Multi-Environment Characterization of 28GHz Millimeter Wave Channels Using Wireless InSite

A Major Project Mid Report Submitted to the National Institute of Technology Karnataka-Surathkal in partial fulfillment of requirements for the awarde of Semester-IV

Master of Technology

in

Communication Engineering And Network

by

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Submitted to

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NITK Surathkal

Mangalore

MAR 2024

CERTIFICATE

This is to certify that the Project report entitled **Multi-Environment Characterization of 28GHz Millimeter Wave Channels Using Wireless InSite** submitted by **G**.Abhiram Chowdary (222CN011) to the NITK Surathkal in partial fulfillment of the M.Tech. degree in Communication Engineering And Network is a bonafide record of the project work carried out by them under our guidance and supervision. This report in any form has not been submitted to any other University or Institute for any purpose.

Dr. Ashvini Chaturvedi
Professor(Guide)
Dept.of ECE
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DECLARATION

I G.Abhiram Chowdary , hereby declare that the major project (end sem evaluation) report **Multi-Environment Characterization of 28GHz Millimeter Wave Channels Using Wireless InSite** submitted for partial fulfillment of the requirements for the evaluation of Master of Technology to the National institute of technology Surathkal, Mangalore is a bonafide work done by me undersupervision of Prof. Ashvini Chaturvedi

This submission represents my ideas in my own words and where ideas or words of others have been included, I have adequately and accurately cited and referenced the original sources.

I also declare that I have adhered to ethics of academic honesty and integrity and have not misrepresented or fabricated any data or idea or fact or source in my submission.

G.Abhiram Chowdary

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04- 03-2024

Contents

1 Abstract

This study employs Wireless InSite, a cutting-edge radio frequency propagation simulation tool, to conduct a comprehensive analysis of 28GHz millimeter-wave channels across diverse environments. The research explores urban, suburban, and indoor scenarios, unraveling the intricacies of signal propagation in each setting. Simulations incorporate factors such as building structures, foliage, and atmospheric conditions to simulate real-world challenges.

In urban environments, the study identifies significant challenges including blockage and reflection from buildings, alongside multipath effects impacting signal reliability. Transitioning to suburban settings, improved line-of-sight conditions are observed, yet challenges persist with foliage and scattered obstacles affecting signal strength. Indoor scenarios are investigated, revealing insights into signal penetration, coverage, and the complexities of reflection and diffraction within enclosed spaces.

The abstract concludes with a call for continued research efforts, emphasizing the need to address challenges in urban environments, optimize communication strategies in suburban and indoor settings, and validate simulation results through real-world measurements. This research contributes valuable insights for the advancement of 5G and future wireless communication systems, providing a roadmap for engineers, researchers, and policymakers navigating the evolving landscape of high-frequency communication.

2 Introduction

The proliferation of wireless communication technologies has reached an inflection point with the exploration of millimeter-wave frequencies, particularly the promising 28GHz spectrum, for applications in 5G and beyond. As the demand for higher data rates and reduced latency intensifies, understanding the propagation characteristics of these frequencies in varied environments becomes paramount. This report delves into the multi-environmental characterization of 28GHz millimeter-wave channels using Wireless InSite, a sophisticated radio frequency simulation tool.

The deployment of millimeter-wave communication systems poses unique challenges and opportunities, and this study seeks to unravel the intricacies associated with diverse deployment scenarios. The 28GHz band offers significant bandwidth for data transmission, but its propagation characteristics are heavily influenced by environmental factors such as building structures, foliage, and atmospheric conditions. By employing Wireless InSite, a tool renowned for its accuracy in simulating real-world RF propagation, this research aims to provide a comprehensive understanding of how millimeter-wave signals interact with their surroundings.

In the following sections, we will explore the propagation characteristics in three distinct environments: urban, suburban, and indoor. Each environment introduces a myriad of challenges, from the dense and complex urban landscape with its potential for signal blockage and multipath effects, to the more open suburban setting where foliage and scattered obstacles may influence signal strength. Indoor scenarios, critical for applications like smart buildings and industrial IoT, present unique challenges related to signal penetration and coverage within enclosed spaces.

As the telecommunications landscape evolves towards the integration of millimeter-wave frequencies, the insights gained from this study are poised to guide the development of robust communication strategies and optimize the deployment of 28GHz systems. This research contributes not only to the advancement of high-frequency communication but also serves as a foundation for addressing the challenges and capitalizing on the opportunities that lie ahead in the dynamic landscape of wireless technology.

3 mmWave Communication Technology and Standards:

The ever-growing demand for faster data rates, low latency, and increased connectivity has propelled the evolution of wireless communication technologies. Among the transformative advancements, millimeter-wave (mmWave) communication has emerged as a key player, ushering in a new era of high-frequency wireless transmission. This section provides an overview of mmWave communication technology and highlights some of the pertinent standards shaping its deployment.

3.1 Millimeter-Wave Communication Technology:

3.1.1 Definition and Frequency Range:

Millimeter-wave communication refers to the use of frequencies within the millimeter-wave band, typically spanning from 30 GHz to 300 GHz. This spectrum offers a significant increase in available bandwidth, unlocking the potential for unprecedented data rates and supporting the demands of emerging applications such as 5G, wireless backhaul, and high-speed wireless connectivity.

3.1.2 Characteristics and Advantages:

MmWave communication exhibits unique characteristics, including short wavelength and high directionality. These traits enable the implementation of highly focused beams, allowing for spatial reuse and increased network capacity. Moreover, the large available bandwidth in the mmWave spectrum facilitates the delivery of multi-gigabit-per-second data rates, addressing the escalating requirements of modern communication systems.

3.1.3 Key Characteristics of Millimeter-Wave Communication

1. **High Data Rates:** The fundamental allure of mmWave communication lies in its ability to support exceptionally high data rates. By harnessing wider bandwidths available at these frequencies, data transmission can occur at speeds previously deemed unattainable.

2. **Short Wavelengths:** MmWave signals are characterized by short wavelengths, enabling the design of compact antennas. This characteristic is particularly advantageous in applications where space is a premium, such as in small cell deployments and portable devices.

3. **Narrow Beams and Directionality:** The shorter wavelengths also facilitate the creation of narrow, highly directional beams. This directional focus not only enables efficient use of available spectrum but also contributes to enhanced security and reduced interference.

4. **Propagation Challenges:** Despite its many advantages, mmWave communication poses unique propagation challenges. Signals at these frequencies are susceptible to higher free-space path loss and are more prone to absorption by atmospheric gases and precipitation.

5. **Applications Across Industries:** The potential applications of mmWave communication span diverse industries, including telecommunications, healthcare, automotive, and beyond. From enabling high-speed wireless broadband to supporting ultra-reliable low-latency communications (URLLC) for critical applications, the impact of mmWave is far-reaching.

3.1.4 Applications:

MmWave technology finds application in various domains, including but not limited to:

1. **5G Networks:** MmWave frequencies play a crucial role in the deployment of 5G, delivering enhanced data rates and enabling ultra-reliable, low-latency communication.

2. **Wireless Backhaul:** MmWave links are instrumental in providing high-capacity backhaul connections, supporting the infrastructure demands of advanced networks.

3. **Point-to-Point Communication:** MmWave technology is employed in point-to-point communication links, enabling high-speed connectivity between locations.

3.2 Standards Shaping mmWave Communication:

3.2.1 5G NR (New Radio):

The 5th Generation New Radio (5G NR) standard, developed by the 3rd Generation Partnership Project (3GPP), is a cornerstone in the deployment of mmWave communication for 5G networks. The 5G NR standard defines the air interface, modulation schemes, and protocols necessary for efficient and interoperable communication in mmWave frequency bands, including those around 28 GHz and 39 GHz.

3.2.2 IEEE 802.11ad/ay (WiGig):

The Institute of Electrical and Electronics Engineers (IEEE) has developed the 802.11ad and 802.11ay standards, collectively known as WiGig. These standards focus on utilizing the 60 GHz band for high-speed, short-range communication. WiGig is employed in applications such as high-performance wireless networking, virtual reality, and augmented reality.

3.2.3 E-band and V-band Standards:

In addition to the aforementioned standards, regulatory bodies and industry alliances have specified standards for specific mmWave frequency bands. For instance, the E-band (71–76 GHz and 81–86 GHz) and V-band (57–64 GHz) are utilized for various communication applications, and standards have been established to ensure compatibility and interoperability.

As mmWave communication technology continues to mature, standards development remains pivotal to fostering a cohesive and interoperable ecosystem. The collaborative efforts of standardization organizations and industry stakeholders are instrumental in shaping the future of mmWave communication, unlocking its full potential across diverse applications and use cases.

4 Wireless InSite

The described tool, Wireless InSite, serves as an electromagnetic simulation platform designed to forecast the impact of buildings and terrain on the propagation of electromagnetic waves. Its primary objective is to anticipate how the arrangement of transmitters and receivers within urban landscapes influences signal strength. This comprehensive simulation tool captures the physical characteristics of irregular terrain and urban structures, executes electromagnetic calculations, and assesses signal propagation characteristics.

4.1 Key Features of Wireless InSite:

1. **Virtual Environment Construction:** The tool allows users to construct a virtual environment using Wireless InSite's editing tools.Alternatively, existing environments can be imported from various popular file formats such as DXF, shapefile, DTED, and USGS.

2. **Site-Defining Tools:** Transmitter and receiver locations can be precisely specified using Wireless InSite's robust site-defining tools. Alternatively, locations can be imported from external data files.

3. **Study Area Definition:** Separate calculations for specific portions of the overall area can be specified by defining study areas.

4. **Ray Tracing Calculations:**Calculations are performed by emitting rays from transmitters and tracing their propagation through the defined geometry. Ray interactions include reflections from feature faces, diffractions around feature edges, and transmissions through feature faces.

5. **Uniform Theory of Diffraction (UTD):** The ray-based solvers of Wireless InSite utilize the Uniform Theory of Diffraction (UTD) to assess the electric field along a ray path. UTD is particularly effective when the scenario geometry is large compared to the wavelength of the propagating wave.

6. **Frequency Range:** The UTD-based models of Wireless InSite provide accurate predictions across a broad frequency range, typically from around 100 MHz to approximately 100 GHz.

7. **X3D Propagation Model:** The X3D propagation model integrates atmospheric absorption, enhancing the tool's capability to perform wave propagation calculations even at millimeter-wave frequencies.

In essence, Wireless InSite facilitates a detailed and accurate assessment of electromagnetic wave propagation in complex urban environments. By combining powerful simulation capabilities, precise location definition, and advanced propagation models, the tool is well-suited for applications spanning a wide frequency spectrum, making it an invaluable resource for engineers and researchers in the field of wireless communication.

5 Implementation in Wireless insite

Deploying simulations for diverse scenarios such as indoor, dense urban, and outdoor complex terrain within the Wireless InSite framework necessitates a methodical approach. This involves delineating the environment, fine-tuning transmitter and receiver configurations, and stipulating simulation parameters. Though the precise procedures may fluctuate based on individual scenario intricacies, the ensuing step-by-step guide offers a universal framework to establish simulations aimed at extracting crucial metrics, including received power, channel impulse response (CIR), electromagnetic (EM) field characteristics, path propagation details, and path loss considerations.

below we are going to do step-by-step simulation in wireless insite for different scenario like :

5.1 Environment Definition:

The initial phase involves capturing the essence of the environment through visual aids such as images, blueprints, or CAD models. This not only establishes the structural foundation but also encapsulates vital details like the materials employed in construction, the overall shape of the environment, and the nature of the terrain. The ensuing sections will delve into the specific parameters essential for crafting simulations tailored to distinct scenarios within the realm of mmWave channels

5.1.1 indoor scenario:

n the context of indoor scenarios, our focus has been on modeling and simulating the NITK Elibrary building.

1. **image:** An image primarily serves as a representation of the blueprint or floor plan necessary for modeling your scenario.below are the floor plan of NITK Elibrary:

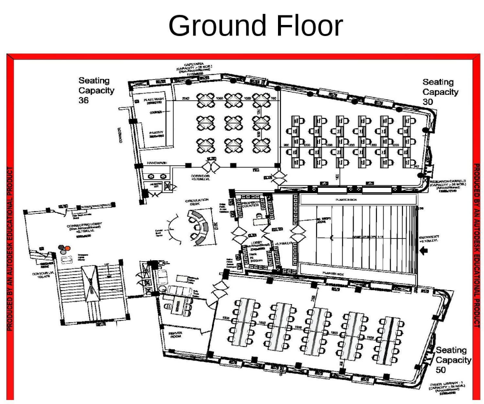


Figure 1: Ground Floor

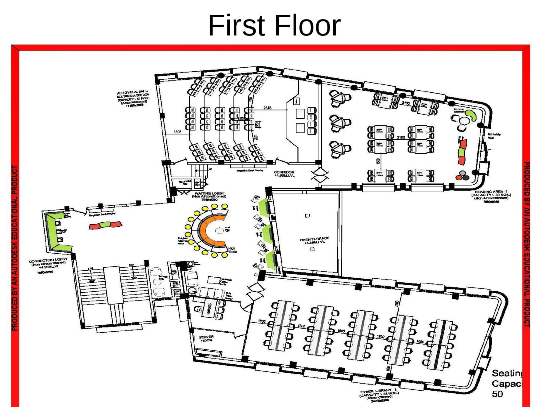


Figure 2: First Floor

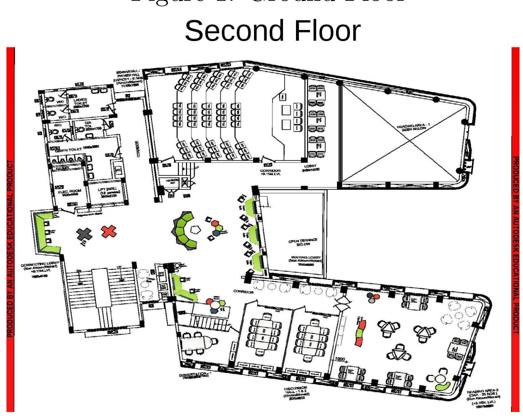


Figure 3: Second Floor

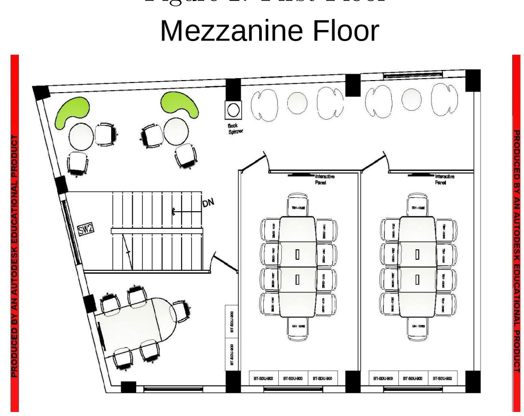


Figure 4: Mezannine Floor

Figure 5: Floor Plans Side by Side

2. **Features:** The ”Feature” option in Wireless InSite serves as a powerful tool for constructing various architectural elements such as walls, doorways, windows, floors, and ceilings. This feature empowers users to model complex structures with a diverse range of materials, allowing for a detailed representation of the environment within the simulation.

