# MEASUREMENT-BASED PERFORMANCE EVALUATION OF 3D-MASSIVE MIMO ANTENNA SYSTEM FOR 5G WIRELESS HetNet

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**ABSTRACT**

*With the advancement of mobile networks technology, the demand for higher throughput and low latency is continuously rising. 5G services require a network with a capacity 1000 times larger and a data speed 10 to 100 times faster. The International Telecommunication Union (ITU) sets 1 Gbit/s as the benchmark for user-perceived peak rate, with an omnipresent perceived speed of 100 Mbit/s for outdoor places. The Next Generation Mobile Networks (NGMN) Alliance put forward a similar set of standards that include a perceived speed of above 1 Gbit/s in dense-urban areas, a ubiquitous 100 Mbit/s in urban areas, and a pervasive 50 Mbit/s in suburban areas. Thus, 5G will be the foundation of a hyper-connected world. In addition to that, Heterogeneous networks (HetNet) are widely accepted to enhance the throughput as they do have low pathloss among the others. HetNet deploys another cell under the coverage area of the macro cell. The HetNet offloads the macro cell that avoids congestion and enhances the coverage of the network. Moreover, multiple-input multiple-output technology with high number of antennas (Massive MIMO) has been an excellent technology that make use of multipath effects and enhance the system capacity dramatically. However, the majority of works that addressed Massive MIMO system focused on one dimensional (azimuthal) beam steering only. Adding the second dimension (elevation) to the massive MIMO system has been denoted as three-dimensional Massive MIMO (3D-Massive MIMO) since beams will cover the 3D space, thus enhancing coverage, reducing interference and enhancing capacity. Our work will focus on the performance evaluation of 3D-Massive MIMO antenna system in a 5G heterogenous network for different scenario and different frequency bands.*

**Keyword:** *3D-Massive MIMO, 5G, HetNet, ITU, NGMN*

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## 1. INTRODUCTION

In the recent years, the mobile network demand has increased four times compared with the fixed networks [1]. The growing demand for mobile network connectivity associated with the increased smartphone ownership, the increase of indoors mobile usage and higher data rate is driving the evolution of the cellular communications. To cope with the ever-increasing throughput demand in wireless technologies, the existing technologies are constantly improving. The long-term evolution (LTE or 4G) networks can't satisfy this alarming demand and hence the fifth generation (5G) communication network [1] is consistently working to enhance the overall performance of the cellular communications. Furthermore, the use of 3D-Massive MIMO antenna system and the deployment of small cell technology has been identified as an important approach to increase the mobile network capacity and coverage [2]. And they can be used to provide indoor and outdoor wireless service.

## 2. Overall architecture of 5G telecommunication network

The overall architecture of the 5G telecommunication network is composed of a Next Generation Radio Access Network (NG-RAN) and a core network or 5G Core (5GC). The Figure 01 illustrate this architecture.

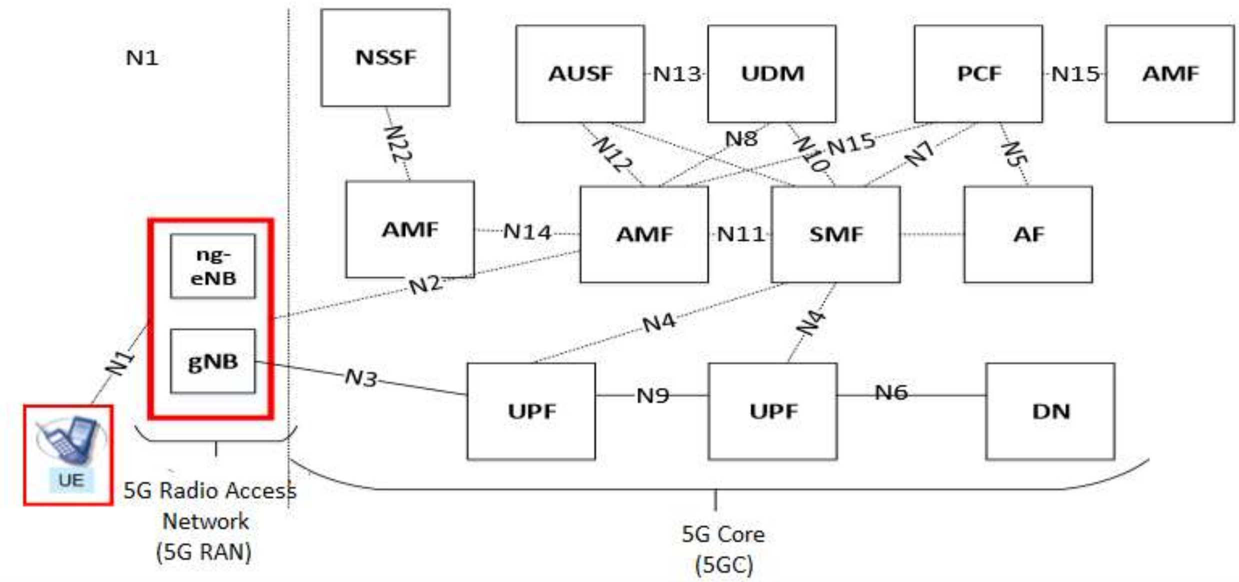


**Figure 01**: 5G architecture and interfaces between entities

AUSF: Authentication Server Function (AuC)
UDM: Unified Data Management (HLR/HSS)
AMF: Access and Mobility Management Function (MME)
SMF: Session Management Function (MME)
NSSF: Network Slice Selection Function
PCF: Policy Control Function
UPF: User Plane Function (S/PGW)
DN: Data Network (PDN)
AF: Application Function
UE: User Equipment

In the network core, the following blocks are present:

- Authentication Server Function (AUSF): Process the authentication of the UE
- Core Access and Mobility Management Function (AMF): Deals with EU Mobility Management
- Policy Control Function (PCF): Deals with the management of any type of policy applicable to the EU (mobility management policy, QoS management, access technology selection management, etc.)
- Session Management Function (SMF): processes the EU session management
- Unified Data Management (UDM): Serves as an interface to all network functions that require access to EU subscription data.
- User plane Function (UPF): processes outgoing and incoming user plan flows from the EU
- Function Application (AF): Can use the PCF interface to request QoS implementation for a given IP flow
- Network Slice Selection Function (NSSF): Identifies the appropriate AMF function for supporting mobility management in the UE
- Data Network (DN): Concerns Data Networks.

