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Network Performance of Massive MIMO Antenna

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[2] PU = Public

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Executive Summary

5G wireless cellular networks rely on the use of Massive MIMO antenna technologies. In this deliverable, we present the impact of Massive MIMO antennas on the performance of 28 GHz wireless networks. Both an indoor and an outdoor scenario are considered. The study is based on the computation of fundamental KPIs of 5G wireless networks such as the SS RSRP, the SS SINR, and the PDSCH Throughput. These parameters are evaluated under the same network settings for two different array antennas, a benchmark antenna and one of the antenna design as a result of this project presented in deliverable WAVECOMBE_D1.3. We have shown that using the same initial network configuration both antennas meet the network performance compliance criteria. However, the new designed antenna needs a smaller number of antennas to meet the minimum performance requirements. Moreover, the network performance with the new designed antenna is much better even with a smaller number of antenna sites. This is because, the new designed antenna has a narrower main beam with a higher beam gain and lower side lobe levels. The KPI improvement is larger for the indoor network than for the outdoor network, i.e., while for the outdoor network the PDSCH throughput was doubled at the 80 % CDF level, it was quadrupled for the indoor environment.

Disclaimer: This work has been performed in the framework of the H2020 project WaveComBE (Grant agreement ID: 766231) co-funded by the EU. This information reflects the consortium's view, but the consortium is not liable for any use that may be made of any of the information contained therein. This deliverable has been submitted to the EU commission, but it has not been reviewed and it has not been accepted by the EU commission yet.

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List of Acronyms and Abbreviations

2D	two dimensional
5G	5^{th} Generation
ACO	Automatic Cell Optimizer
CDF	cumulative distribution function
dBi	decibels per isotropic
EIRP	effective isotropic radiated power
EM	electromagnetic
GHz	giga Hertz
GSM	global system for mobile communications
H-Plane	horizontal-plane
KPI	key performance indicators
LO	local oscillator
LTE	long term evolution
MHz	mega Hertz
MIDACO	Mixed Integer Distributed Ant Colony Optimization
MIMO	multiple-input multiple-output
mmWave	millimeter wave
NR	new radio
PDSCH	Physical Downlink Shared Channel
RF	radio frequency
RSRP	reference signal received power
RX	receiver
SINR	signal-to-interference-plus-noise-ratio
SS	synchronization signal
TX	transmitter
V-Plane	vertical-plane
WCDMA	wideband code division multiplexing
Wi-Fi	wireless fidelity

1. Introduction

5G wireless cellular networks have been designed to provide users with high peak data rates simultaneously. Large chunks of bandwidth are available at the mmWave portion of the EM spectrum. At these frequencies highly directive antennas with high gain are necessary to compensate for the significant propagation path loss [1]. A way to realize highly directive communication with a large coverage area, multibeam array antennas [2] or phased array antennas [3] can be used. The high gain and narrow beamwidth of the antennas allows to increase signal quality while reducing the interference footprint in the cell.

We present in this deliverable the impact of Massive MIMO antennas on the performance of 28 GHz wireless networks. Both an indoor and an outdoor scenario are considered. The study is based on the computation of fundamental KPIs of 5G wireless networks such as the SS RSRP, the SS SINR, and the PDSCH Throughput. These parameters are evaluated under the same network settings for two different array antennas, a benchmark antenna and the new antenna design as a result of this project presented in deliverable D1.3 (the 28 GHz 16x16 phased array based on Gap waveguide with 45°-slanted polarization and 65 dBm EIRP) [4].

The reminder of the report is organized as follows. Section 2 presents the main parameters of the benchmark and the designed antenna. Section 3 presents the network planning tool. Sections 4 and 5 present the simulation environment, the network simulation settings and the corresponding results of the computed 5G KPI's obtained with the benchmark and the designed antennas for the indoor and the outdoor network scenarios, respectively. The conclusions are given in Section 6. Appendix A lists the published papers and publications in preparation.

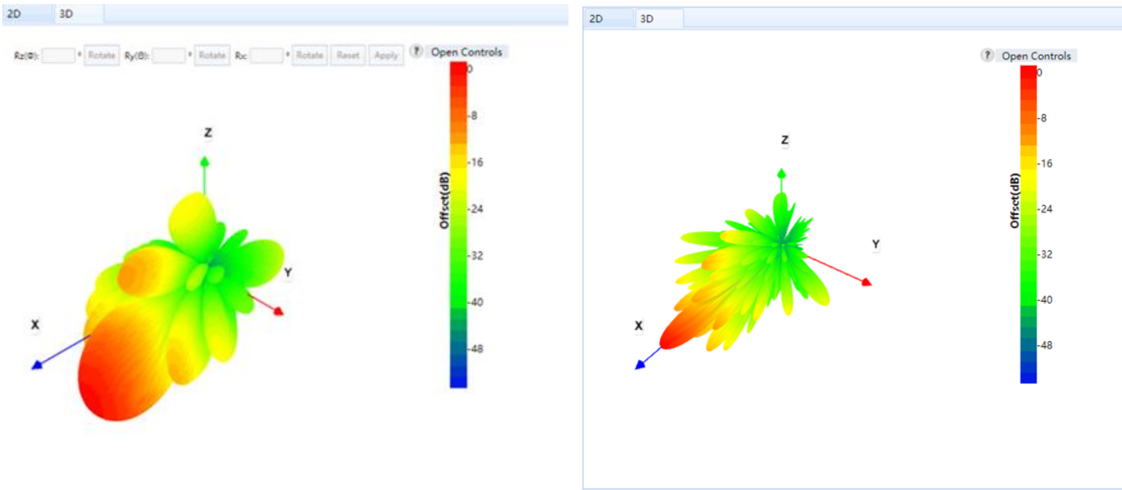
2. Simulation Parameters of the two indoor antennas

Table 1 lists the antenna parameters of the benchmark and one of the designed antennas presented in deliverable D1.3 [4]. As can be seen from Tabl1 the designed antenna in this project (in the following referred to as 'the designed antenna') has about 9 dB larger gain as compared to the benchmark antenna. Also, the designed antenna has narrower beam-widths. These two antenna characteristics allow to focus energy towards the desired user, while reducing the interference toward other users.

The beamforming radiation patterns of the benchmark antenna and designed antenna are shown in Fig.1a) and Fig.1b), respectively.