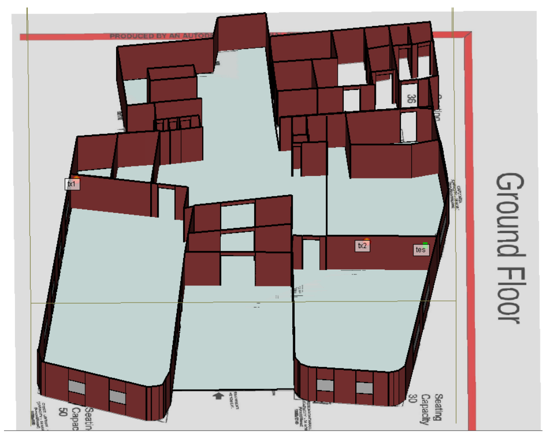


Figure 6: Ground Floor

Figure 7: First Floor

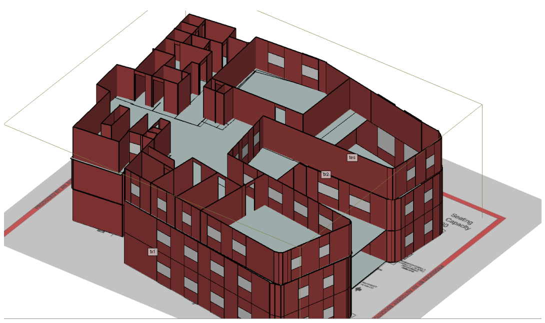


Figure 8: Second Floor

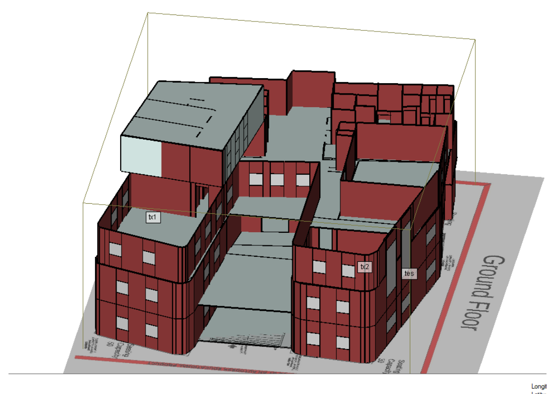
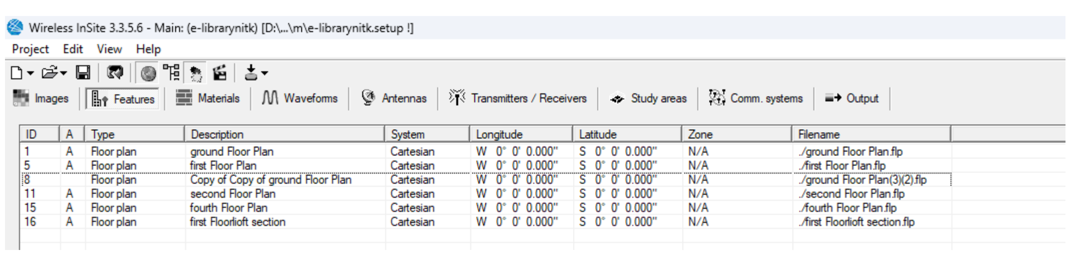


Figure 9: Mezannine Floor

Figure 10: Features Side by Side



ID	A	Type	Description	System	Longitude	Latitude	Zone	Filename
1	A	Floor plan	ground Floor Plan	Cartesian	W 0° 0' 0.000"	S 0° 0' 0.000"	N/A	./ground Floor Plan.flp
5	A	Floor plan	first Floor Plan	Cartesian	W 0° 0' 0.000"	S 0° 0' 0.000"	N/A	./first Floor Plan.flp
8		Floor plan	Copy of Copy of ground Floor Plan	Cartesian	W 0° 0' 0.000"	S 0° 0' 0.000"	N/A	./ground Floor Plan(3)(2).flp
11	A	Floor plan	second Floor Plan	Cartesian	W 0° 0' 0.000"	S 0° 0' 0.000"	N/A	./second Floor Plan.flp
15	A	Floor plan	fourth Floor Plan	Cartesian	W 0° 0' 0.000"	S 0° 0' 0.000"	N/A	./fourth Floor Plan.flp
16	A	Floor plan	first Floorloft section	Cartesian	W 0° 0' 0.000"	S 0° 0' 0.000"	N/A	./first Floorloft section.flp

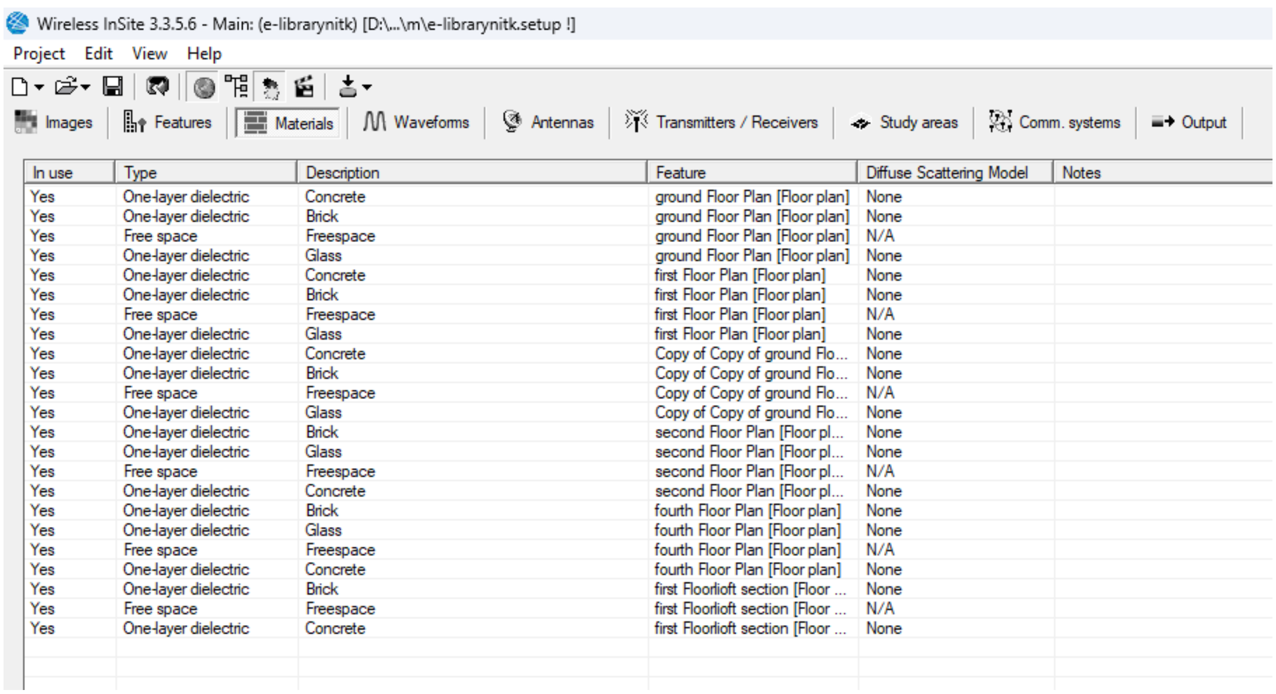
Figure 11: Features

3. **Materials:**

   Within the realm of Wireless InSite, all entities categorized as "FEATURES" fundamentally consist of distinct "MATERIALS." This manual collectively refers to the properties of a material as "material types." These properties encompass both the electromagnetic attributes of the surface and its display characteristics.

   The material properties directly influence reflection and transmission coefficients, while diffraction coefficients derive indirectly from their dependence on these reflection and transmission coefficients. In certain material types, the thickness plays a role in determining these coefficients, while for others, it solely impacts the visual representation of the facet. Color and shininess, however, exclusively affect how the facet appears across all material types.

   Wireless InSite offers user-friendly tools facilitating the assignment of a MATERIAL to individual faces or groups of faces. Additionally, materials can be saved to the material database, providing a convenient resource for application in other projects.



In use	Type	Description	Feature	Diffuse Scattering Model	Notes
Yes	One-layer dielectric	Concrete	ground Floor Plan [Floor plan]	None	
Yes	One-layer dielectric	Brick	ground Floor Plan [Floor plan]	None	
Yes	Free space	Freespace	ground Floor Plan [Floor plan]	N/A	
Yes	One-layer dielectric	Glass	ground Floor Plan [Floor plan]	None	
Yes	One-layer dielectric	Concrete	first Floor Plan [Floor plan]	None	
Yes	One-layer dielectric	Brick	first Floor Plan [Floor plan]	None	
Yes	Free space	Freespace	first Floor Plan [Floor plan]	N/A	
Yes	One-layer dielectric	Glass	first Floor Plan [Floor plan]	None	
Yes	One-layer dielectric	Concrete	Copy of Copy of ground Flo...	None	
Yes	One-layer dielectric	Brick	Copy of Copy of ground Flo...	None	
Yes	Free space	Freespace	Copy of Copy of ground Flo...	N/A	
Yes	One-layer dielectric	Glass	Copy of Copy of ground Flo...	None	
Yes	One-layer dielectric	Brick	second Floor Plan [Floor pl...	None	
Yes	One-layer dielectric	Glass	second Floor Plan [Floor pl...	None	
Yes	Free space	Freespace	second Floor Plan [Floor pl...	N/A	
Yes	One-layer dielectric	Concrete	second Floor Plan [Floor pl...	None	
Yes	One-layer dielectric	Brick	fourth Floor Plan [Floor plan]	None	
Yes	One-layer dielectric	Glass	fourth Floor Plan [Floor plan]	None	
Yes	Free space	Freespace	fourth Floor Plan [Floor plan]	N/A	
Yes	One-layer dielectric	Concrete	fourth Floor Plan [Floor plan]	None	
Yes	One-layer dielectric	Brick	first Floorloft section [Floor ...	None	
Yes	Free space	Freespace	first Floorloft section [Floor ...	N/A	
Yes	One-layer dielectric	Concrete	first Floorloft section [Floor ...	None	

Figure 12: material used in NITK e-Library

5.1.2 urban scenario:

for urban scenario we took model of Rosalyn Urban neighborhood in Arlington, Virginia,USA, from wireless insite.it has area of 500mX500m.

1. **Image and Features:**

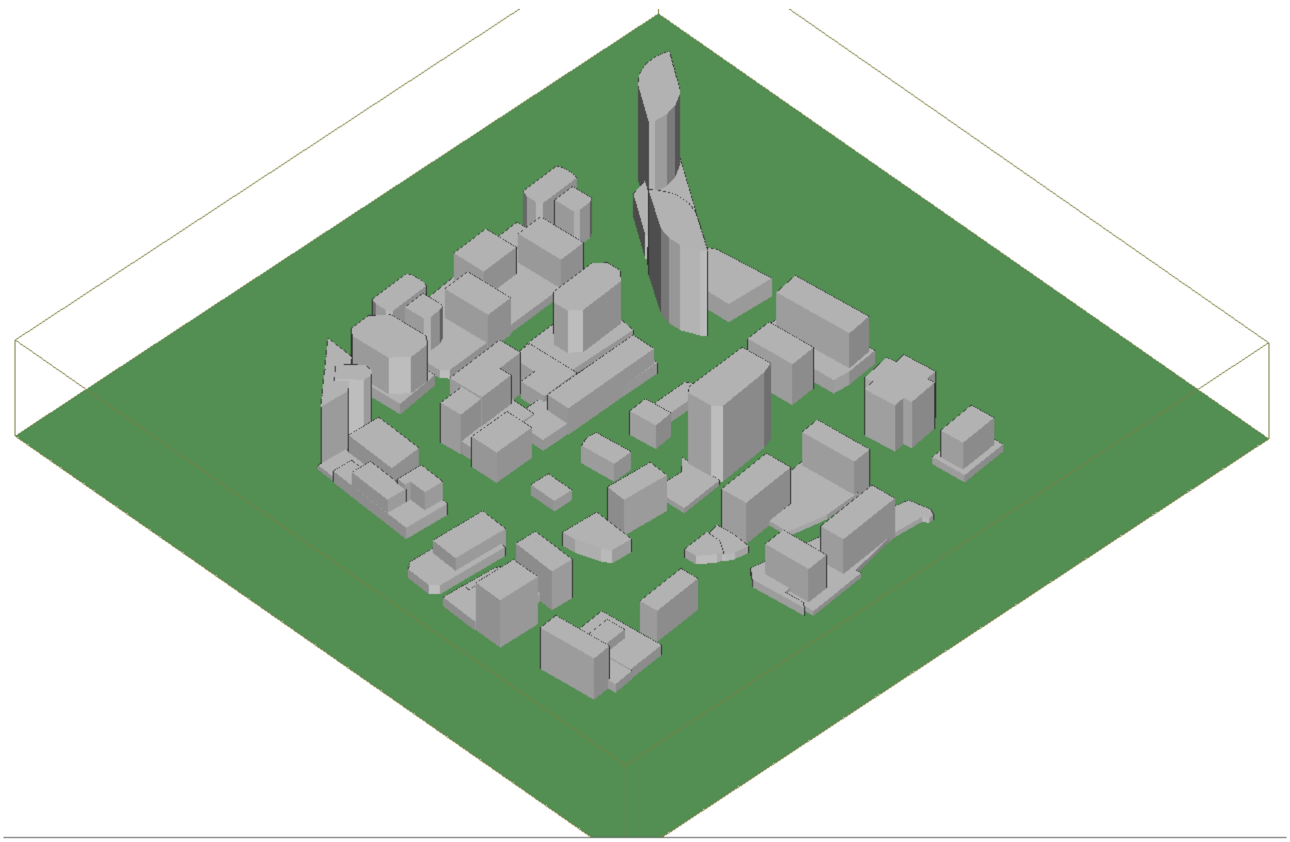
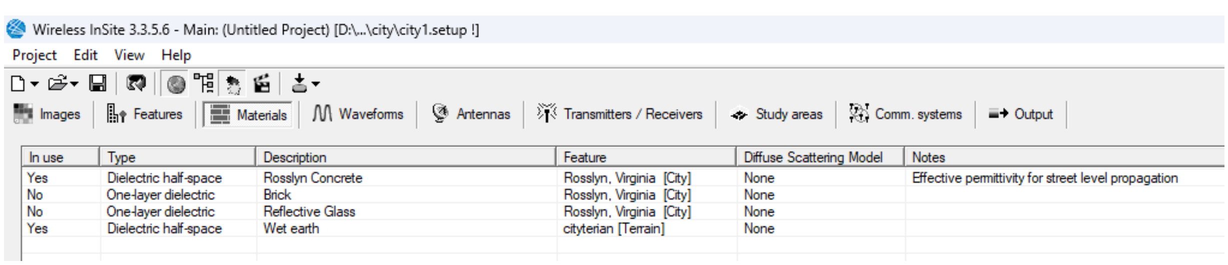


Figure 13: Rosslyn Urban neighborhood in Arlington, Virginia,USA

2. **material:**



In use	Type	Description	Feature	Diffuse Scattering Model	Notes
Yes	Dielectric half-space	Rosslyn Concrete	Rosslyn, Virginia [City]	None	Effective permittivity for street level propagation
No	One-layer dielectric	Brick	Rosslyn, Virginia [City]	None	
No	One-layer dielectric	Reflective Glass	Rosslyn, Virginia [City]	None	
Yes	Dielectric half-space	Wet earth	cityterian [Terrain]	None	

Figure 14: material used in Rosslyn Urban neighborhood in Arlington, Virginia,USA

5.1.3 outdoor scenario:

In the context of an outdoor scenario, we have meticulously designed a custom mountainous terrain to gain insights into remote and long-distance communication dynamics. Enhancing the simulation's complexity, we've incorporated three distinct cities, each spanning an area of 500m by 500m, and strategically positioned them at varying elevations. This deliberate setup allows for comparative analysis, offering a comprehensive understanding of the effects of topography on communication performance across extended distances.