## 3. System model

In the case of a cellular communication system using a 3D-Massive MIMO antenna system, as shown in the Figure 02, the base station (BS) is composed of a large number antenna transmitter (Tx) and receiver (Rx). The antennas position is defined in a cartesian coordinates $(x_t, y_t, z_t)$ and $(r, y_r, z_r)$ [3].

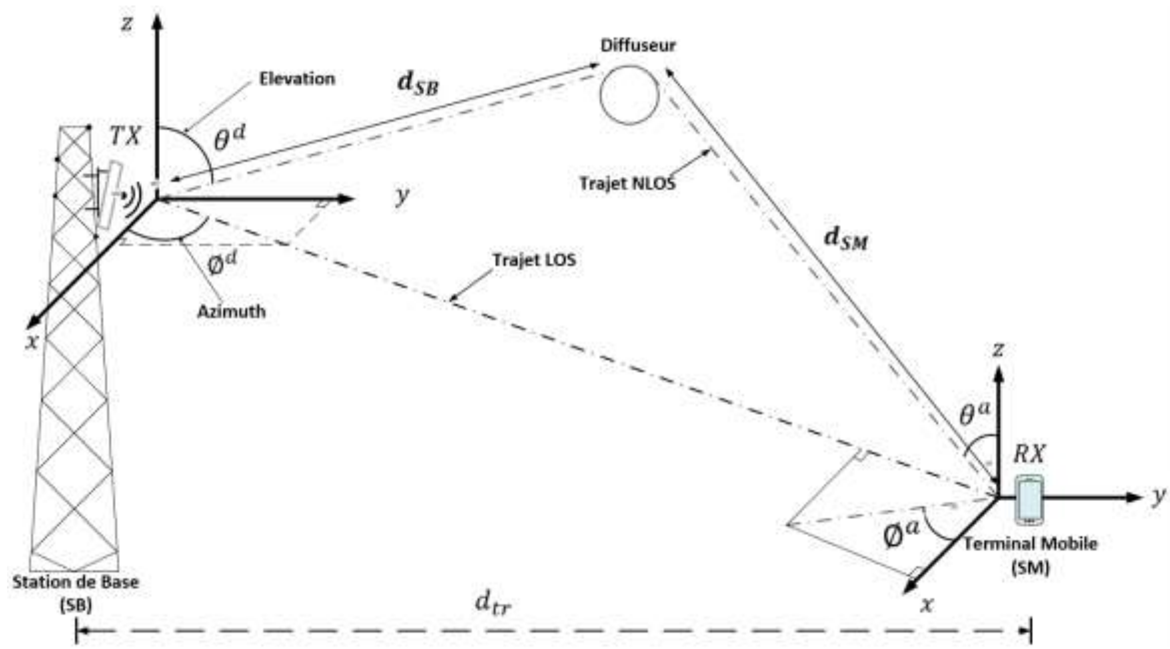


**Figure 02** : 3D-Massive MIMO channel propagation model

The generation of 3D-Massive MIMO channel coefficient is given by successive step as described in the Figure 03 [3].

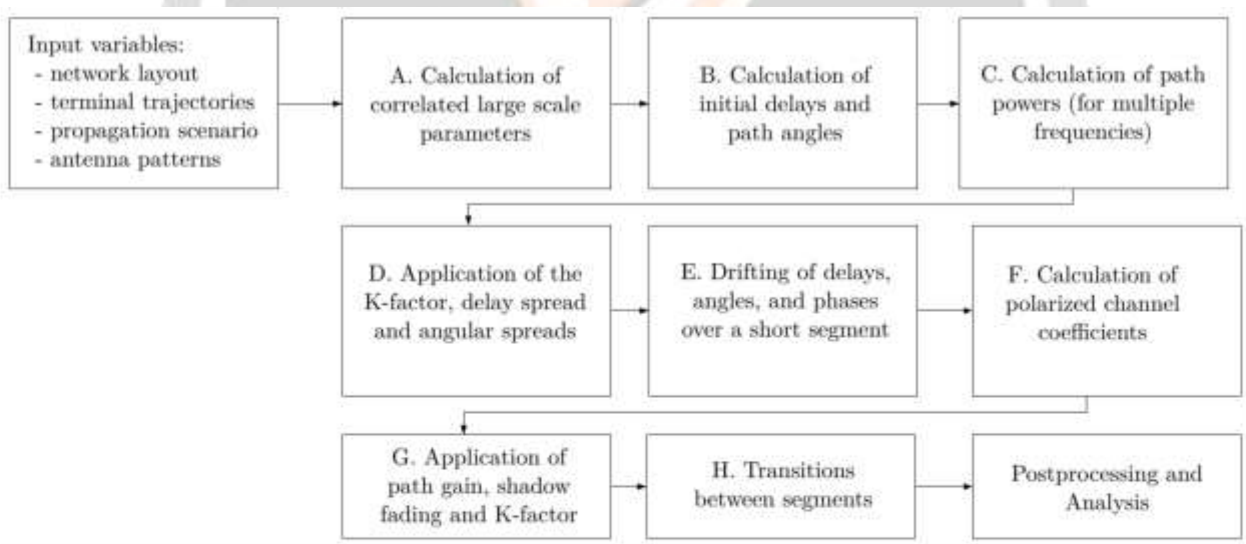


**Figure 03** : 3D-Massive MIMO channel coefficient génération

## 4. Performance evaluation of 3D-Massive MIMO system

### 4.1. Path gain

The path gain $P_G$ of the signal transmitted by the base station BS is given by:

$$P_G = -A.\log_{10} d_{tr} - B - C.\log_{10} f + X \quad (1)$$

Where $d_{tr}$ the distance between the base station and the terminal

$f$ the frequency used

$A, B, C$ and $X$ the coefficient for a specific scenario

From equation (1) and taking into account the shadowing effect $\mathcal{O}$, the effective gain is given by:

$$P_i^{eff} = \sqrt{10^{0.1(P_G + O_G)}} \quad (2)$$

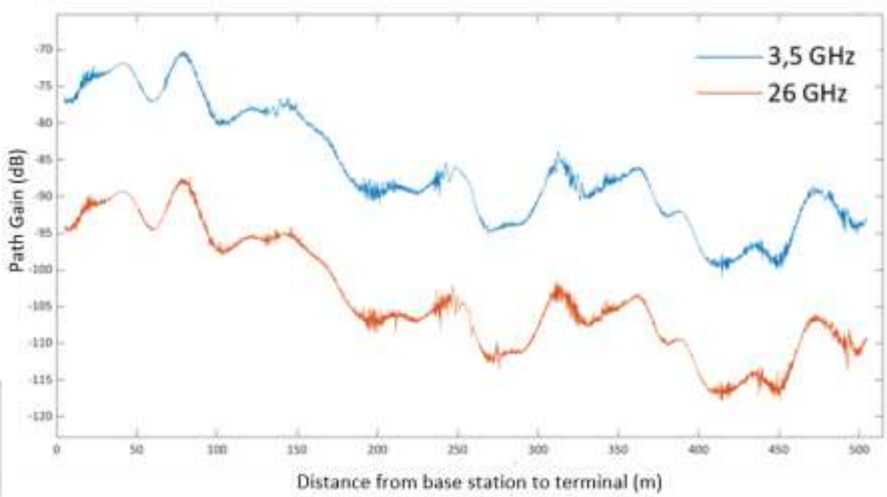


**Fig -3:** Path gain in an Uma environment and for LOS trajectory

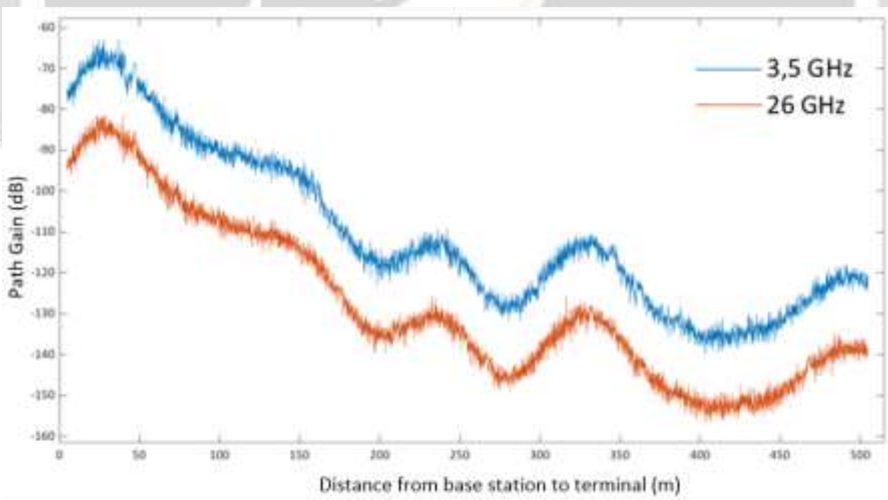


**Figure 04:** Path gain in an Uma environment and for NLOS trajectory

The Table 01 below show the result of the simulation for a path gain in an Uma and Umi scenario.

**Table 01**: Path gain analysis of 3D-Massive antenna in terms of distance, for an Uma scenario

| Parameters | | | | | | Path Gain (dB) | |
|---|---|---|---|---|---|---|---|
| Scenario | Antenna high | | Zones | Distance(m) $d_{tr}$ | $f$(GHz) | 250m | 450m |
| | $h_{SB}$ (m) | $h_{SM}$ (m) | | | | | |
| Urban macro | 25 | 1,5 | LOS | 500 | 3,5 | **-87** | **-100** |
| | | | | | 26 | **-105** | **-115** |
| | | | NLOS | | 3,5 | **-120** | **-130** |
| | | | | | 26 | **-136** | **-150** |

The result, summarized by the Table 01 show that the use of mm-wave band present a low antenna gain, specially in a NLOS condition.