Table1: Antenna parameters

	Benchmark Antenna	Designed Antenna
Frequency (MHz)	26500-29500	26700-29100
Broadcast beam Number	16	65
Broadcast beam Gain (dBi)	19.6	29.1
V-Plane 3dB beam width (deg)	26	6
H-Plane 3dB beam width (deg)	14	6
Front-to-back ratio (dB)	36.8	35.6
Service beam number	64	65
Service Beam Gain (dBi)	20	29.1
V-Plane 3dB beam width (deg)	26	6
H-Plane 3dB beam width (deg)	14	6
Front-to-back ratio (dB)	28.8	35.6



(a) (b)

Fig.1 Beamforming radiation patterns of (a) benchmark antenna and (b) antenna design

3. Network Planning and Simulation Tool

The performance of the designed antenna is simulated with the Ranplan Professional software [5], which is a 3D network planning and optimization tool. It has the capability to run system-level simulations and has been tested and validated in the literature [6].

The Ranplan Professional software is integrated with a ray tracing propagation engine. It has the capability to capture the complex channel gain considering large-scale fading and small-scale fading of a real 3D scenario. It supports propagation channel simulation up to mmWave frequency bands, which has been tested and validated in the literature [7].

The input information for the radio propagation channel computation is the following:

1) The radiation patterns of the antenna elements of the massive MIMO array antenna as well as other properties such as the number of antenna elements, the aperture size, the array antenna topology and antenna locations.

2) The 3D propagation scenarios, where the information includes the 3D geometrical structure of the scenario, the electric properties of walls, windows, doors, ceilings, grounds and furniture, the number of users and their locations.

3) The accuracy factors of the ray tracing tool, which include the maximum number of the transmission, the diffraction, and the reflection to be calculated before a ray is abandoned.

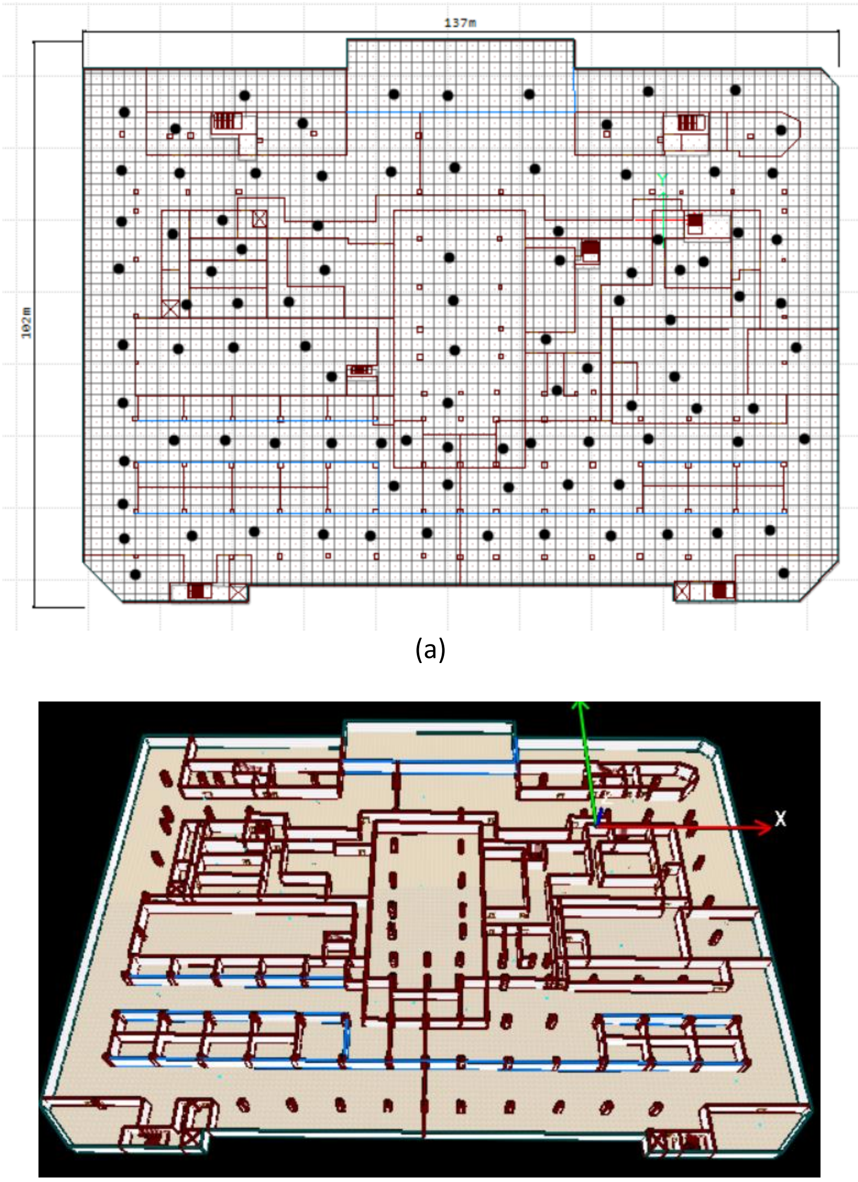
Using the output of the ray tracing propagation engine, the Ranplan Professional tool is capable of simulating a whole network. Hence, 5G KPIs including the SS RSRP, SS SINR, and the PDSCH throughput (among many other) can be readily computed.

Considering the massive MIMO antenna and beamforming, Ranplan Professional support to modelling the massive MIMO antenna based on the radiation pattern of each beam.

Ranplan Professional also integrated an Automatic Cell Optimizer (ACO) module which can automatically tune the transmitter location, transmitter number, transmit power, and antenna configuration within a cellular network (GSM, WCDMA, LTE, 5G and Wi-Fi) to achieve the user defined multiple Key Performance Indicators (KPIs) such as signal strength, SINR, throughput. This is applicable to both in the design phase and retrospectively to optimize existing networks.

4. Indoor Simulation Scenario

The selected indoor scenario is a one floor of an office building as shown in Fig. 2. As can be seen from Fig. 2 there are columns, concrete heavy walls, glass walls, doors and windows modelled in the scenario. The parameters of the simulation and network design requirement are listed in Table 2.