1. **Image and Features:**

Figure 15: oudoor top remote terrian

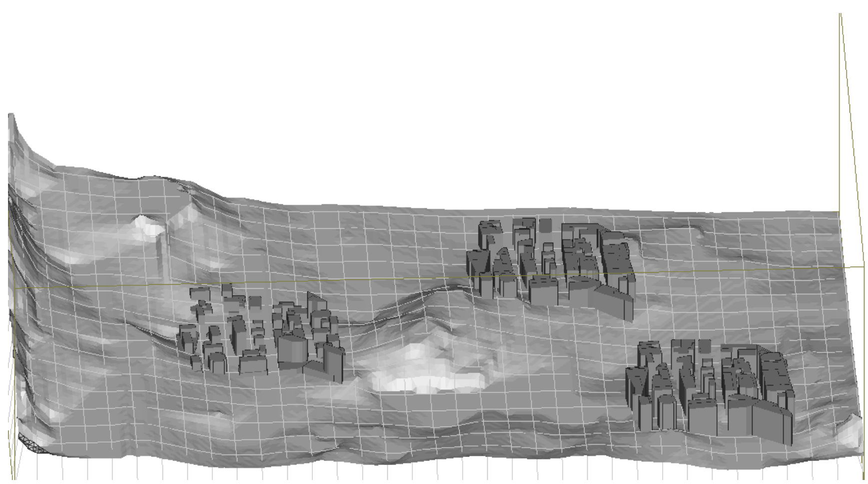
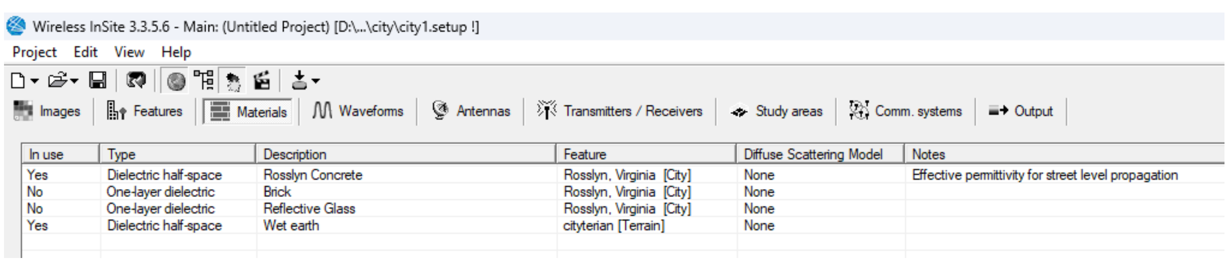


Figure 16: oudoor side remote terrian

Figure 17: oudoor front remote terrian

2. **material:**



In use	Type	Description	Feature	Diffuse Scattering Model	Notes
Yes	Dielectric half-space	Rosslyn Concrete	Rosslyn, Virginia [City]	None	Effective permittivity for street level propagation
No	One-layer dielectric	Brick	Rosslyn, Virginia [City]	None	
No	One-layer dielectric	Reflective Glass	Rosslyn, Virginia [City]	None	
Yes	Dielectric half-space	Wet earth	cityterian [Terrain]	None	

Figure 18: material used in cities

5.2 Waveform:

Wireless InSite provides a multitude of waveform options for simulating specific responses. Focusing on mmWave channels, we have opted for a 28 GHz frequency with a 100 MHz bandwidth, utilizing a sinusoidal waveform for our simulation.

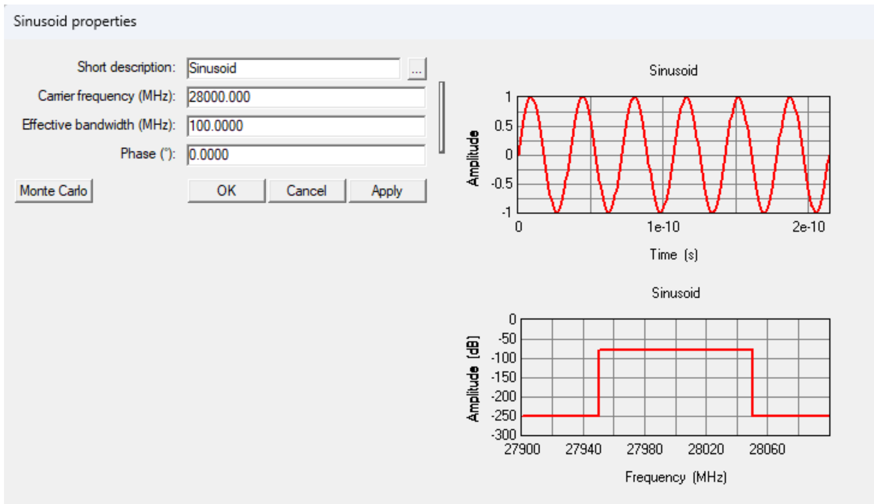


Figure 19: waveform

5.3 Atennas:

Utilizing omnidirectional antennas in wireless simulations proves advantageous for their ability to radiate signals uniformly in all directions. This simplicity and flexibility make them practical choices for scenarios requiring broad coverage, such as wireless networks or IoT applications. Omnidirectional antennas are particularly useful in environments with multipath propagation, offering consistent coverage even in the presence of obstacles or reflections. In simulation tools like Wireless InSite, configuring these antennas is straightforward, making them valuable for initial assessments and comparative studies before exploring more complex configurations. While omnidirectional antennas provide a realistic baseline, the choice of antenna type ultimately depends on the specific characteristics and requirements of the wireless communication scenario.

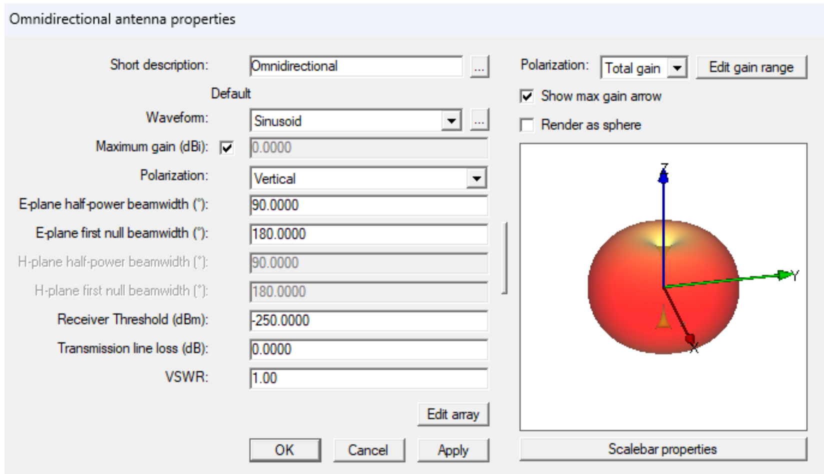


Figure 20: antenna pattern

5.4 transmitter and receiver:

5.4.1 outdoor scenario:

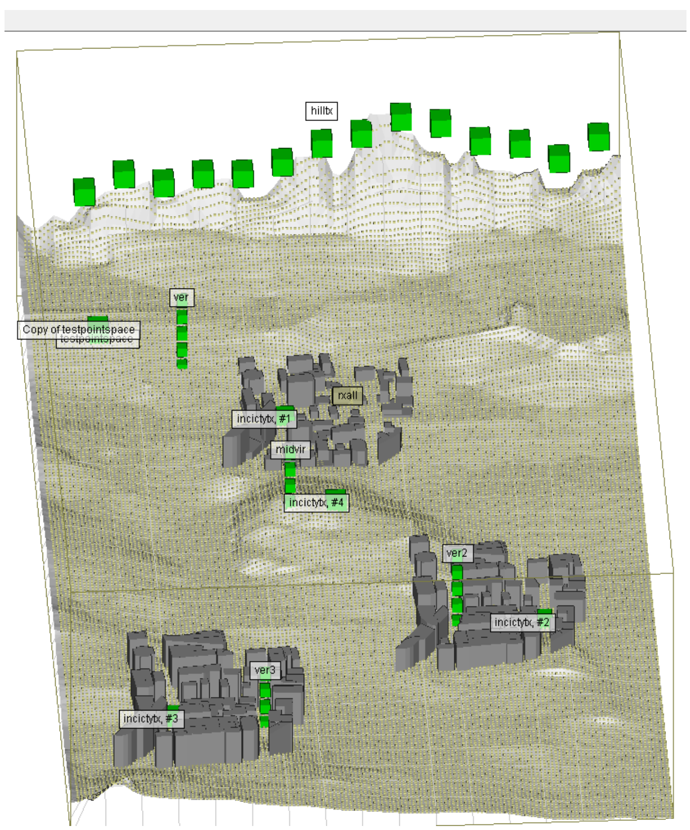


Figure 21: tx and rx

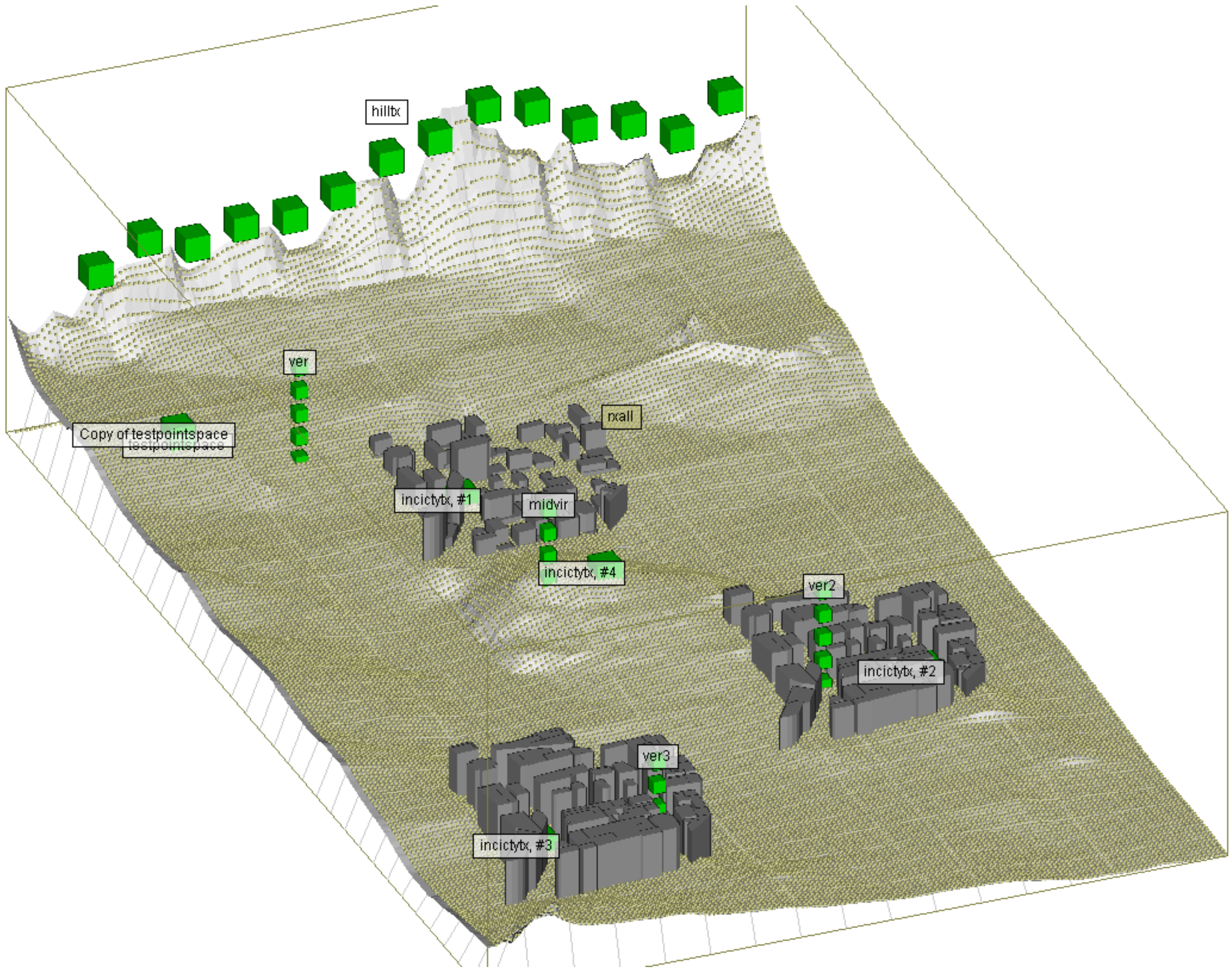
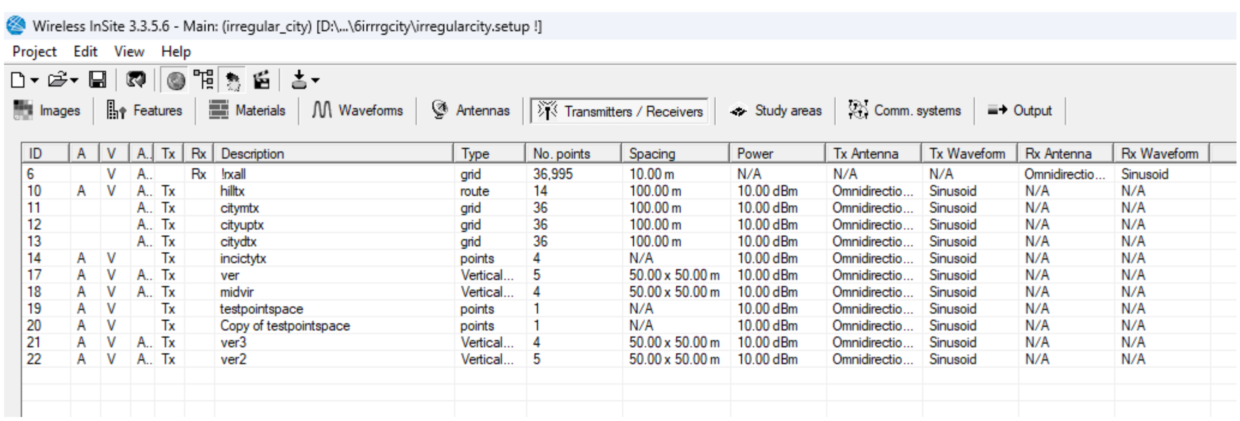


Figure 22: tx and rx



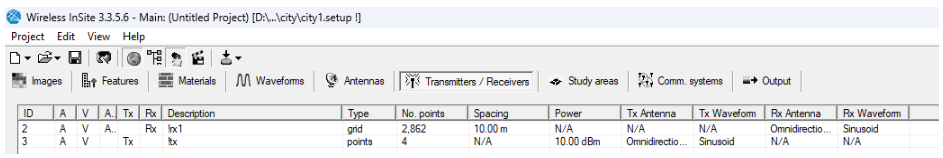
ID	A	V	A..	Tx	Rx	Description	Type	No. points	Spacing	Power	Tx Antenna	Tx Waveform	Rx Antenna	Rx Waveform
6		V	A..		Rx	!rxall	grid	36,995	10.00 m	N/A	N/A	N/A	Omnidirectio...	Sinusoid
10	A	V	A..	Tx		hilltx	route	14	100.00 m	10.00 dBm	Omnidirectio...	Sinusoid	N/A	N/A
11			A..	Tx		citymtx	grid	36	100.00 m	10.00 dBm	Omnidirectio...	Sinusoid	N/A	N/A
12			A..	Tx		cityuptx	grid	36	100.00 m	10.00 dBm	Omnidirectio...	Sinusoid	N/A	N/A
13			A..	Tx		citydtx	grid	36	100.00 m	10.00 dBm	Omnidirectio...	Sinusoid	N/A	N/A
14	A	V		Tx		incictytx	points	4	N/A	10.00 dBm	Omnidirectio...	Sinusoid	N/A	N/A
17	A	V	A..	Tx		ver	Vertical...	5	50.00 x 50.00 m	10.00 dBm	Omnidirectio...	Sinusoid	N/A	N/A
18	A	V	A..	Tx		midvir	Vertical...	4	50.00 x 50.00 m	10.00 dBm	Omnidirectio...	Sinusoid	N/A	N/A
19	A	V		Tx		testpointspace	points	1	N/A	10.00 dBm	Omnidirectio...	Sinusoid	N/A	N/A
20	A	V		Tx		Copy of testpointspace	points	1	N/A	10.00 dBm	Omnidirectio...	Sinusoid	N/A	N/A
21	A	V	A..	Tx		ver3	Vertical...	4	50.00 x 50.00 m	10.00 dBm	Omnidirectio...	Sinusoid	N/A	N/A
22	A	V	A..	Tx		ver2	Vertical...	5	50.00 x 50.00 m	10.00 dBm	Omnidirectio...	Sinusoid	N/A	N/A

Figure 23: tx and rx list

In this setup, there are 36,995 receivers positioned at 10m intervals, situated 2m above the terrain. The transmitter configurations include "hilltx," a group of 14 transmitters atop a hill designed for studying long-range communication. Additionally, there are three vertical antenna groups, namely ver3, ver2, and ver, each spaced 50m vertically, aimed at studying height-related aspects. Complementing these, there are individual low-height transmitters providing a diverse range of scenarios for comprehensive simulation analysis.

