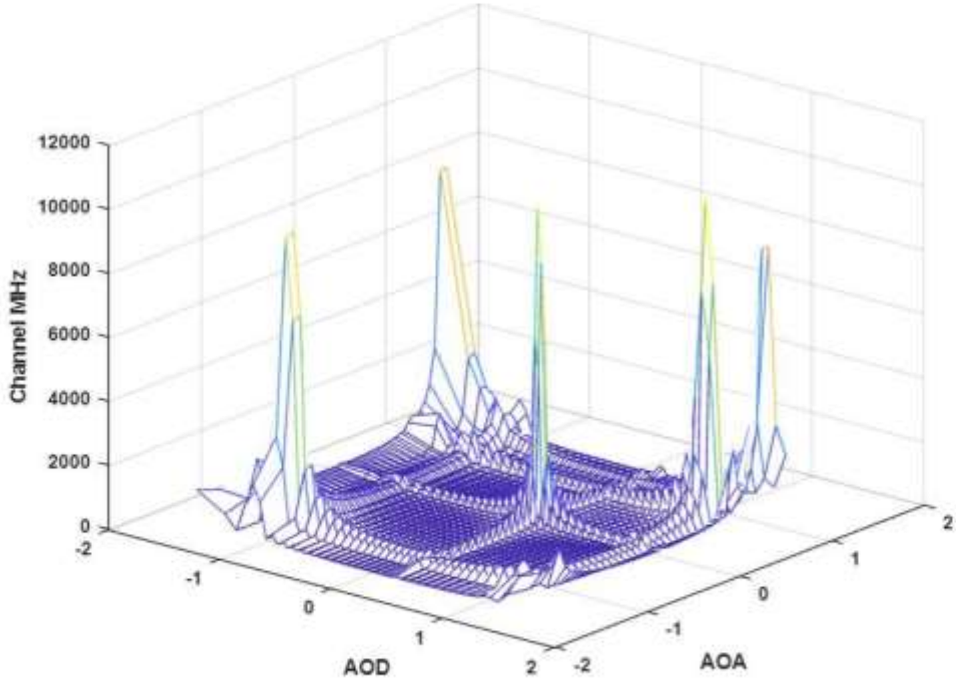


**Figure 8.** Identification of most suitable location for placing the small cells using AOD, AOA and Frequency

## VI. CONCLUSION

In our research work we have presented a comprehensive overview of Adaptive beamforming and Switching techniques in 5G mmWave networks using massive MIMO systems. We have reviewed the recent research on various techniques of 5G network implementation both theoretically as well as practically, analyzed their shortcomings and then identified the techniques which are more compatible along with massive MIMO systems.

We have used MATLAB for the simulation of the 5G mmWave network in order to find the optimal positioning of small cells and minimize their number, thus reducing the overall cost. The calculation of optimal beamforming is the main source of computational complexity. The running time with optimal beamforming takes hours or days, while it only takes a few minutes when only the heuristic beamforming schemes are computed. This shows clearly the need for simple heuristic beamforming. The limitations of beamforming were compensated by the use of Adaptive beam switching technique.

By using these techniques, we have successfully overcome the shortcomings due to the limited range and low penetration power of the high frequency 5G mmWaves. Our project is both economically and technically feasible as we are deploying it with the help of existing infrastructure and minimizing the need of any additional hardware.

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