(a)

(b)

Fig.2 Indoor simulation scenario. (a) 2D view and (b) 3D view

Table 2. Indoor scenario parameters and network requirement

Size of scenarios (m^3)	137 × 102 ×4
Height of Tx antennas (m)	3.4
Tx Antenna deployment method	Ceiling Mounted
Height of users (m)	1.0
System Type	5G NR
System Frequency (GHz)	26
Bandwidth (MHz)	100
Sub Carrier Spacing (KHz)	60
Candidate Site Location	96
SS RSRP Compliance	-95 @95%
SS SINR Compliance	3dB @95%

Before the network optimization, we define the candidate location that can deploy antennas in the scenario, define the variable range and the adjustable step, define the target compliance of each KPI we want to achieve. This is based on the 5G NR network planning and optimization guideline from Ranplan [8]. The detailed optimization parameters are listed in Table 3.

Table 3. Indoor Scenario Optimization Parameters

Simulator tool	Ranplan Professional
Propagation model	3D ray tracing
Optimization engine	MIDACO
Array antenna topologies	Co-located
Candidate site	65
Tx power range (dBm)	15-25
Tx power step (dB)	2
Azimuth range (deg)	0-359
Azimuth step (deg)	45
Down tilt range (deg)	0-10
Down tilt step (deg)	2
SS RSRP Compliance	-95 @95%
SS SINR Compliance	3dB@95%

Firstly, we use the benchmark antenna to provide the service, after running ACO, we can see that, we need 45 antennas to get the optimization results.

Then we use the new designed antenna to provide the service, after running ACO, we can see that, we need only need 40 antennas to get the optimization results.

The we run the simulation of the following 3 KPIs and compare the results of the benchmark antenna and new designed antenna.

Fig. 3 shows the spatial distribution of the SS RSRP in the indoor scenario with (a) the benchmark antenna and (b) the designed antenna. As can be seen by comparing Fig. 3 (a) and Fig. 3 (b), the designed antenna show larger area with higher signal strength.

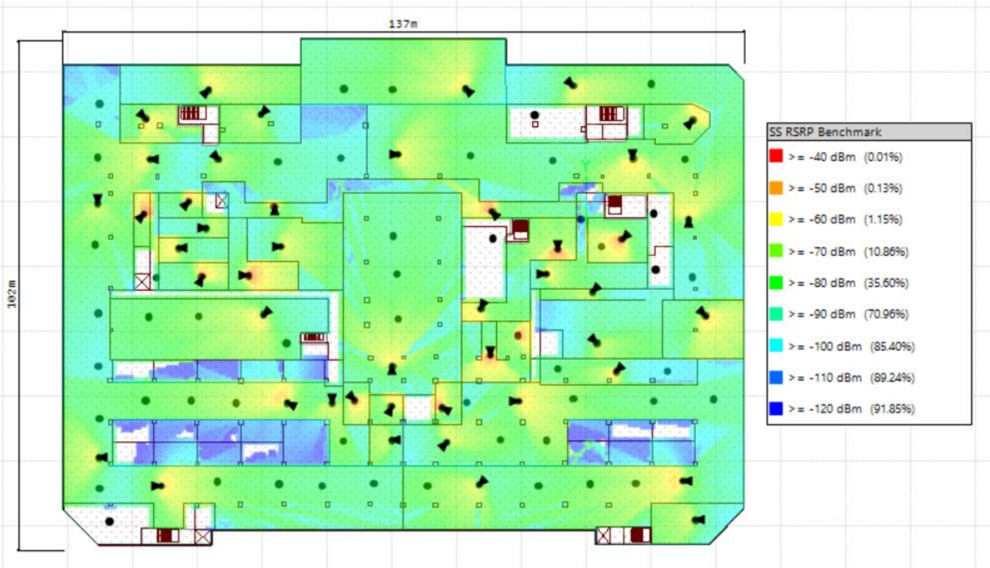
Fig. 4 shows the CDFs of the predicted SS RSRP (Fig. 3) in the indoor scenario with the new antenna and the benchmark antenna. The SS RSRP gain obtained by using the designed antenna is about 10 dB at the 50% CDF level. This is expected since it is about the difference in antenna gain between the designed and the benchmark antennas.

Fig. 5 shows the spatial distribution of the SS SINR in the indoor scenario with (a) the benchmark antenna and (b) the designed antenna. Also here an improvement of signal quality is observed when using the designed antenna as compared to the benchmark antenna.

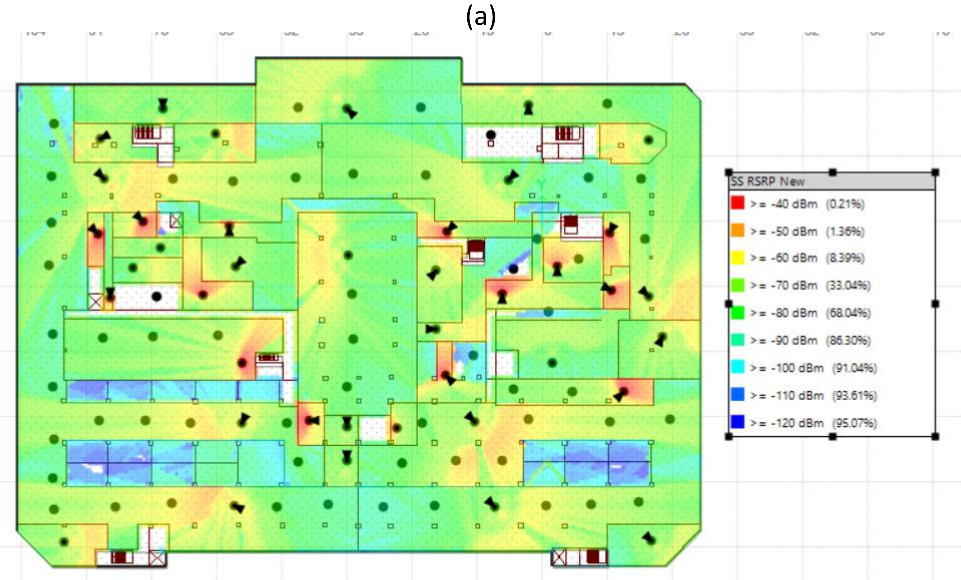
Fig. 6 shows the CDFs of the predicted SS SINR (Fig. 5) in the indoor scenario with the new antenna and the benchmark antenna. As can be seen by comparing the curves in Fig. 6, the SNIR gain computed at the 80 % CDF level is about 10 dB.

Fig. 7 shows the spatial distribution of the PDSCH throughput in the indoor scenario with (a) the benchmark antenna and (b) the designed antenna.