5.4.2 urban scenario:

here we can see 2862 receiver with 10m spacing and 4 transmitter



ID	A	V	A..	Tx	Rx	Description	Type	No. points	Spacing	Power	Tx Antenna	Tx Waveform	Rx Antenna	Rx Waveform
2	A	V	A..		Rx	!rx1	grid	2,862	10.00 m	N/A	N/A	N/A	Omnidirectio...	Sinusoid
3	A	V		Tx		!tx	points	4	N/A	10.00 dBm	Omnidirectio...	Sinusoid	N/A	N/A

Figure 24: tx and rx

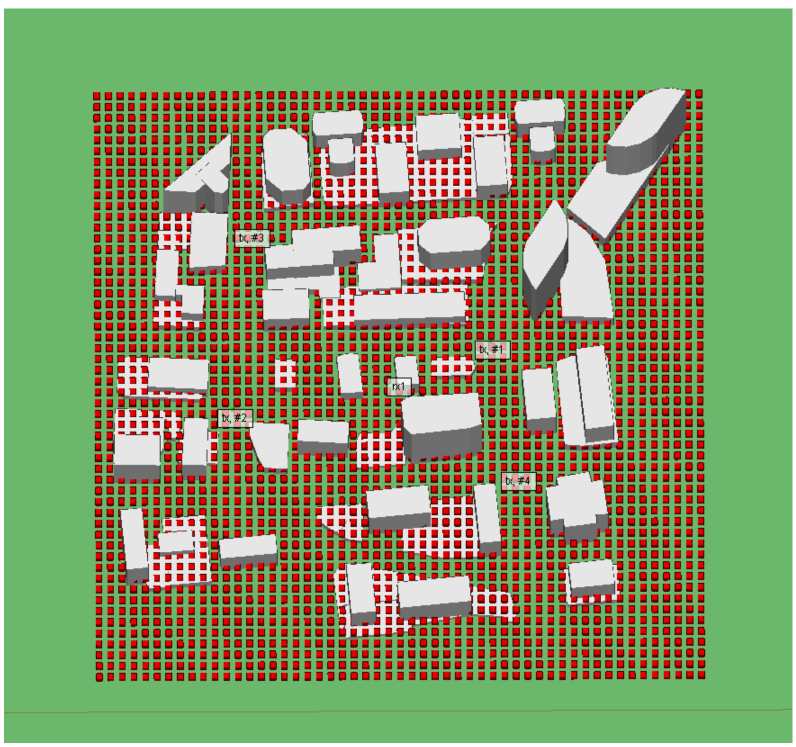
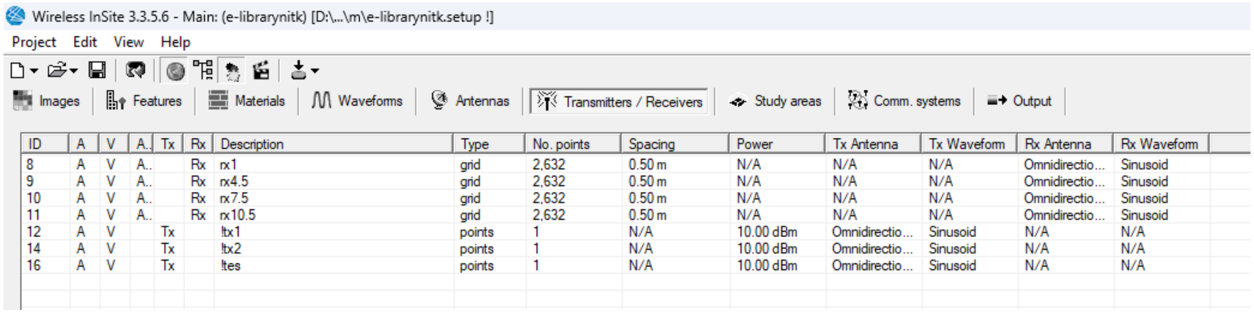


Figure 25: tx and rx

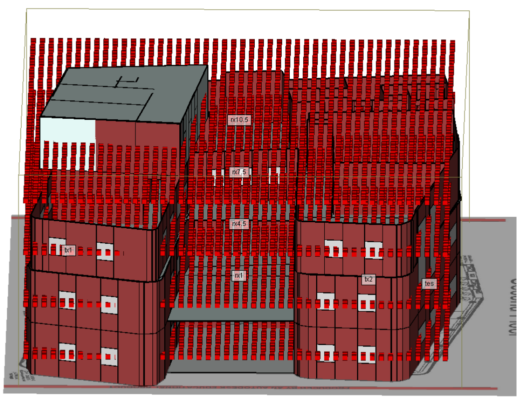
5.4.3 indoor scenario:

here we can see 2632 receiver with 5m spacing in every floor and 3 transmitter in groud floor

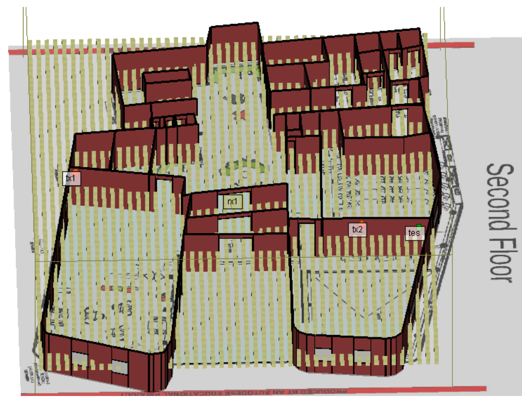


ID	A	V	A..	Tx	Rx	Description	Type	No. points	Spacing	Power	Tx Antenna	Tx Waveform	Rx Antenna	Rx Waveform
8	A	V	A..		Rx	rx1	grid	2,632	0.50 m	N/A	N/A	N/A	Omnidirectio...	Sinusoid
9	A	V	A..		Rx	rx4.5	grid	2,632	0.50 m	N/A	N/A	N/A	Omnidirectio...	Sinusoid
10	A	V	A..		Rx	rx7.5	grid	2,632	0.50 m	N/A	N/A	N/A	Omnidirectio...	Sinusoid
11	A	V	A..		Rx	rx10.5	grid	2,632	0.50 m	N/A	N/A	N/A	Omnidirectio...	Sinusoid
12	A	V		Tx		!tx1	points	1	N/A	10.00 dBm	Omnidirectio...	Sinusoid	N/A	N/A
14	A	V		Tx		!tx2	points	1	N/A	10.00 dBm	Omnidirectio...	Sinusoid	N/A	N/A
16	A	V		Tx		!tes	points	1	N/A	10.00 dBm	Omnidirectio...	Sinusoid	N/A	N/A

Figure 26: tx and rx



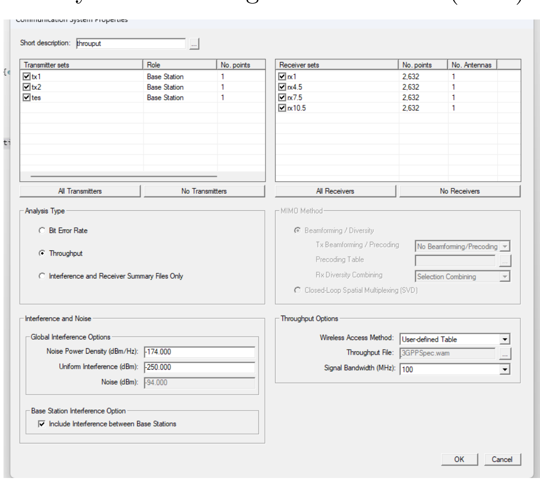
tx and rx



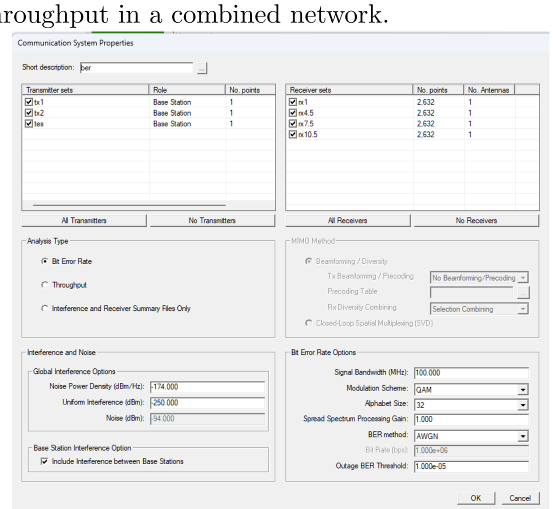
tx and rx

5.5 Study area and communication system:

The study area primarily focuses on configuring output requests and optimizing communication systems, specifically for simulating Bit Error Rate (BER) and throughput in a combined network.



throughput properties



BER properties

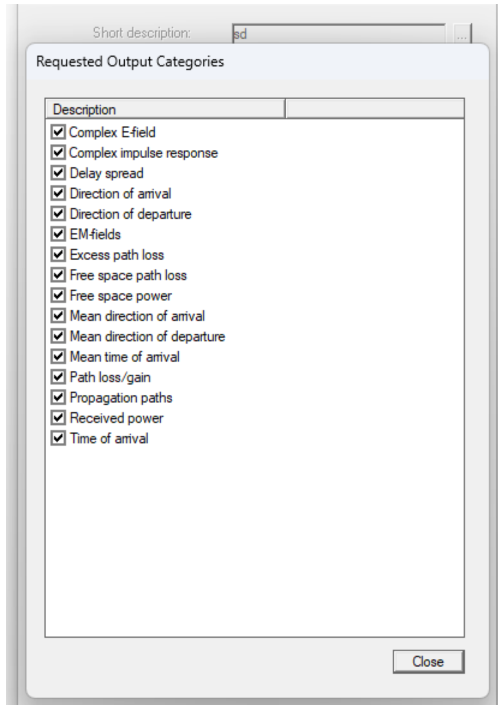
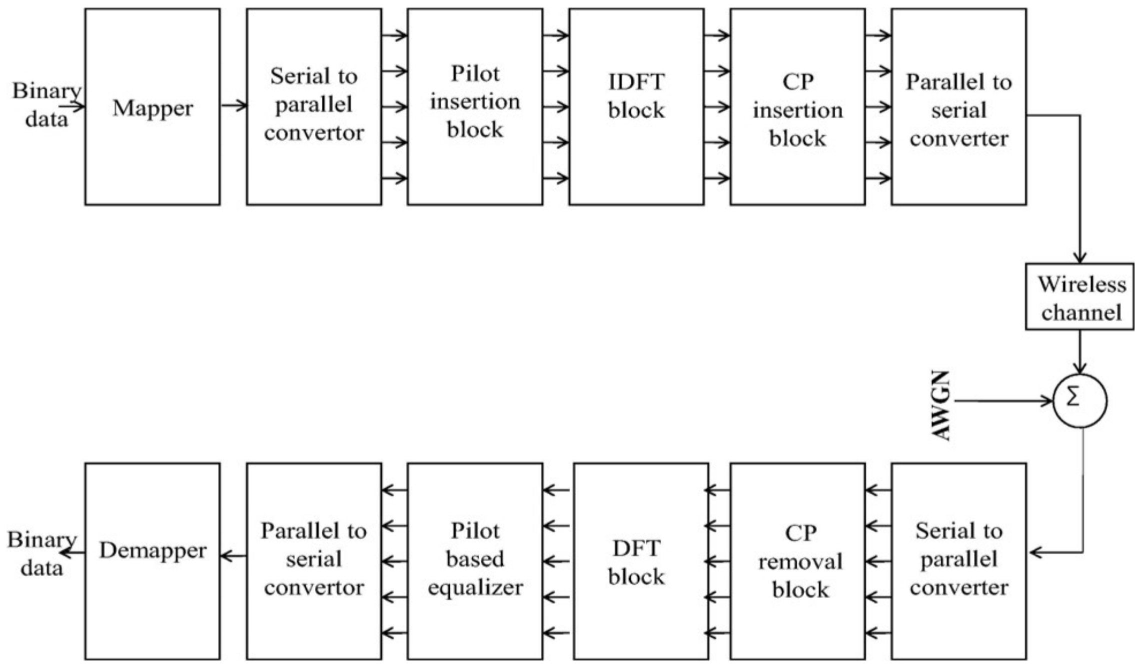


Figure 27: output list

6 OFDM system

6.1 OFDM MODEL

A schematic diagram of the OFDM system model is illuminated in Fig.2.1. Suppose that the binary data sequence is firstly encoded and mapped with quadrature amplitude modulation (QAM) modulation schemes.



The modulated signal is converted from serial to parallel ones, and the pilot tones are inserted to estimate the CIR of the channel model. In the OFDM system, the parallel data are transformed by inverse fast Fourier transform (IFFT) with N orthogonal narrowband subcarriers. The time domain signal x(n) is obtained from the frequency domain signals X(k) as follows:

$$x(n) = (\frac{1}{N}) \sum_{k=0}^{N-1} X(k) e^{j \frac{2\pi}{N} nk}$$

After IFFT, the N parallel subcarriers are converted to a serial bitstream and the cyclic prefix samples are inserted as guard intervals to alleviate the ISI. So the time-domain transmitted signal including cyclic prefix can be represented as follows:

$$x_g(n) = \begin{cases} x(N+n) & \text{n} = -N_g, -N_g+1, \ldots\ldots -1 \\ x(n) & \text{n} = 0, 1, \ldots\ldots N-1 \end{cases}$$

where ng is the length of cyclic prefix samples. It means that the last ng samples of x(n) are duplicated as cyclic prefix and inserted to the beginning of this symbol, resulting the signal xg(n) with length of N + ng. After through the underwater acoustic channel, the received signal yg(n) is given by:

$$y_g(n) = x_g(n) \otimes h(n) + w(n), -N_g < n < N-1$$

where the operator corresponds to the circular convolution and w(n) is the additive white Gaussian noise (AWGN) with zero-mean. h(n) is the channel impulse response that can be represented as follows:

$$h(n) = \sum_{i=0}^{r-1} h_i \delta(n - \tau_i)$$

where is impulse response, r is the number of multipaths, hi and i are the discrete complex gain and time delay of the i-th tap.