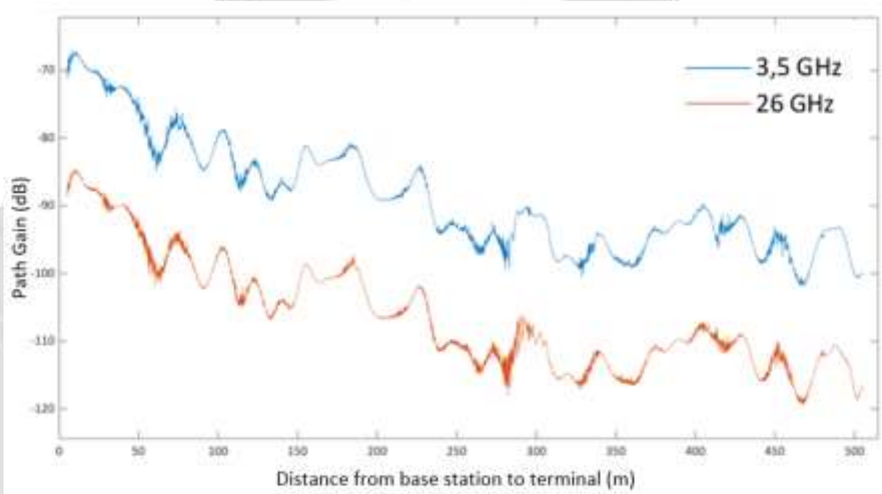


**Figure 04:** Path gain in a Umi environment and for LOS trajectory

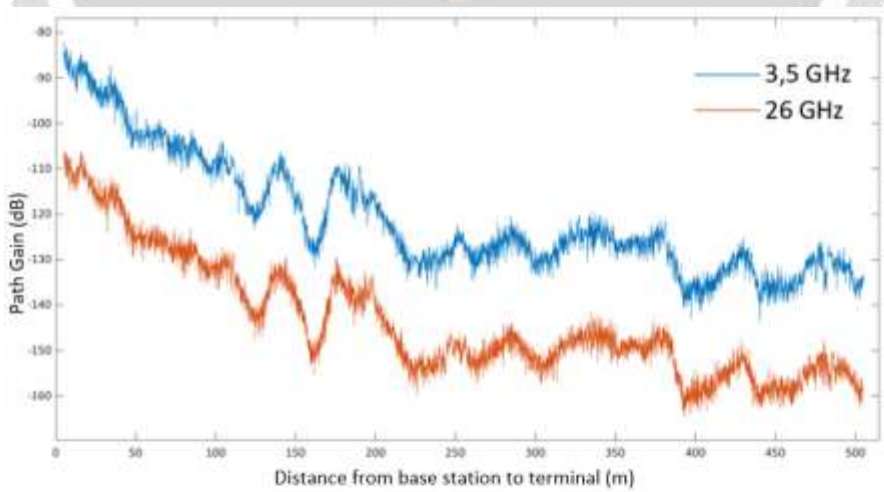


**Figure 05:** Path gain in a Umi environment and for NLOS trajectory

Figure 03 and Figure 04 show the same result as the precedent result, that means that the path gain obtain by the use of mm-wave band is very bad compared to the path gain obtain by the use of sub 6GHz band. In contrast, we can see that the use of mm-wave gives better performance in an indoor environment.

**4.2. Power signal of 3D-Massive MIMO antenna**

The power signal, in a NLOS environment is given by:

$$P_l^{[1]} = \exp\left(-\tau_l^{[1]} \cdot \frac{r_\tau - 1}{r_\tau} \cdot \sigma_\tau\right) \cdot 10^{\frac{-z_l}{10}} \quad (3)$$

From equation (3), the signal power of the first path is given by:

$$P_1^{[2]} = K \sum_{l=2}^{L} P_l^{[1]} \quad (4)$$

$$P_{2\ldots l}^{[2]} = P_{2\ldots l}^{[1]} \quad (5)$$

And finally, the total power of the transmitted signal is given by:

$$P_l = \frac{P_l^{[2]}}{\sum_{l=1}^{L} P_l^{[2]}} \quad (6)$$

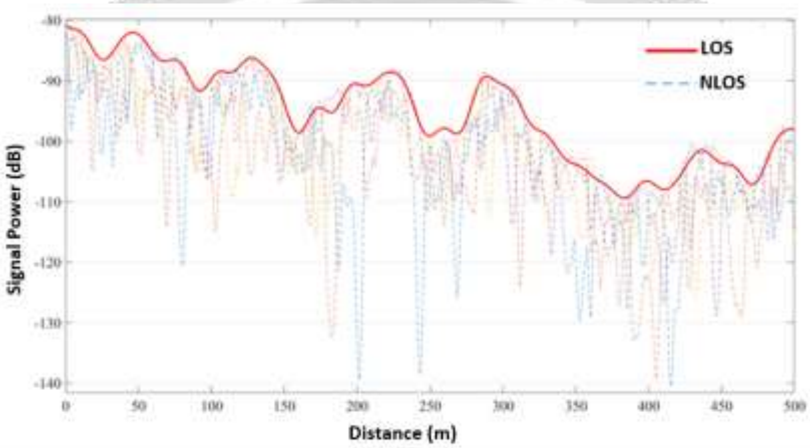


**Figure 06:** Received signal power, in a UMa environment and for 3,5GHz band

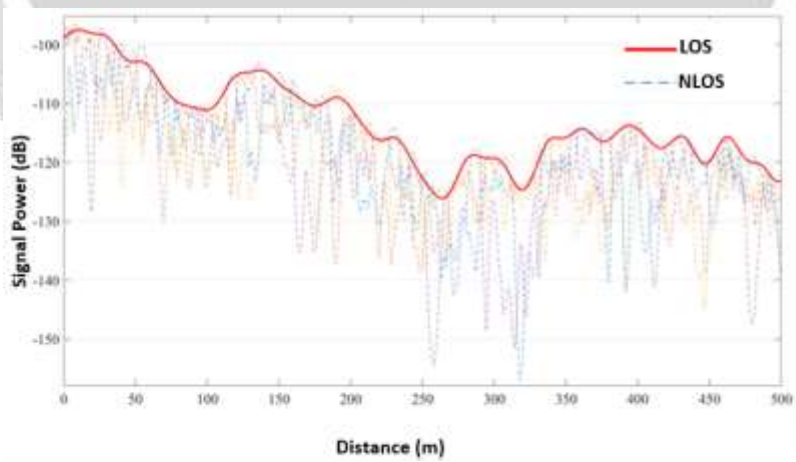


**Figure 07:** Received signal power, in a UMa environment and for 26GHz band

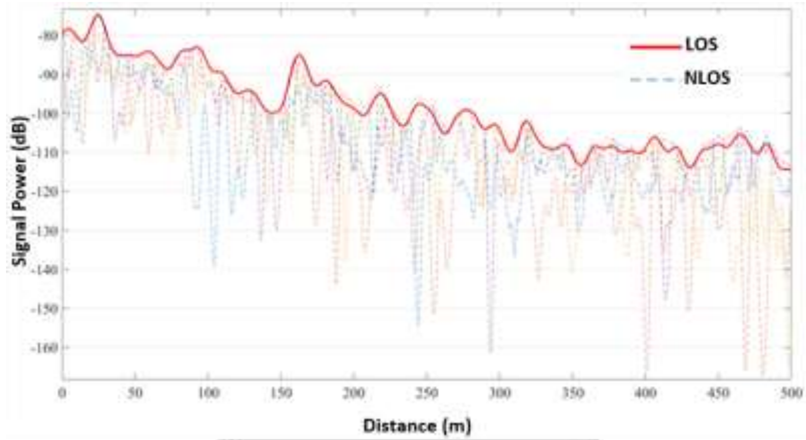


**Figure 08:** Received signal power, in a UMi environment and for 26GHz band

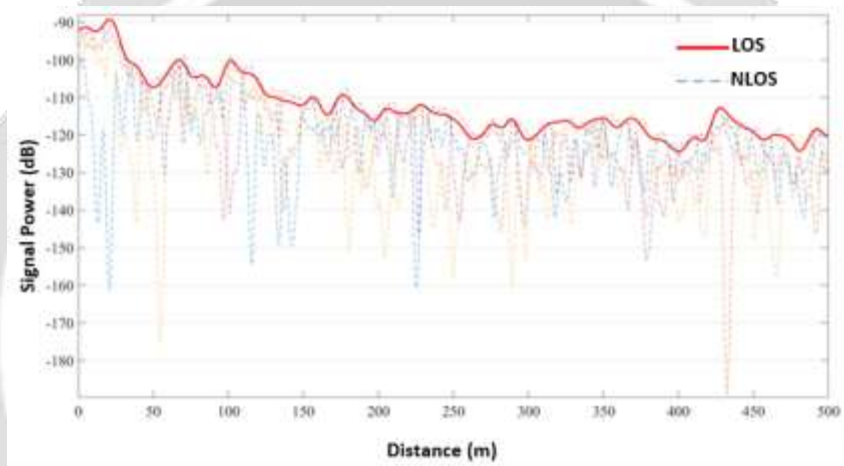


**Figure 09:** Path gain in a Umi environment and for NLOS trajectory

**Table 02**: Analysis of antenna signal power in a UMa scenario

| Parameters | | | | | | Signal(dB) | |
|---|---|---|---|---|---|---|---|
| **Scénario** | **Antenna high** | | **Zone** | **Distance(m) $d_{tr}$** | ***f*(GHz)** | **250m** | **450m** |
| | **$h_{SB}$ (m)** | **$h_{SM}$ (m)** | | | | | |
| **Urban macro** | 25 | 1,5 | LOS | 500 | 3,5 | -98 | -102 |
| | | | | | 26 | -125 | -120 |
| | | | NLOS | | 3,5 | -115 | -125 |
| | | | | | 26 | -139 | -142 |
| **Urbain micro** | 10 | 1,5 | LOS | 500 | 3,5 | -105 | -108 |
| | | | | | 26 | -115 | -120 |
| | | | NLOS | | 3,5 | -105 | -130 |
| | | | | | 26 | -155 | -130 |

The result, summarized by the Table 02 show that the use 3D-Massive MIMO antenna allow to have a better signal quality even in a NLOS environment. Moreovere, the use of mm-wave band in an Urban Microcellular environment allow to solve the coverage problem in a macrocellular network.

### 4.3. Cumulative distribution function of the SINR in 5G HetNet

The figure 5 and 6 shows, respectively, the cumulative distribution of SINR using a massive MIMO antenna and 3D-Massive MIMO antenna using the 3,5GHz frequency band.