Fig. 8 shows the CDFs of the predicted PDSCH throughput in the indoor scenario with the new antenna and the benchmark antenna. As can be seen from Fig. 8, the PDSCH throughput increases from 50 Mbps to 200 Mbps at the 80 % CDF level, i.e., the use of the designed antenna increases this throughput by a factor 4.



(a)



(b)

Fig.3 Spatial distribution of the SS RSRP in the indoor scenario with (a) the benchmark antenna and (b) the designed antenna

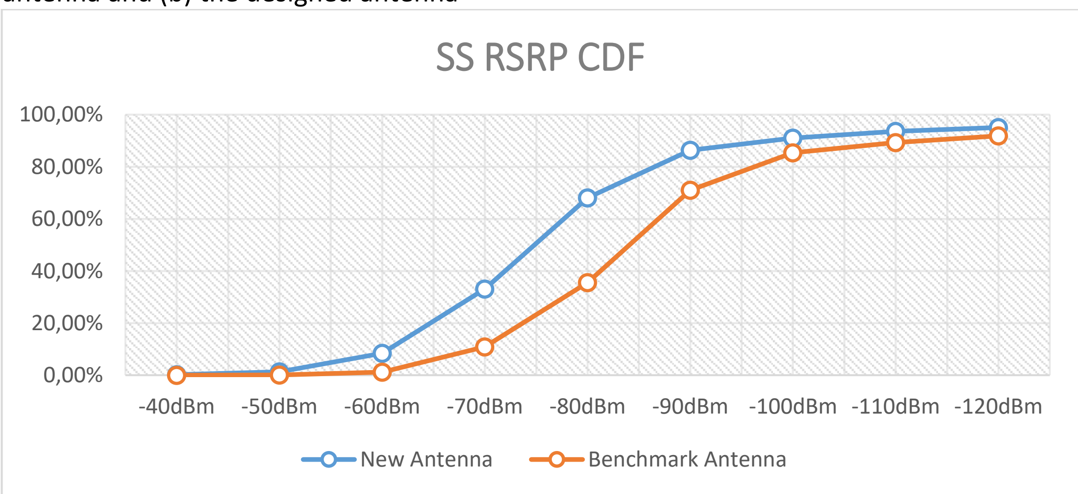
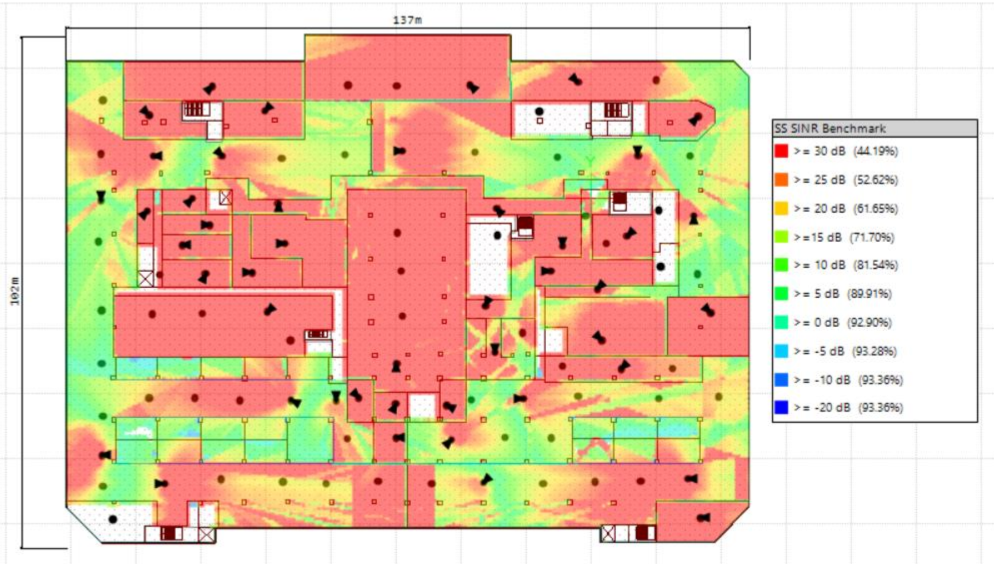
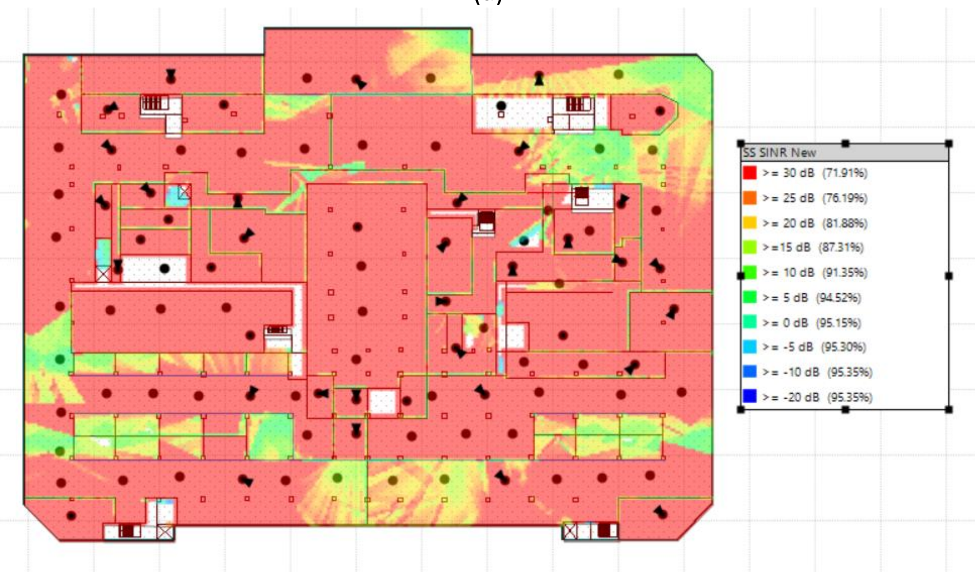


Fig. 4 CDFs of the predicted SS RSRP in the indoor scenario with the new antenna and the benchmark antenna



(a)



(b)

Fig.5 Spatial distribution of the SS SINR in the indoor scenario with (a) the benchmark antenna and (b) the designed antenna