In the receiver, the received signal is split into parallel subcarriers and the cyclic prefix is removed out. Then the time-domain signal y(n) is transformed to frequency-domain signal Y(k) by fast Fourier transform (FFT) operations as follows:

$$Y(k) = (\frac{1}{N}) \sum_{k=0}^{N-1} y(n) e^{-j\frac{2\pi}{N}nk}, k = 0, 1, \ldots\ldots, N-1$$

thus under the assumption that the ISI is completely eliminated, the received signal can be formulated as:

$$Y(k) = X(k)H(k) + W(k), k = 0, 1, \ldots\ldots, N-1$$

where H(k), W(k) are the Fourier transform of h(n) and w(n), respectively. It is noted that the relationship between the transmitted signal and received signal for a mmwave channel can be clearly expressed by means of H(k) and W(k) in the frequency-domain.

The compensated signal after channel estimation is congregated into a serial sequence, which is then demodulated and decoded by the corresponding methods in the transmitter. At this point, the output of OFDM system model is obtained as the final binary data sequence.

6.2 CHANNEL ESTIMATION

The aim of channel estimation is to estimate channel parameters from the received signal. As discussed , each subcarrier component of the received signal can be expressed as the product of the transmitted signal and channel frequency response at the subcarrier as long as no inter-carrier interference (ICI) occurs. Thus, the transmitted signal can be recovered by estimating the channel response at each subcarrier. In general, channel estimation is executed with the help of pilot symbols, which are known to both transmitter and receiver. As shown in Fig. 2, the pilot symbols can be inserted into the frequency or time direction in OFDM frames, namely comb-type and block-type, respectively. After obtaining the state estimation at the pilot symbols, the channel responses of all subcarriers between pilot symbols can be estimated by employing various interpolation methods, such as linear interpolation, second-order interpolation, spline cubic interpolation.

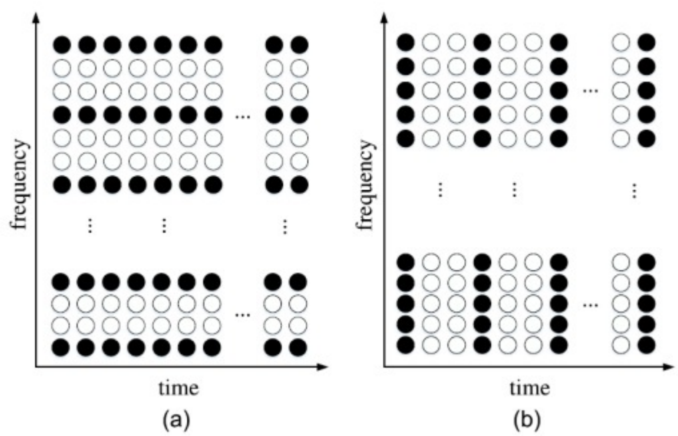


Figure 2.2: Two different types of pilot structures for UWA-OFDM systems.

LS algorithm is the most typical representative of the traditional channel estimation method, essentially to solve a problem of extreme value. Assuming the estimated channel impulse response is Hˆ LS , LS algorithm gives the solution to channel estimation for OFDM systems as follows:

$$\hat{H}_{LS} = (X^H X)^{-1} X^H Y = X^{-1} Y$$

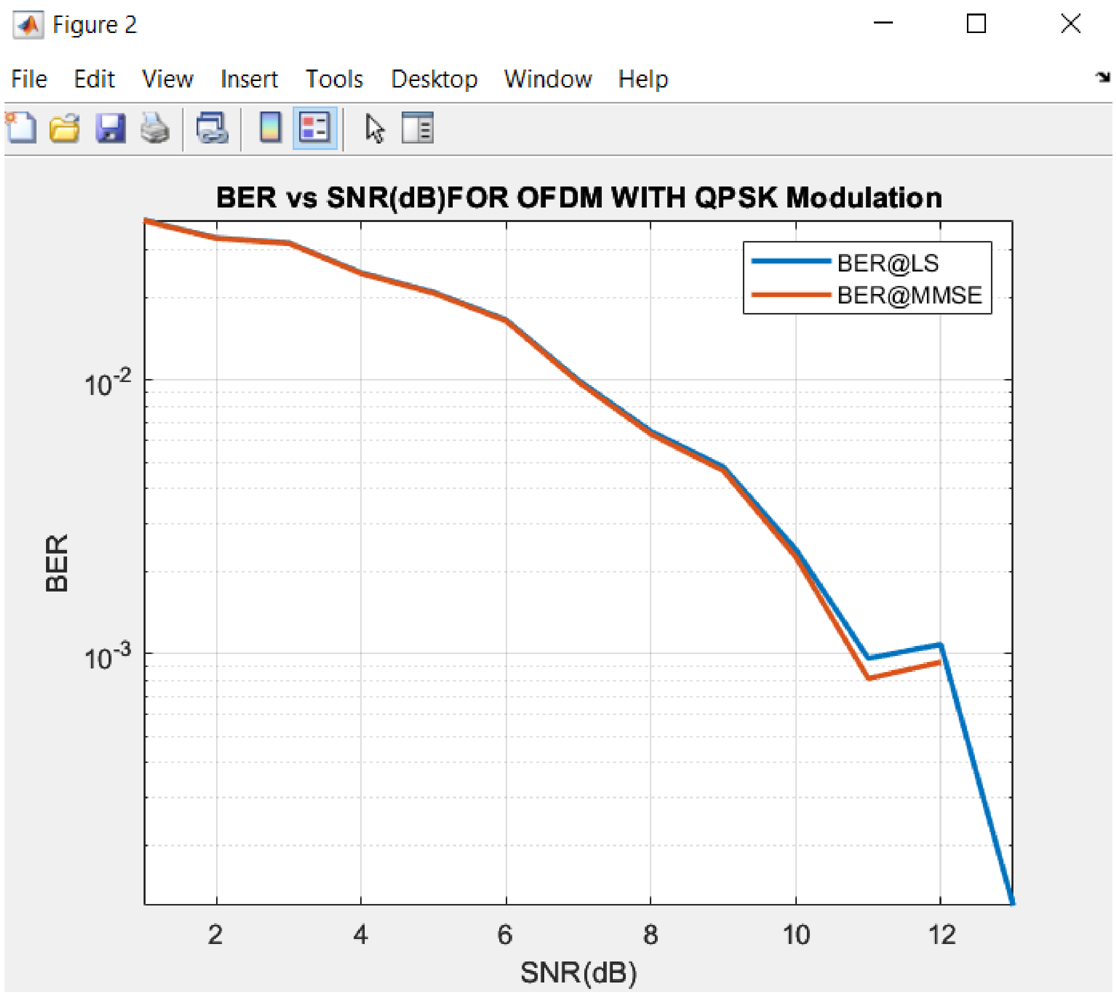
where the superscript (.) H stands for the Hermitian transpose. It denotes that LS channel estimator is directly obtained by minimizing the square distance between the received symbols Y and the transmitted symbols X. Therefore, it is widely used for channel estimation due to its simplicity and without channel statistics required. However, it neglects the noise interference in the calculation process, resulting poor performance in complex communication environment. To overcome the noise-sensitive defects of LS algorithm, MMSE algorithm is calculated based on minimizing the mean square error (MSE) of the actual channel and its estimation. Combined with the LS channel estimation result Hˆ LS in (2.7), the MMSE estimator can be achieved as follows:

$$\hat{H}_{MMSE} = R_{H\hat{H}}(R_{HH} + \frac{{\delta_n}^2}{{\delta_x}^2} I)^{-1} \hat{H}_{LS}$$

where RHH = E(HHH) refers to the autocorrelation matrix of channel response in frequency domain, and RHH˜ denotes the cross-correlation matrix between the actual channel and temporary estimated channel.n 2 and x 2 are the variance of AWGN and transmitted signal, respectively. The influence of noise is taken into account by MMSE algorithm to improve the channel estimation accuracy. However, it is more complex than the LS algorithm because it requires some prior knowledge about the channel statistical properties, including the channel autocorrelation matrix and noise variance.

7 Results

In this study, our primary modulation schemes QPSK, QAM16,QAM32and QAM64. We utilize an image as input to investigate the impact of noise, modulation, and channel extraction methods. Presented below are the obtained results



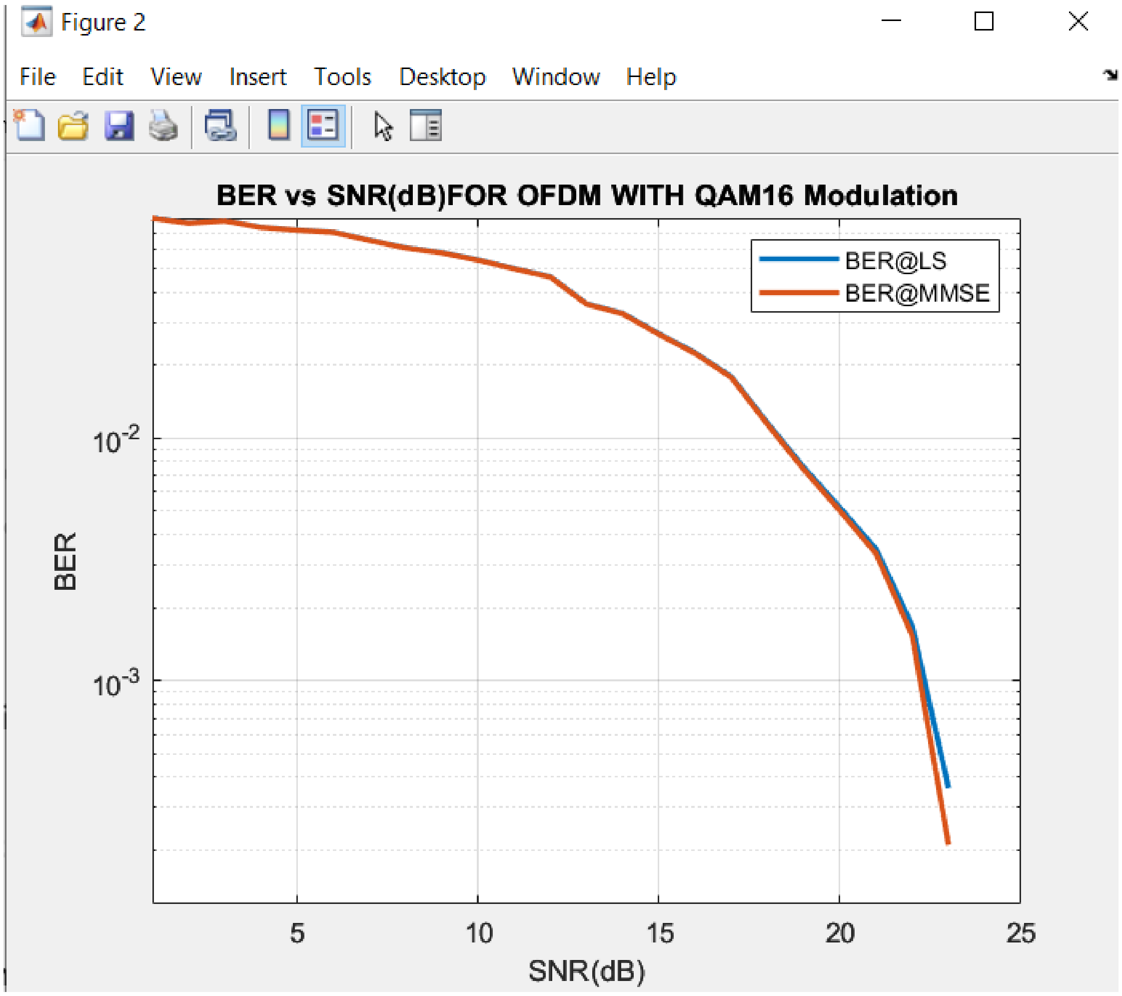


Figure 2
File Edit View Insert Tools Desktop Window Help
BER vs SNR(dB)FOR OFDM WITH QAM16 Modulation
BER@LS
BER@MMSE
10^{-2}
10^{-3}
BER
5
10
15
20
25
SNR(dB)

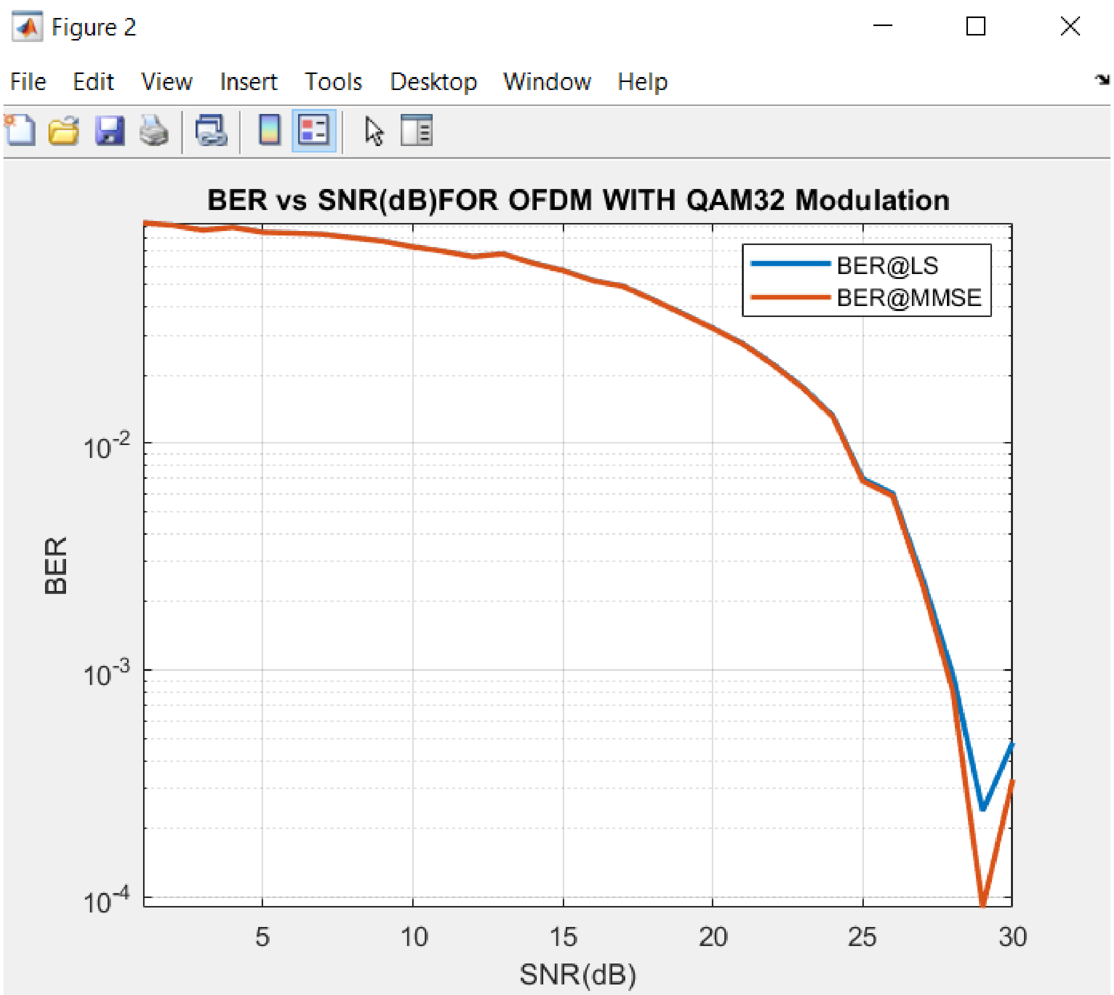


Figure 2
File Edit View Insert Tools Desktop Window Help
BER vs SNR(dB)FOR OFDM WITH QAM32 Modulation
BER@LS
BER@MMSE
BER
10^{-2}
10^{-3}
10^{-4}
5
10
15
20
25
30
SNR(dB)