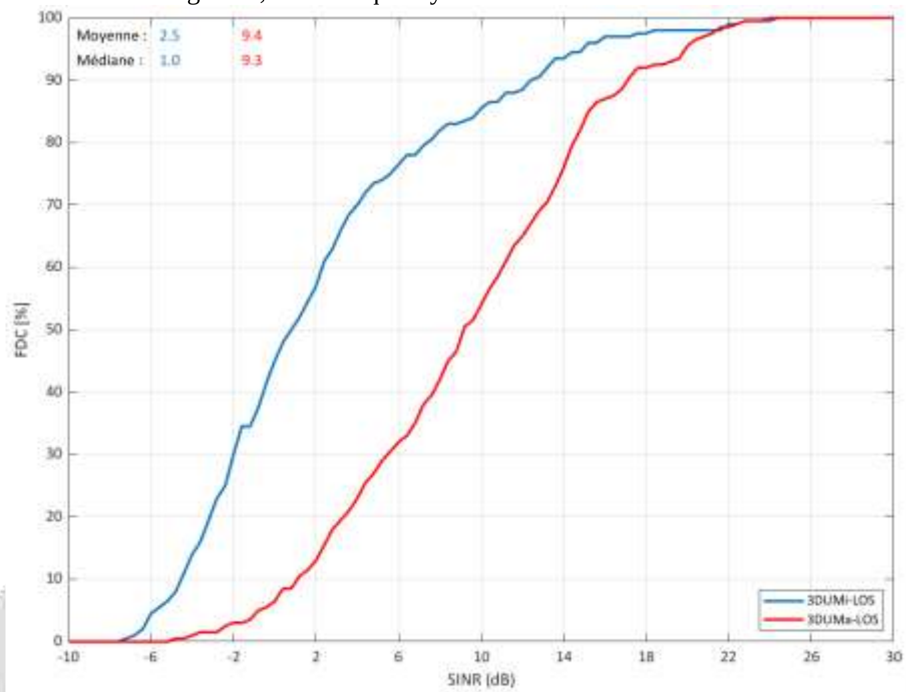


**Figure 09:** LOS Massive MIMO 3,5GHz

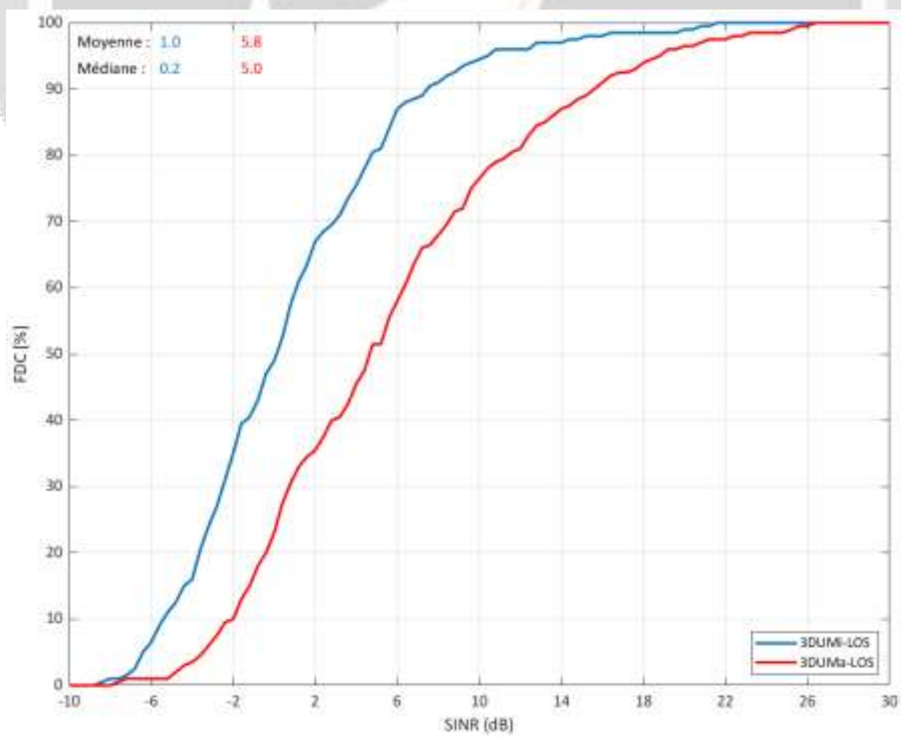


**Figure 10 :** LOS 3D-Massive MIMO 3,5GHz

**Table 03**: FDC of SINR, in a UMa and Umi LOS environment and for 3,5GHz band

| Parameters | | | | | SINR (dB) | | | |
|---|---|---|---|---|---|---|---|---|
| Scénario | Antenna high | | Zone | *f* (GHz) | Massive MIMO | | 3D-Massive MIMO | |
| | $h_{SB}$ (m) | $h_{SM}$ (m) | | | 50% | 95% | 50% | 95% |
| **Urbain macro** | 20 | 1,5 | LOS | 3,5 | 9,4 | 20 | 1,0 | 10 |
| **Urbain micro** | 10 | | | | 2,5 | 14 | 5,8 | 20 |