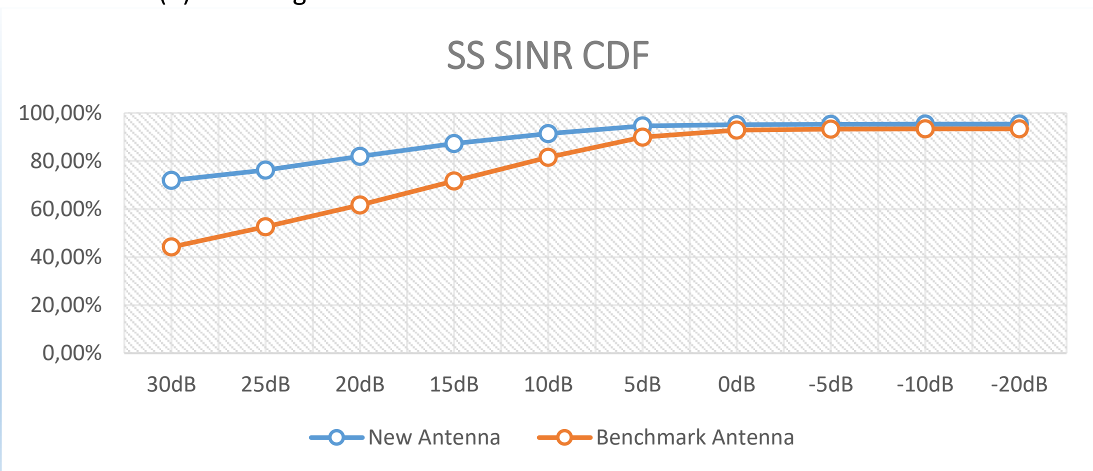
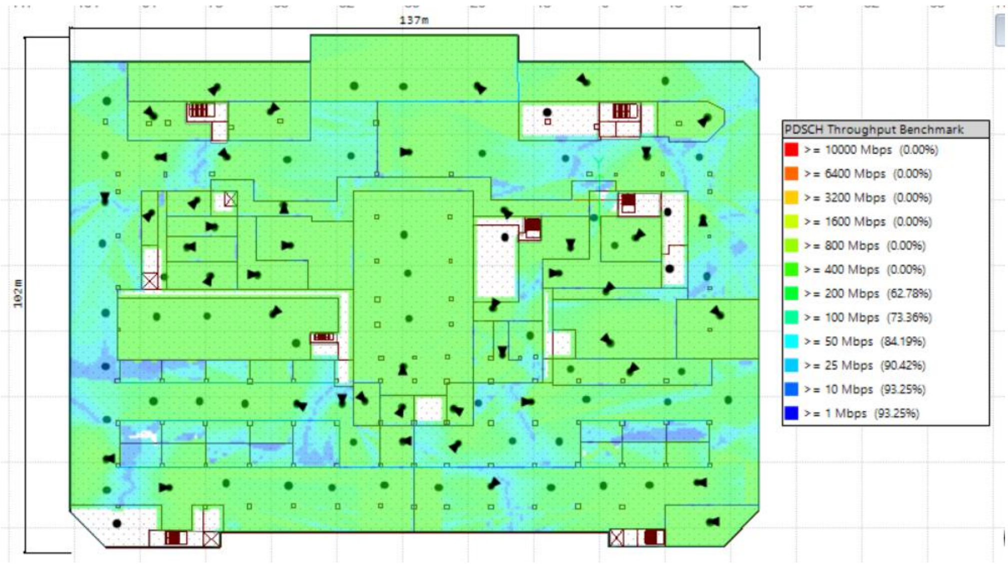
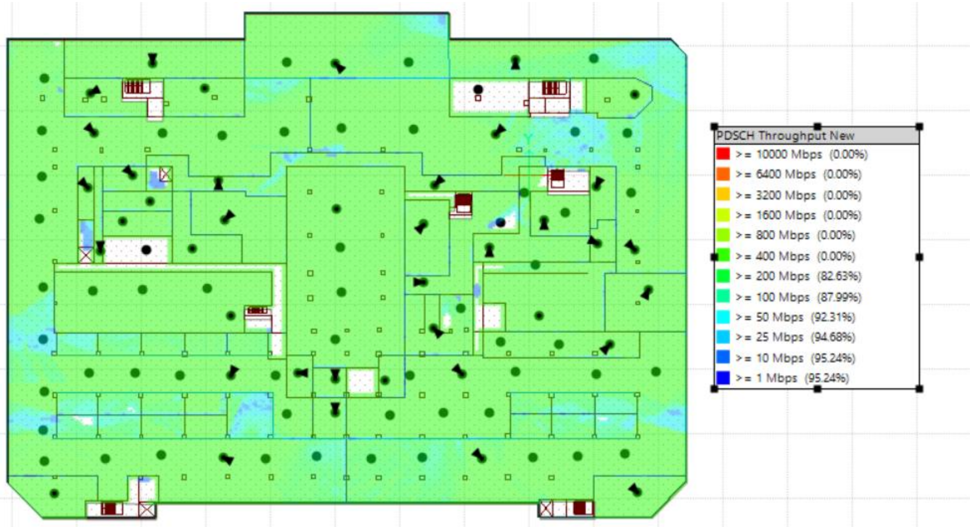


Fig. 6 CDFs of the predicted SS SINR in the indoor scenario with the new antenna and the benchmark antenna



(a)



(b)

Fig.7 Spatial distribution of the PDSCH throughput in the indoor scenario with (a) the benchmark antenna and (b) the designed antenna