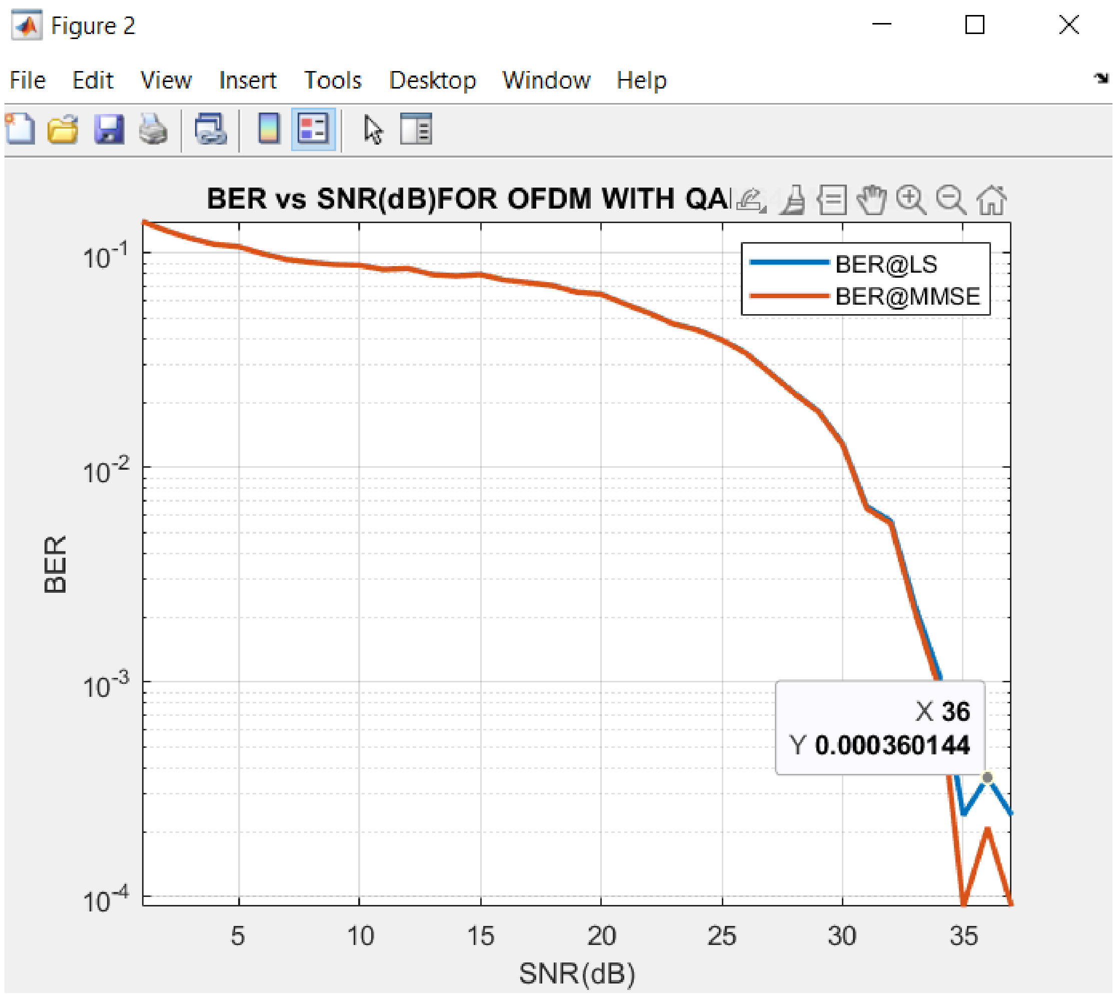


Figure 2
File Edit View Insert Tools Desktop Window Help
BER vs SNR(dB)FOR OFDM WITH QA
BER@LS
BER@MMSE
X 36
Y 0.000360144
10^{-1}
10^{-2}
10^{-3}
10^{-4}
BER
5
10
15
20
25
30
35
SNR(dB)

7.1 Results for indoor scenario:

7.1.1 Recived power

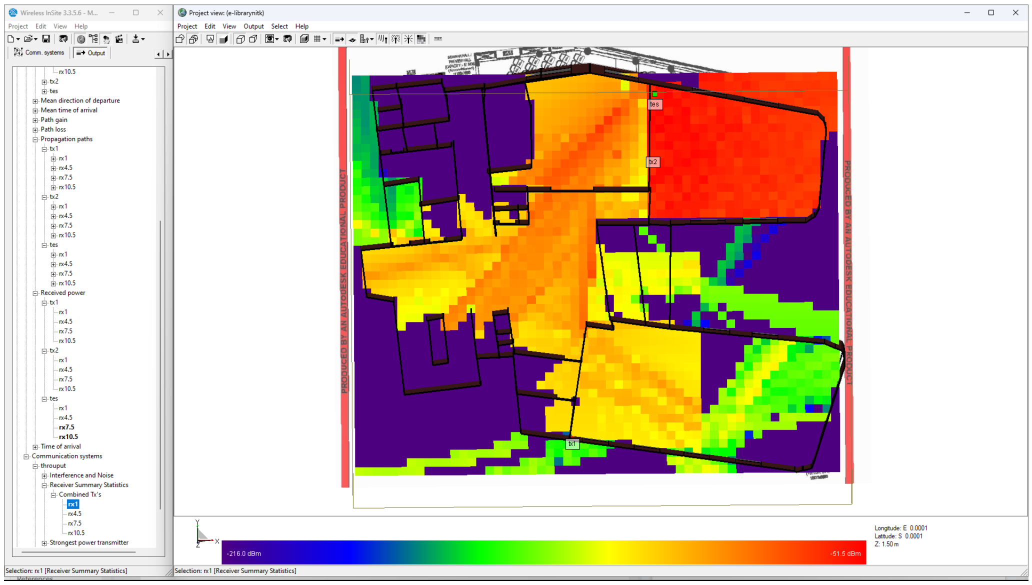


Figure 28: comb recived power

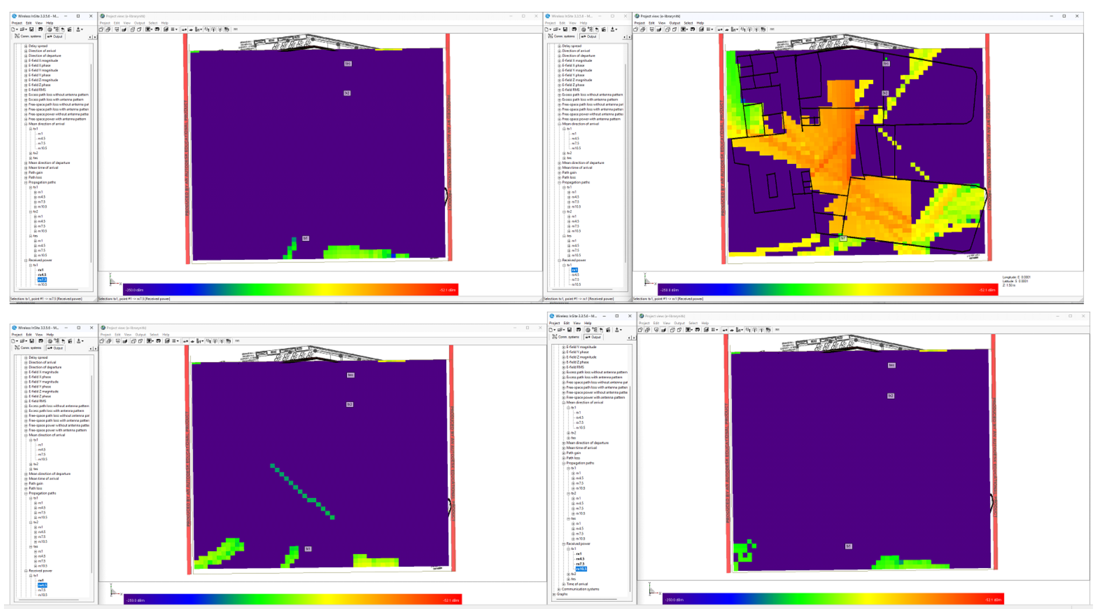


Figure 29: tx1 recived power

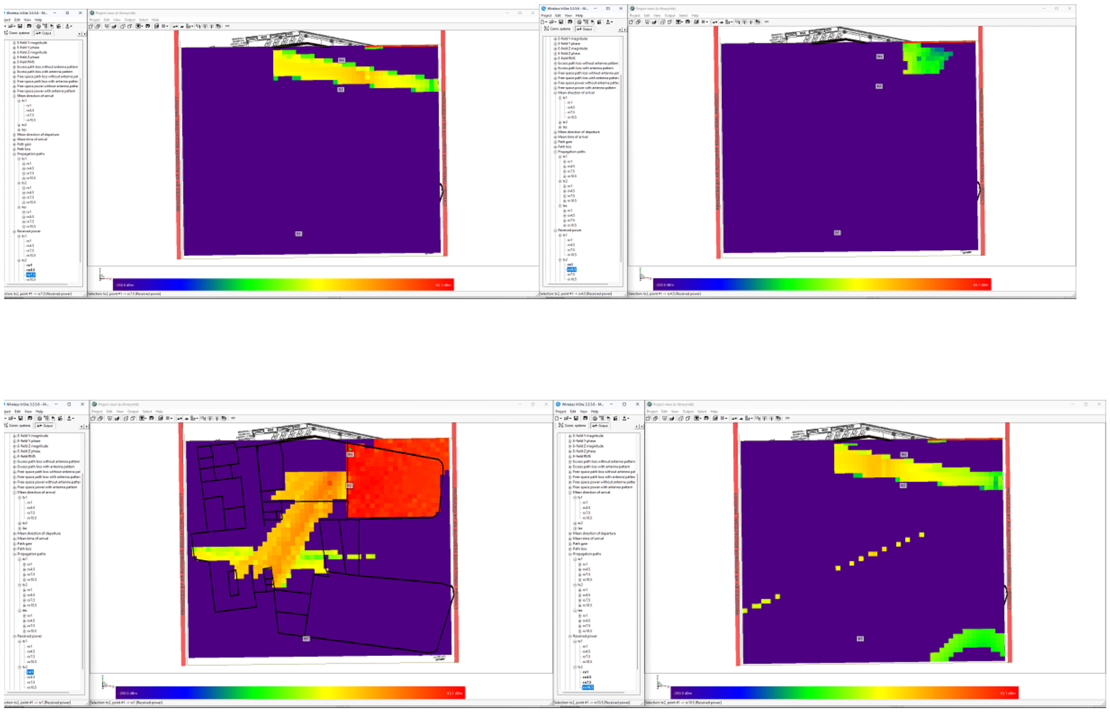


Figure 30: tx2 recived power

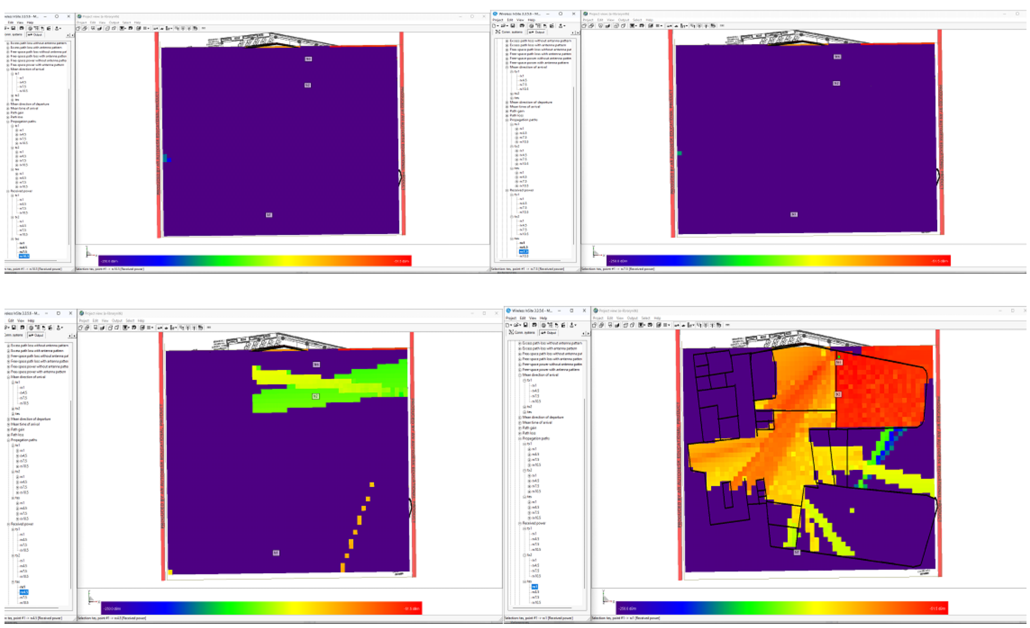


Figure 31: tes recived powe

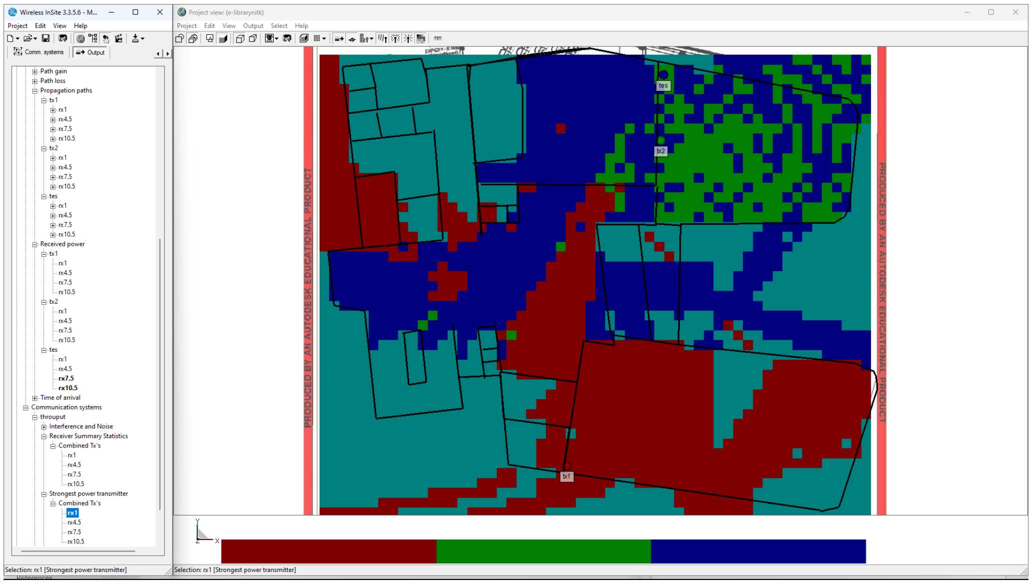
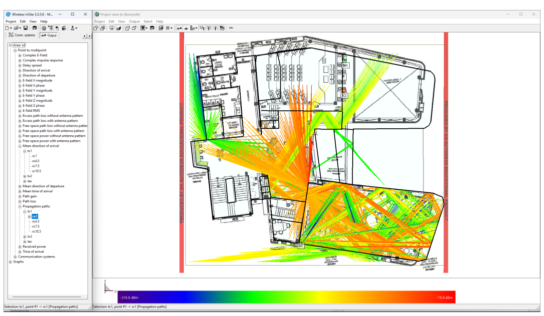
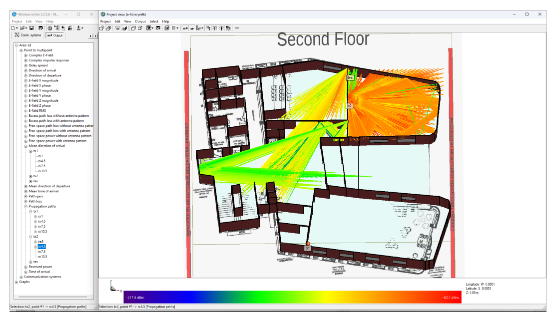