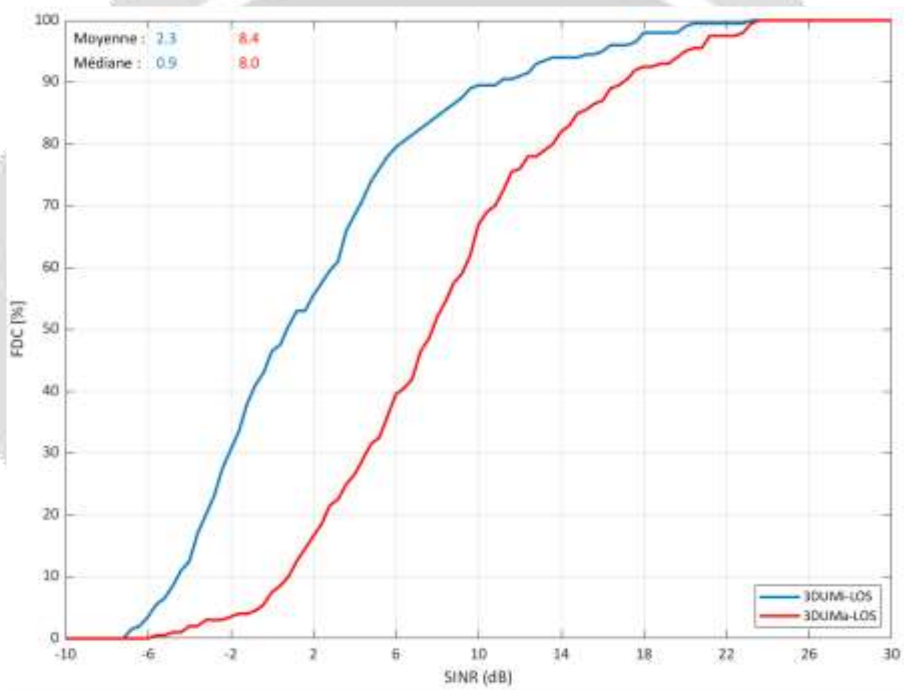


**Figure 11:** LOS Massive MIMO 26GHz

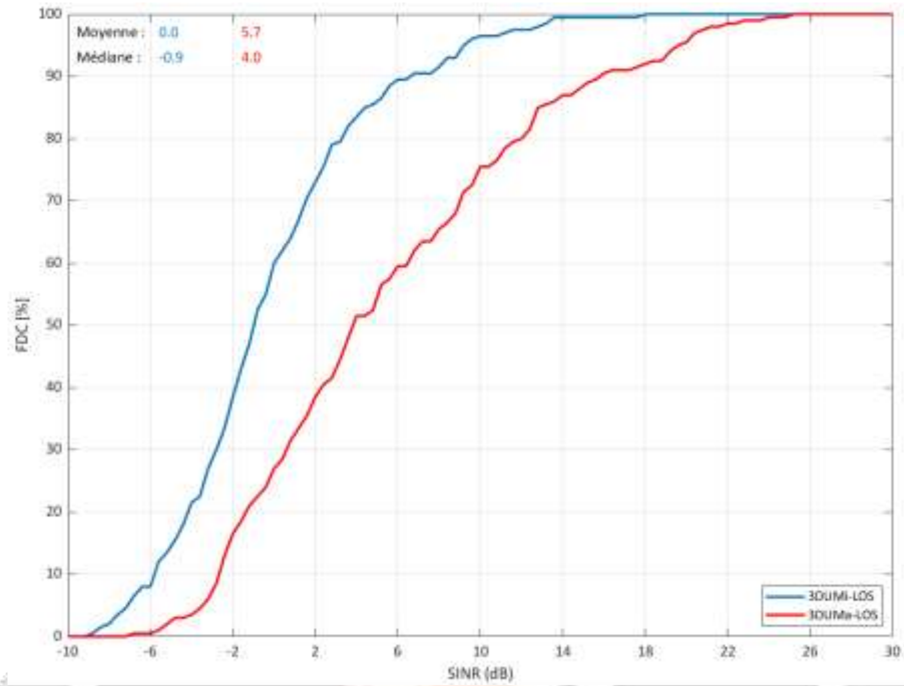


**Figure 12:** LOS 3D-Massive MIMO 26GHz

**Table 04**: FDC of SINR, in a UMa and Umi LOS environment and for 26GHz band

| Parameters | | | | | SINR (dB) | | | |
|---|---|---|---|---|---|---|---|---|
| **Scénario** | **Antenna high** | | **Zone** | ***f* (GHz)** | **Massive MIMO** | | **3D-Massive MIMO** | |
| | **$h_{SB}$ (m)** | **$h_{SM}$ (m)** | | | 50% | 95% | 50% | 95% |
| **Urbain macro** | 20 | 1,5 | LOS | 26 | 8,4 | 20 | 5,7 | 20 |
| **Urbain micro** | 10 | | | | 2,3 | 16 | - | 9 |

The Table 03 and the Table 04 show that the use of 3D-Massive MIMO antenna system allow to have a lower SINR value compared to the use of Massive MIMO antenna system. Moreover, the use of 3D-Massive MIMO antenna with a mm-wave band is more powerful than the use of a traditional Massive MIMO antenna system.

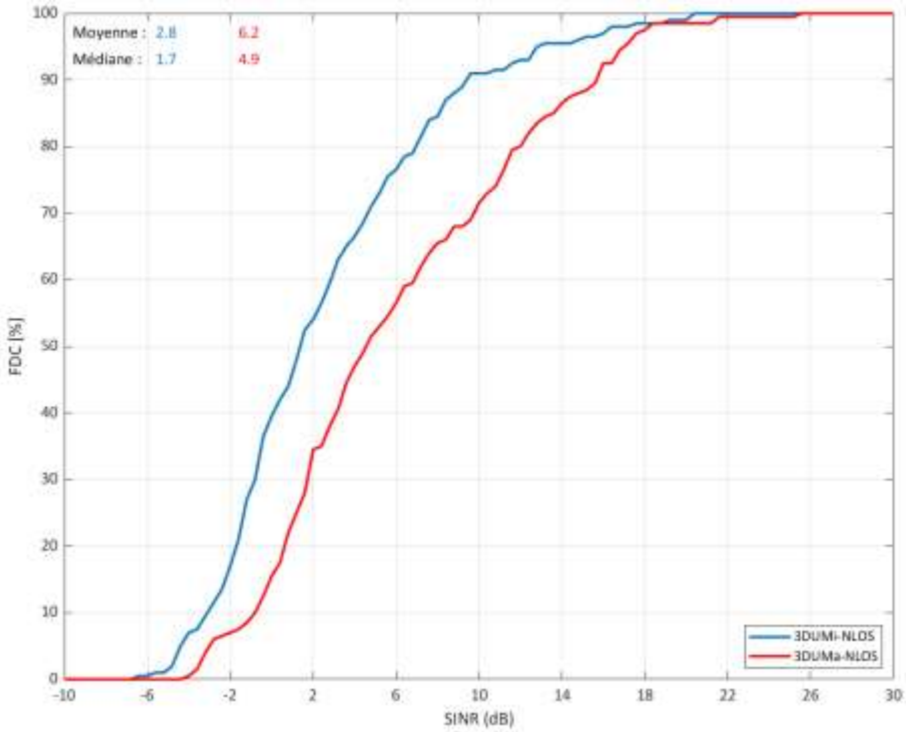


**Figure 13: N**LOS Massive MIMO 3,5GHz

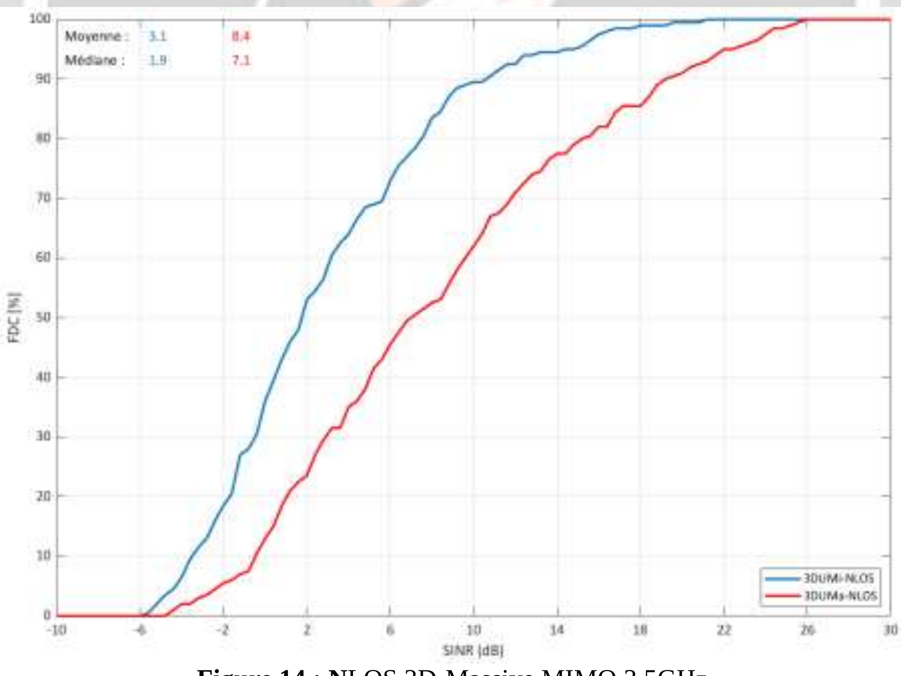


**Figure 14 : N**LOS 3D-Massive MIMO 3,5GHz

**Table 05**: FDC of SINR, in a UMa and Umi NLOS environment and for 3,5GHz band

| Parameters | | | | | SINR (dB) | | | |
|---|---|---|---|---|---|---|---|---|
| **Scénario** | **Antenna high** | | **Zone** | ***f* (GHz)** | **Massive MIMO** | | **3D-Massive MIMO** | |
| | $h_{SB}$ **(m)** | $h_{SM}$ **(m)** | | | 50% | 95% | 50% | 95% |
| **Urbain macro** | 20 | 1,5 | NLOS | 3,5 | 6,2 | 16 | 8,4 | 24 |
| **Urbain micro** | 10 | | | | 2,8 | 14 | 3,1 | 14 |