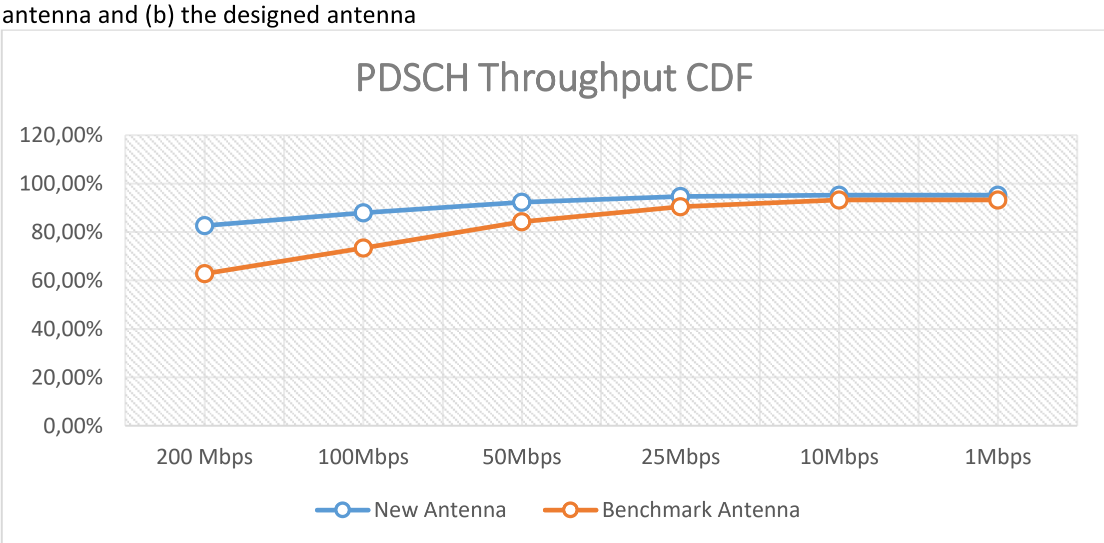
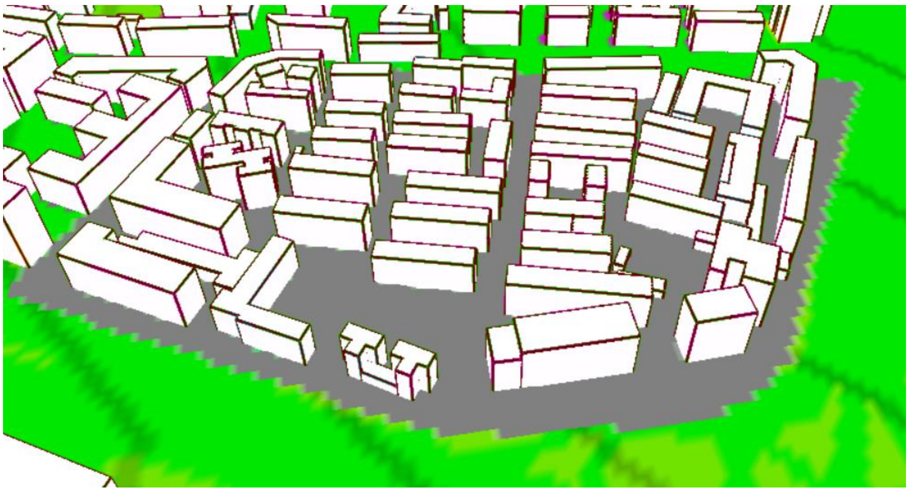


Fig. 8 CDFs of the predicted PDSCH Throughput in the indoor scenario with the new antenna and the benchmark antenna

5. Outdoor Simulation Scenario

The selected outdoor scenario is a campus area, which have an area of about 500 × 300 m^2, which include 55 Buildings, as shown in Fig. 9. The parameters of the simulation and network design requirement are listed in Table 4.

(a)



(b)

Fig.9 Outdoor simulation scenario. (a) 2D view and (b) 3D view

Before the network optimization, we define the candidate location that can deploy antennas in the scenario, for the mmWave frequency band antenna, as the pathloss is very high, the antenna is mounted at the top of the lamp (6m) to provide service for the ground area at 1 m height. We define the variable range and the adjustable step, define the target compliance of each KPI we want to achieve. This is based on the 5G NR network planning and optimization guideline from Ranplan [8]. The detailed optimization parameters are listed in Table 4.

Table 4: Outdoor scenario parameters and network parameters

Size of scenarios (m^3)	504×301×105
Number of Building	55
Height of Tx antenna (m)	6.0
Tx Antenna deployment method	Lamp Mounted
Height of users (m)	1.0
System Type	5G NR
System Frequency (GHz)	26
Band width (MHz)	100
Sub Carrier Spacing (KHz)	60
Candidate Site Location	60
SS RSRP Compliance	-95 @95%
SS SINR Compliance	3dB@95%

Table 5. Outdoor Scenario Optimization Parameters

Simulator tool	Ranplan Professional
Propagation model	3D ray tracing
Optimization engine	MIDACO
Array antenna topologies	Co-located
Candidate site	60
Tx power range (dBm)	35-43
Tx power step (dB)	2
Azimuth range (deg)	0-359
Azimuth step (deg)	45
Down tilt range (deg)	0-10
Down tilt step (deg)	2
SS RSRP Compliance	-95 @95%
SS SINR Compliance	3dB@95%

Firstly, we use the benchmark antenna to provide the service, after running ACO, we need 17 antennas to get the optimization results.

Then we use the new designed antenna to provide the service, after running ACO, we need only need 10 antennas to get the optimization results.

The we run the simulation of the following 3 KPIs and compare the results of the benchmark antenna and new designed antenna.

Fig. 10 shows the spatial distribution of the SS RSRP in the indoor scenario with (a) the benchmark antenna and (b) the designed antenna. As can be seen by comparing Fig. 10 (a) and Fig. 10 (b), the designed antenna show larger area with higher signal strength.

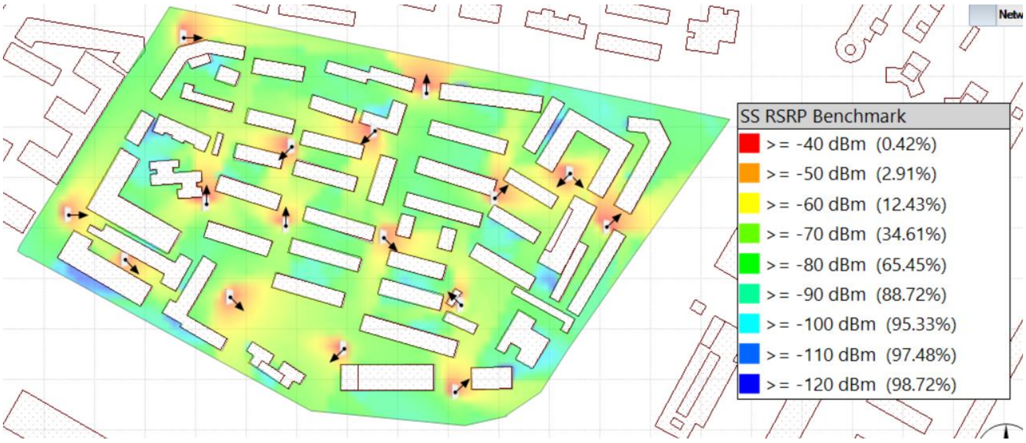
Fig. 11 shows the CDFs of the predicted SS RSRP (Fig. 10) in the indoor scenario with the new antenna and the benchmark antenna. The SS RSRP gain obtained by using the designed antenna is about 5 dB at the 50% CDF level. This is lower than in the indoor environment since in the outdoor environment the waves are scattered more than in the indoor environment where the line-of-sight are most likely to happen and less power is captured by the narrower beam.

Fig. 12 shows the spatial distribution of the SS SINR in the indoor scenario with (a) the benchmark antenna and (b) the designed antenna. Also here an improvement of signal quality is observed when using the designed antenna as compared to the benchmark antenna.

Fig. 13 shows the CDFs of the predicted SS SINR (Fig. 12) in the indoor scenario with the new antenna and the benchmark antenna. As can be seen by comparing the curves in Fig. 13, the SNIR gain computed at the 80 % CDF level is less than 5 dB.

Fig. 14 shows the spatial distribution of the PDSCH throughput in the indoor scenario with (a) the benchmark antenna and (b) the designed antenna.

Fig. 15 shows the CDFs of the predicted PDSCH throughput in the indoor scenario with the new antenna and the benchmark antenna. As can be seen from Fig. 15, the PDSCH throughput increases from 25 Mbps to 50 Mbps at the 80 % CDF level, i.e., the use of the designed antenna increases this throughput by a factor 2.



(a)

(b)

Fig.10 Spatial distribution of the SS RSRP in the outdoor scenario with (a) the benchmark antenna and (b) the designed antenna

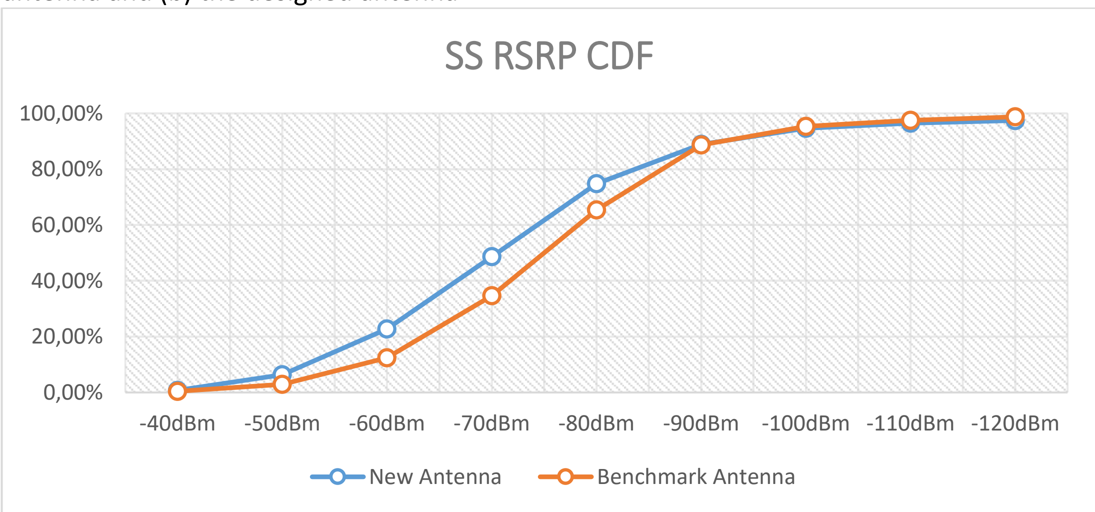
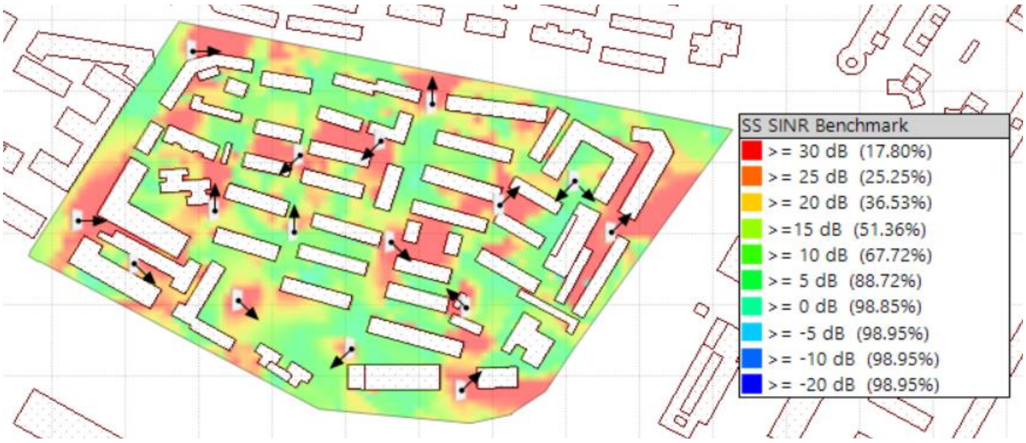


Fig. 11 CDFs of the predicted SS RSRP in the outdoor scenario with the new antenna and the benchmark antenna



(a)

(b)

Fig.12 Spatial distribution of the SS SNIR in the outdoor scenario with (a) the benchmark antenna and (b) the designed antenna