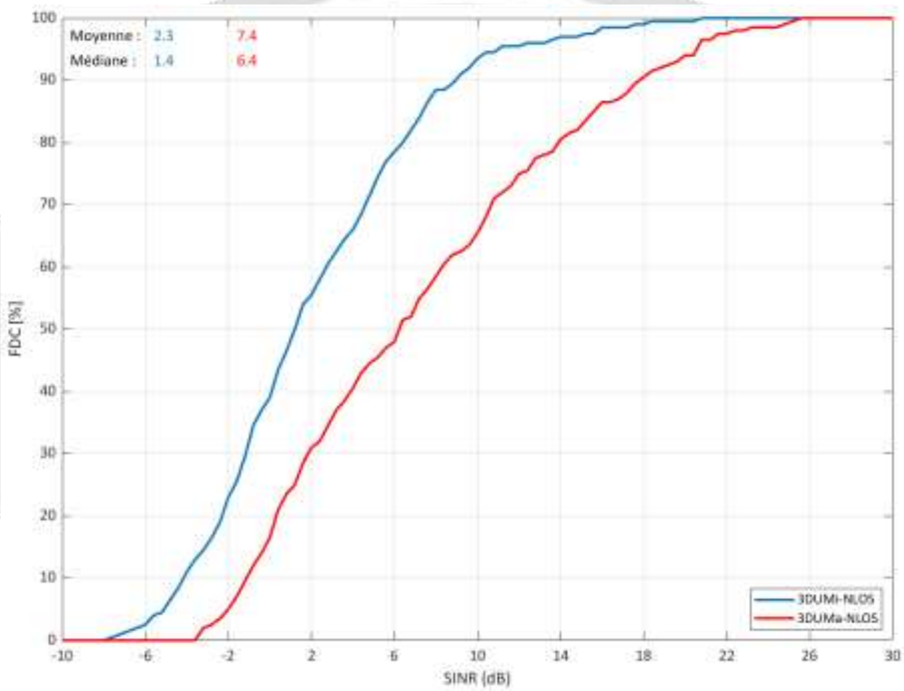


**Figure 15 : N**LOS Massive MIMO 26GHz

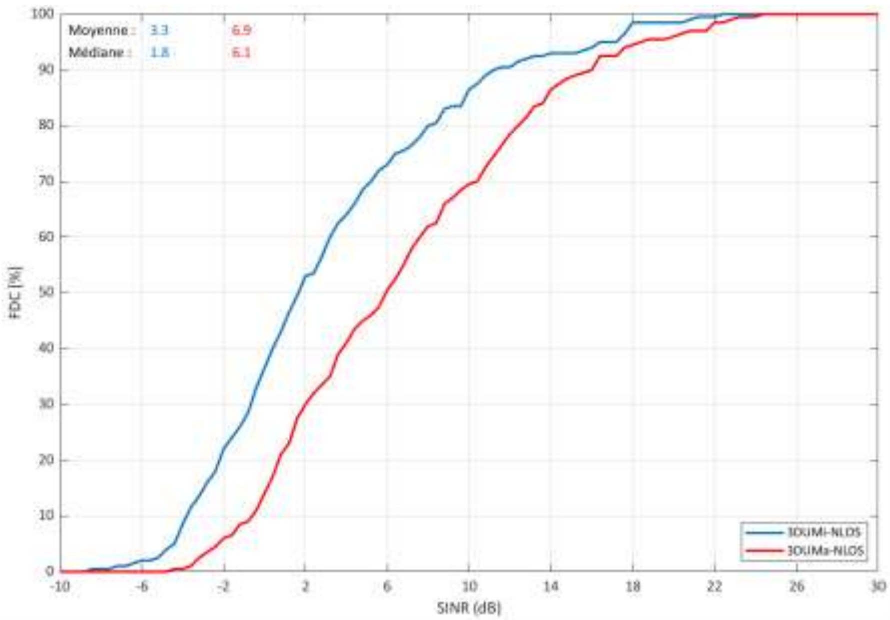


**Figure 16 : N**LOS 3D-Massive MIMO 26GHz

**Table 06**: FDC of SINR, in a UMa and Umi NLOS environment and for 26GHz band

| Parameters | | | | | SINR (dB) | | | |
|---|---|---|---|---|---|---|---|---|
| **Scénario** | **Antenna high** | | **Zone** | ***f* (GHz)** | **Massive MIMO** | | **3D-Massive MIMO** | |
| | $h_{SB}$ **(m)** | $h_{SM}$ **(m)** | | | 50% | 95% | 50% | 95% |
| **Urbain macro** | 20 | 1,5 | NLOS | 26 | 8,4 | 20 | 5,7 | 20 |
| **Urbain micro** | 10 | | | | 2,3 | 16 | - | 10 |

The Table 05 and the Table 06 show that the use of 3D-Massive MIMO antenna system allow to have a lower SINR value compared to the use of Massive MIMO antenna system. Moreover, the use of 3D-Massive MIMO antenna with a mm-wave band is more powerful than the use of a traditional Massive MIMO antenna system even in a NLOS environment.

## 5. CONCLUSIONS

In this paper, the performance of 3D-Massive MIMO is analyzed on the basis of measurement in different scenario and for different frequency bands. Comparisons are conducted for Massive MIMO and 3D-Massive MIMO antenna system by using the 3,5-frequency band and the 26Ghz band, in an Urban micro and an Urban macro scenario. Analysis and comparison results reveal that the use of 3D-Massive MIMO antenna allow to have a higher antenna gain and higher signal power compared to the traditional Massive MIMO antenna system. At last, we observed that deploying an HetNet network by the use small cell technology help reach the 5G objective, which is to give more coverage and more capacity.

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