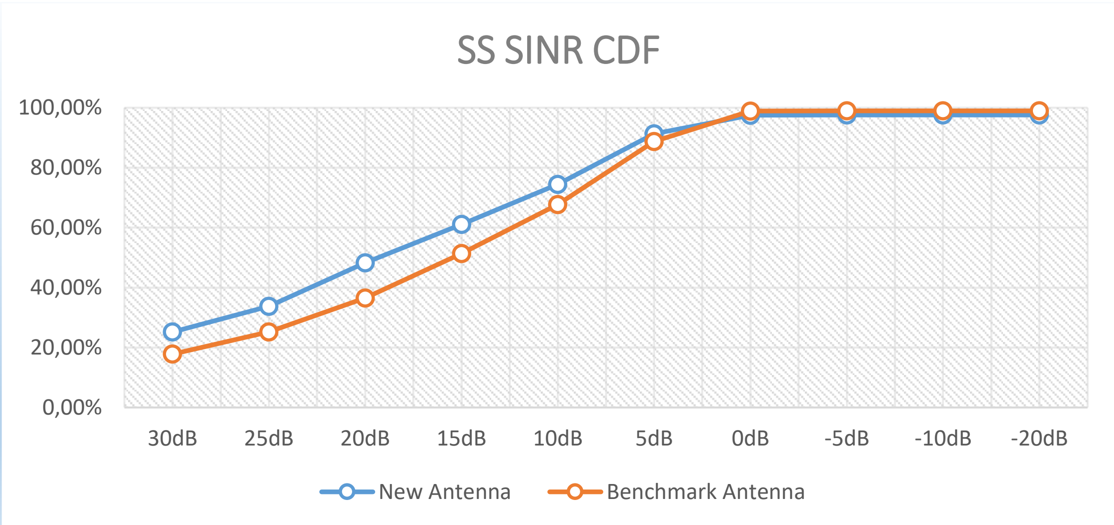
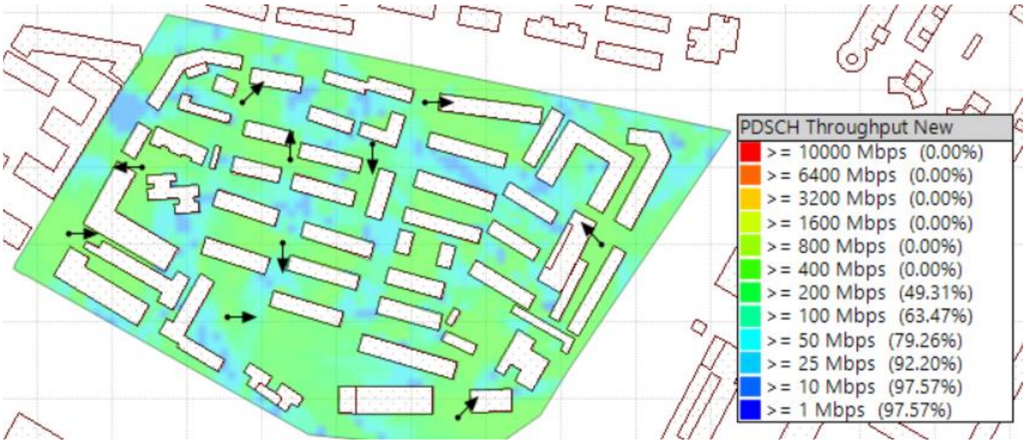


Fig. 13 CDFs of the predicted SS SNIR in the outdoor scenario with the new antenna and the benchmark antenna

(a)



(b)

Fig.14 Spatial distribution of the of PDSCH throughput in the outdoor scenario with (a) the benchmark antenna and (b) the designed antenna

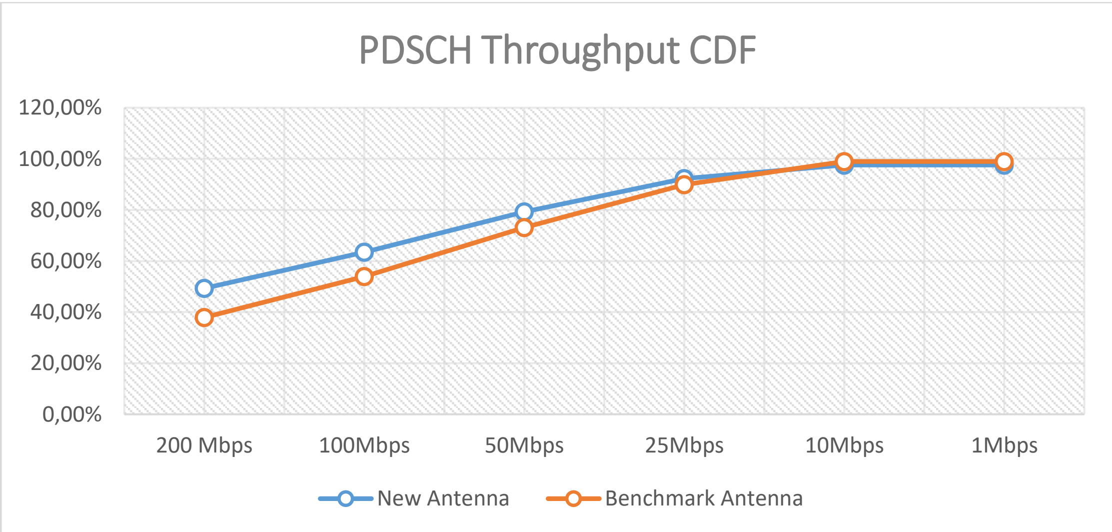


Fig. 15 CDFs of the predicted PDSCH Throughput in the outdoor scenario with the new antenna and the benchmark antenna

4. Conclusions

In the study presented above we have shown that using the same initial network configuration both antennas meet the network performance compliance criteria. However, the new designed antenna needs a smaller number of antennas. Moreover, the network performance with the new designed antenna is much better even with a smaller number of antenna sites. This is because, the new designed antenna has a narrower main beam with a higher beam gain and lower side lobe levels. The KPI improvement is larger for the indoor network than for the outdoor network, i.e., while for the outdoor network the PDSCH throughput was doubled at the 80 % CDF level, it was quadrupled for the indoor environment.

A. List of Publications (published and in preparation)

1. C. Qin, Y. Miao, Y. Gao, J. Chen, J. Zhang and A. A. Glazunov, "Simulation-based Investigation on Spatial Channel Hardening of Massive MIMO in Different Indoor Scenarios and with Different Array Topologies," 2020 XXXIIIrd General Assembly and Scientific Symposium of the International Union of Radio Science, Rome, Italy, 2020, pp. 1-4, doi: 10.23919/URSIGASS49373.2020.9232421.
2. A. A. Glazunov, C. Qin, Y. Gao, J. Chen, J. Zhang and J. Zhang, "Effective Channel Hardening and Effective Channel Orthogonality", Frontiers in Communications and Networks (to be submitted)

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[6] C. Qin, Y. Miao, Y. Gao, J. Chen, J. Zhang and A. A. Glazunov, "Simulation-based Investigation on Spatial Channel Hardening of Massive MIMO in Different Indoor Scenarios and with Different Array Topologies," 2020 XXXIIIrd General Assembly and Scientific Symposium of the International Union of Radio Science, Rome, Italy, 2020, pp. 1-4, doi: 10.23919/URSIGASS49373.2020.9232421.

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[8] Ranplan Wireless Network Design Ltd., "5G NR Network Planning Guideline."