Figure 32: strongest power transmitter

7.1.2 propagation path



tx1 propagation path



tx2 propagation path

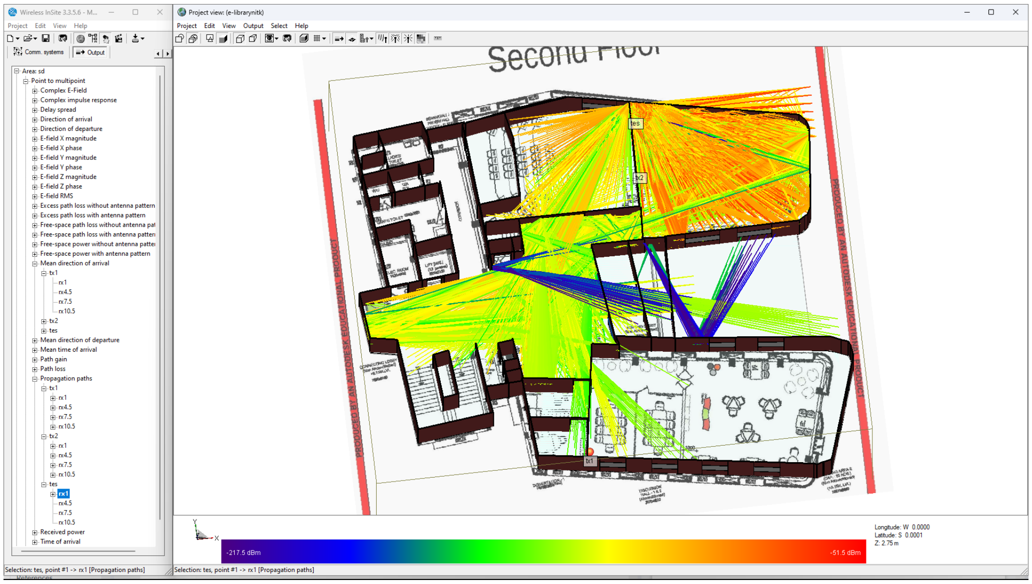
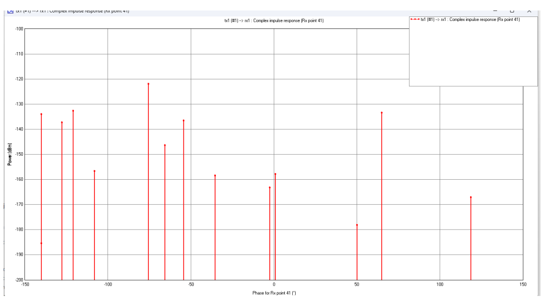
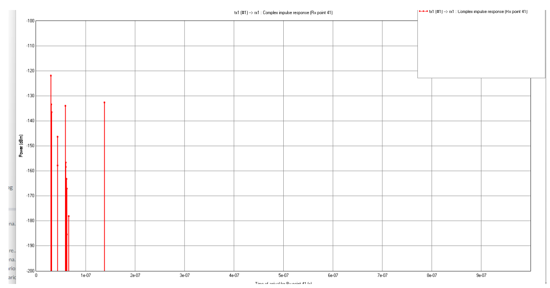


Figure 33: tes propagation path

7.1.3 Channel impulse response

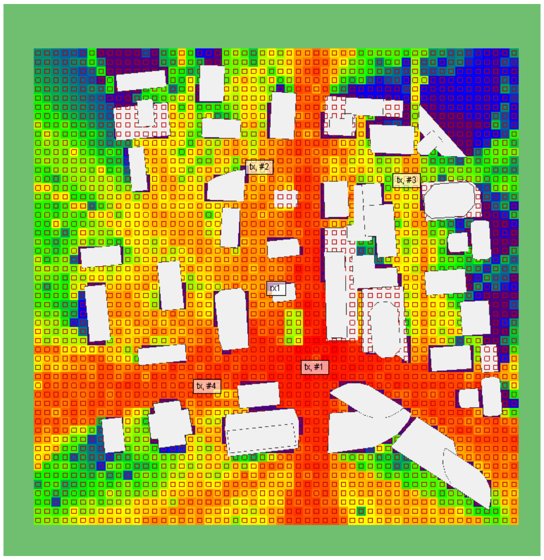


CIR power vs phase

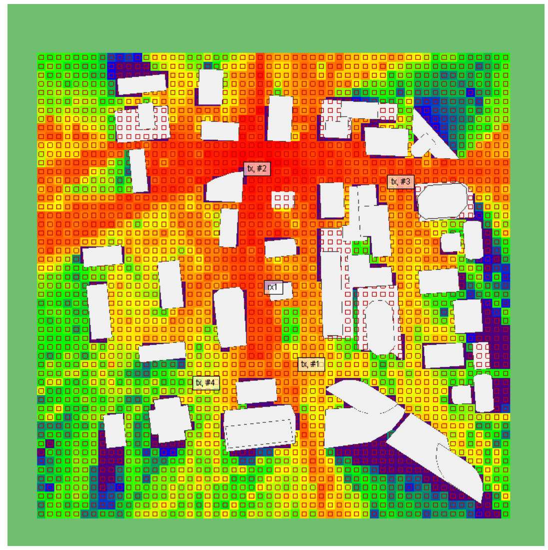


CIR power vs time of arrival

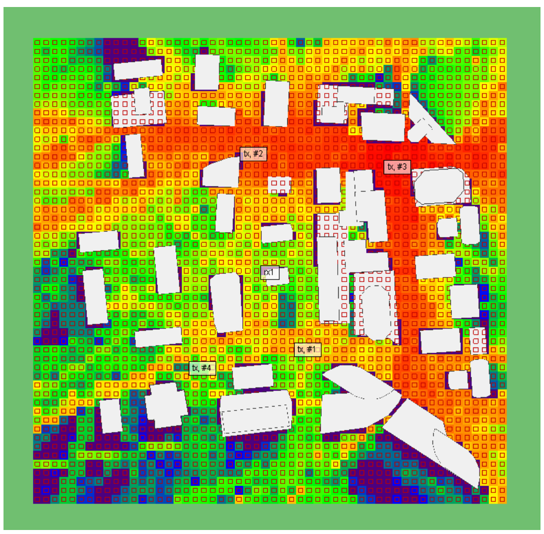
7.2 Results of urban scenario:



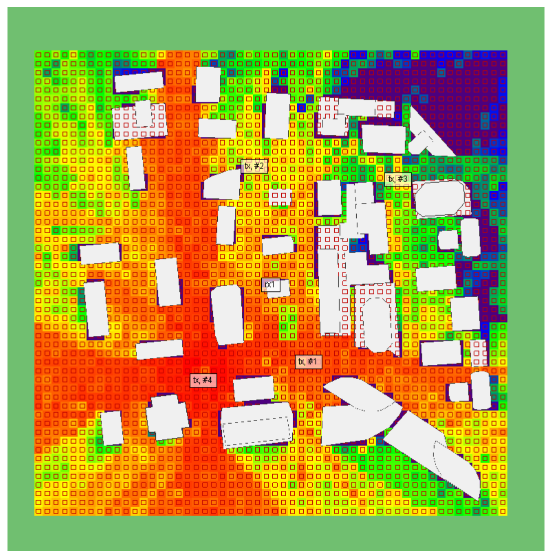
tx1 recived power



tx2 recived power



tx3 recived power



tx4 recived power

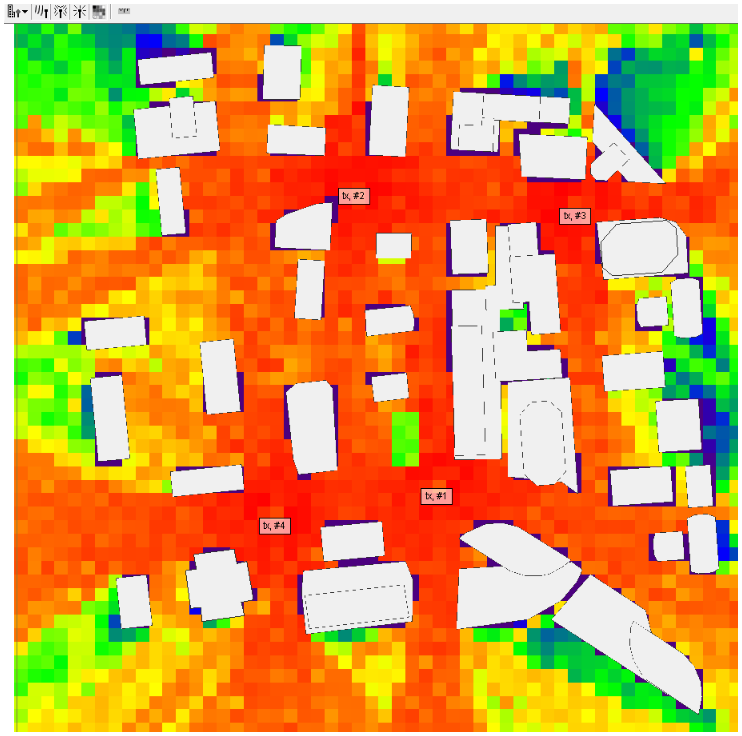


Figure 34: combined tx city received power

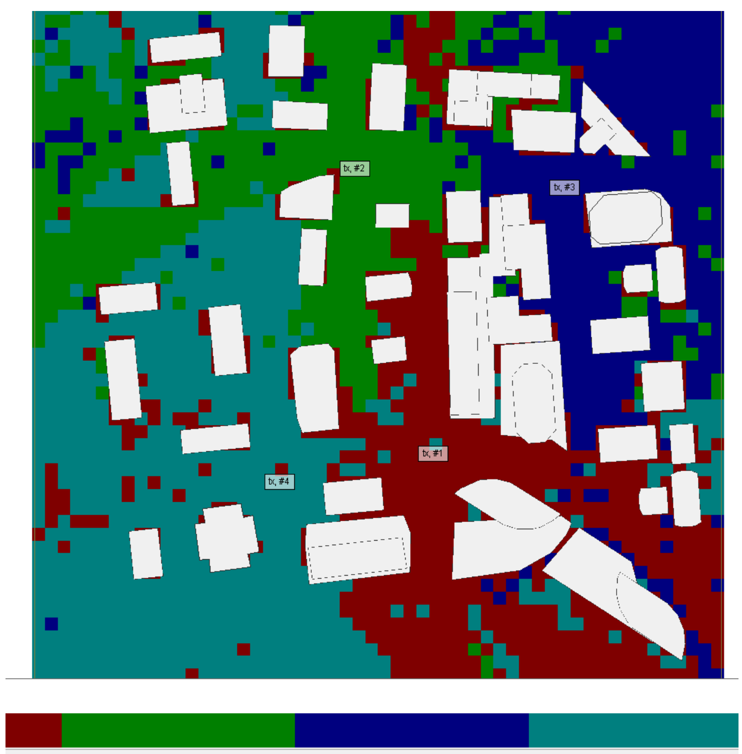


Figure 35: combined tx city received power

7.2.1 propagation path:

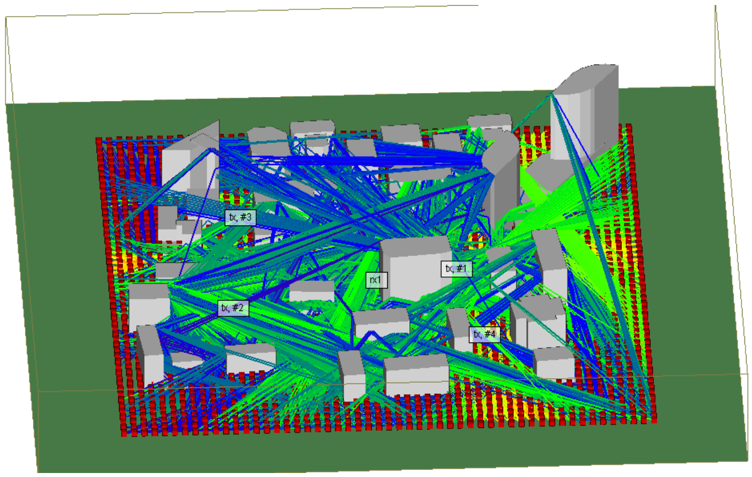


Figure 36: tx1 propagation path

7.2.2 throughput:

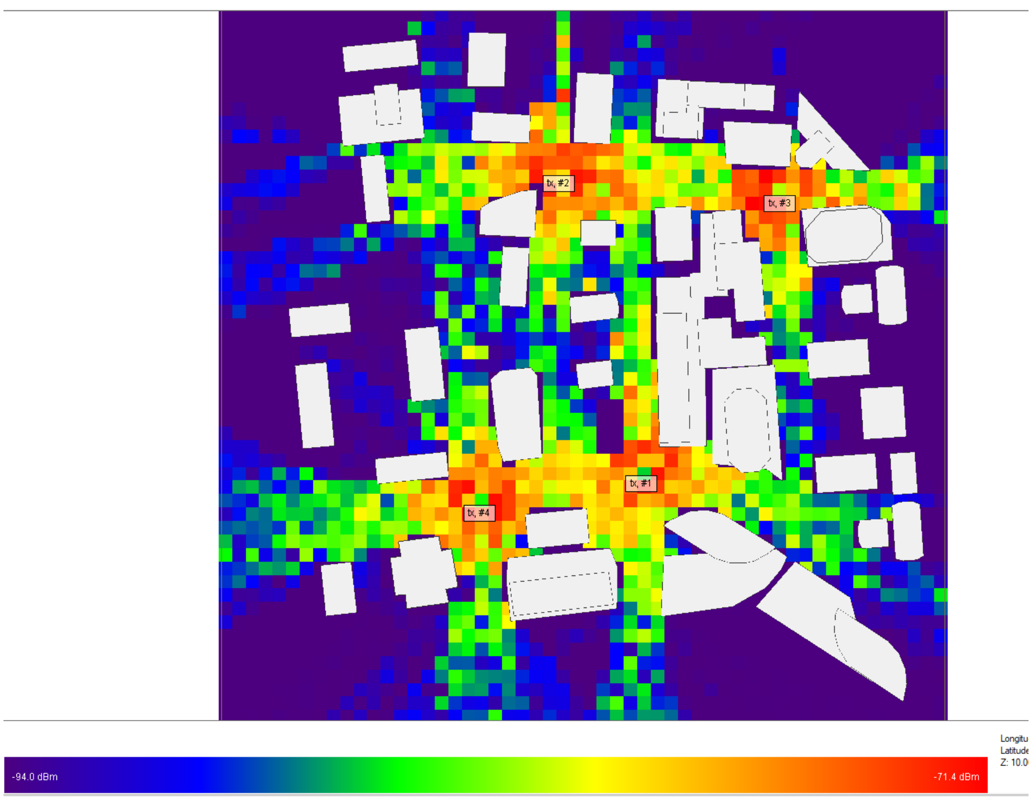


Figure 37: combined throughput in city

7.3 outdoor scenario:

7.3.1 Received power:

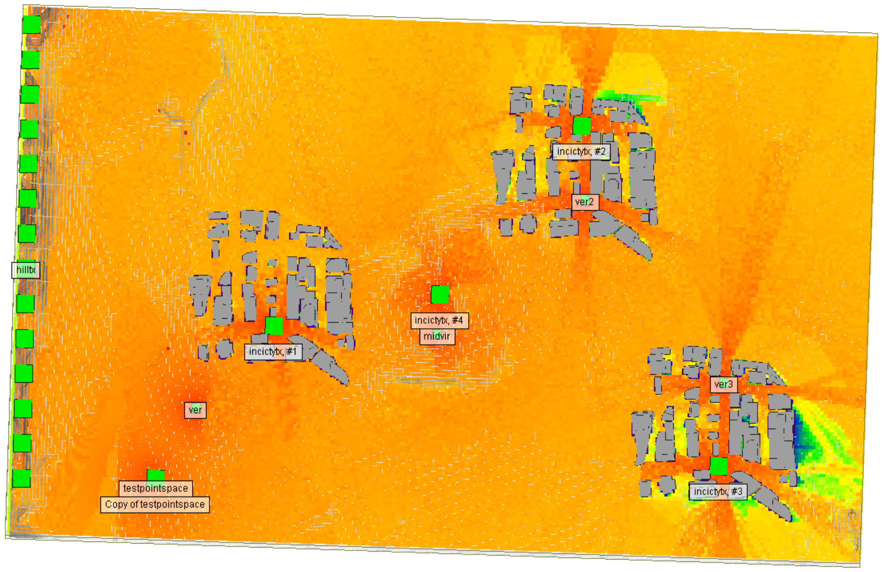


Figure 38: combined recived power in ouotdoor scenario

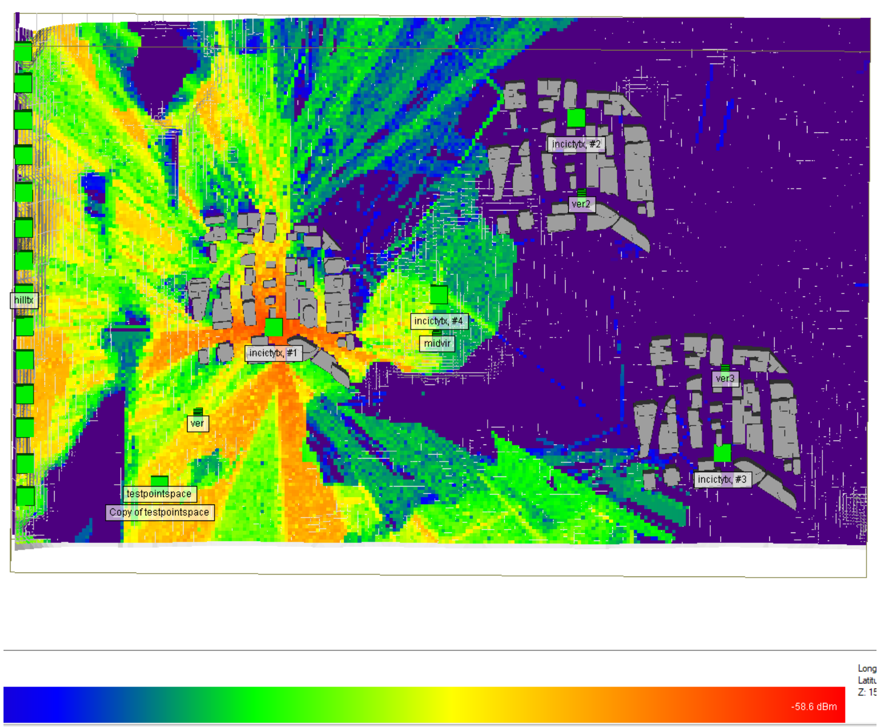


Figure 39: outdoor city1 tx-recived power in ouotdoor scenario

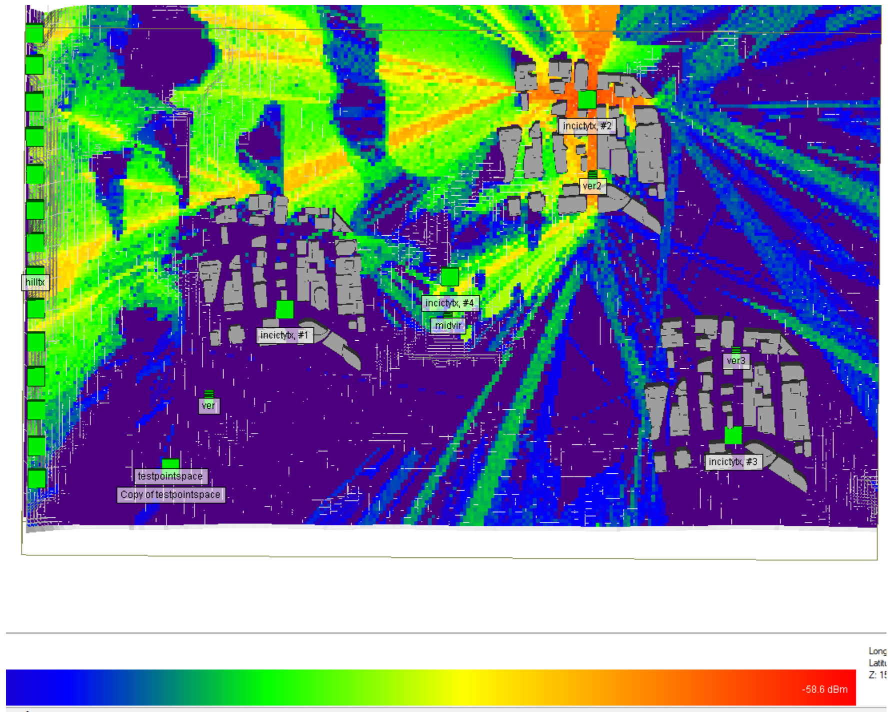


Figure 40: outdoor city2 tx- recived power in ouotdoor scenario

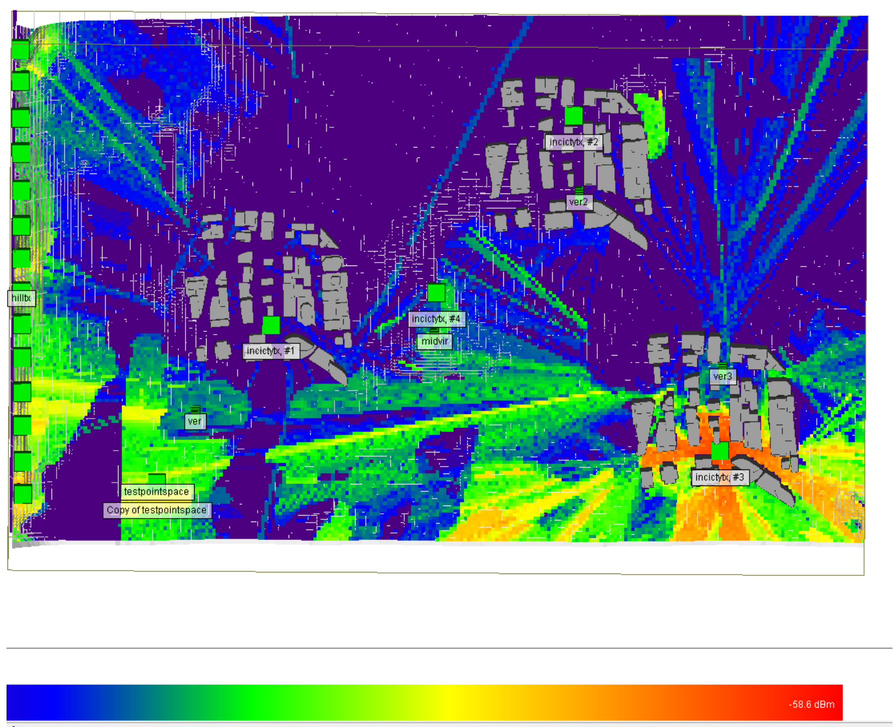


Figure 41: outdoor city3 tx- recived power in ouotdoor scenario

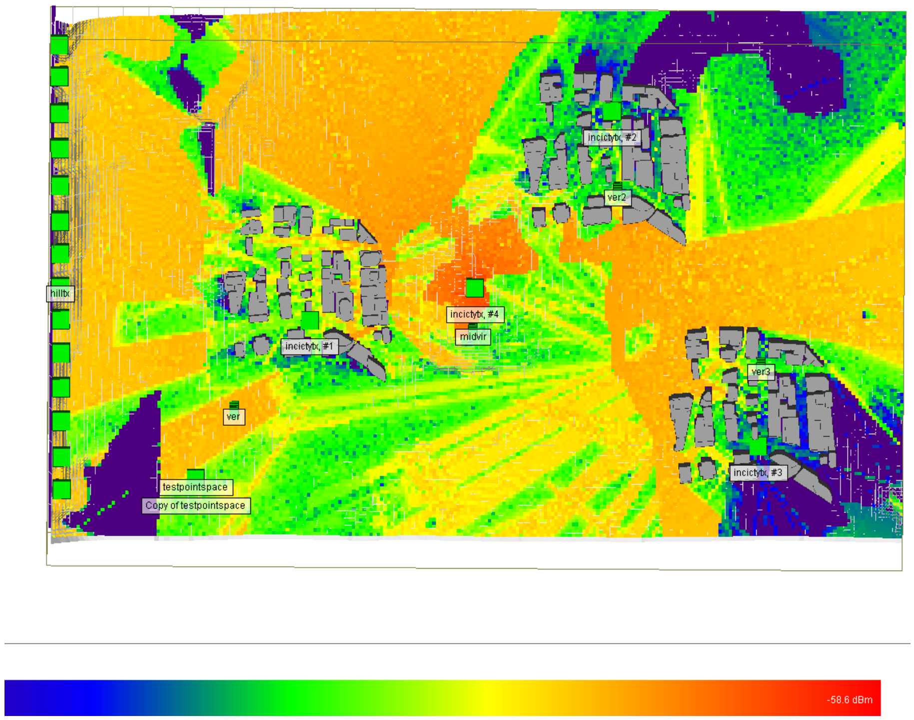


Figure 42: center tx- recived power in ouotdoor scenario

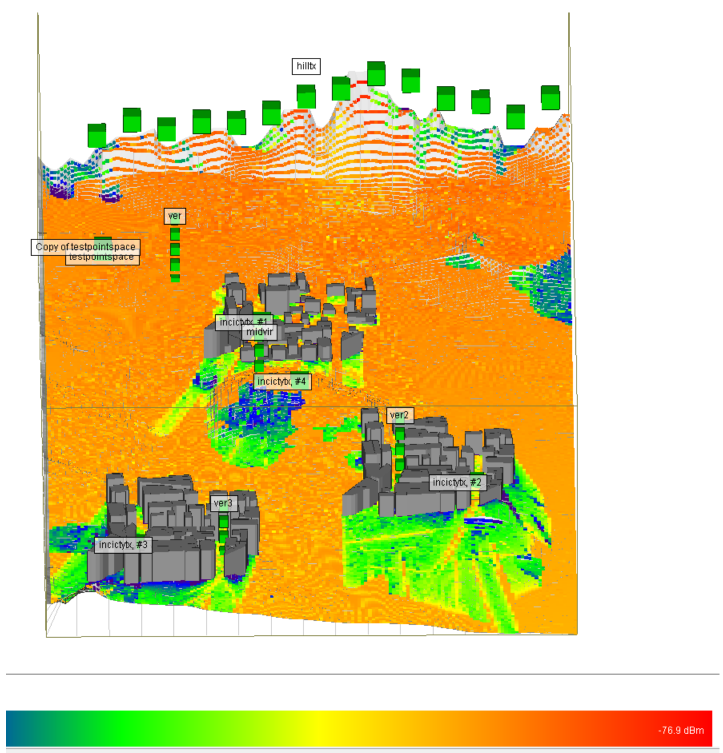


Figure 43: hill mid transmitter-recived power in ouotdoor scenario

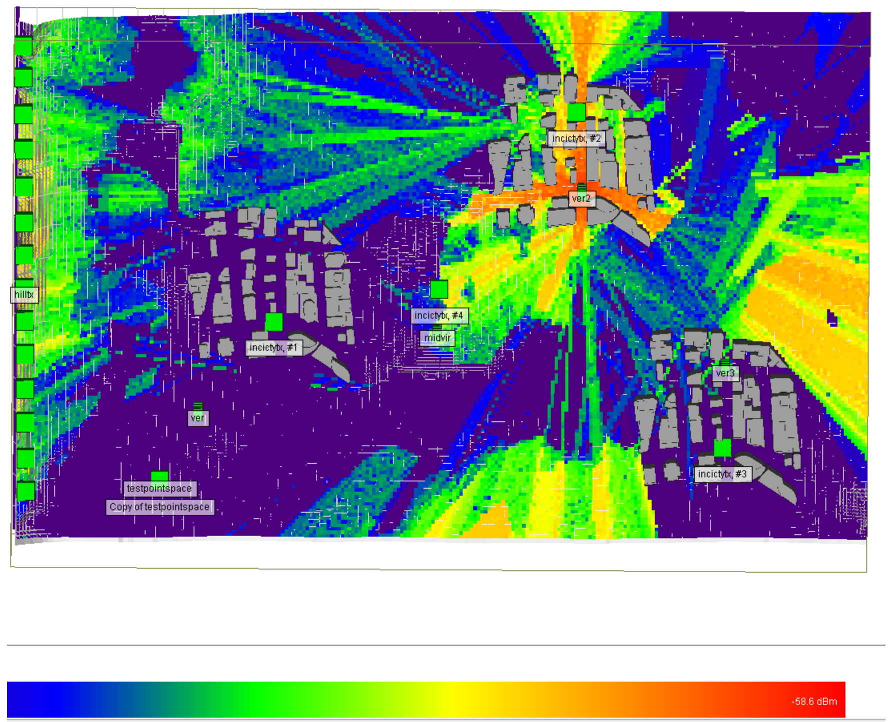


Figure 44: antenna heigth=5m

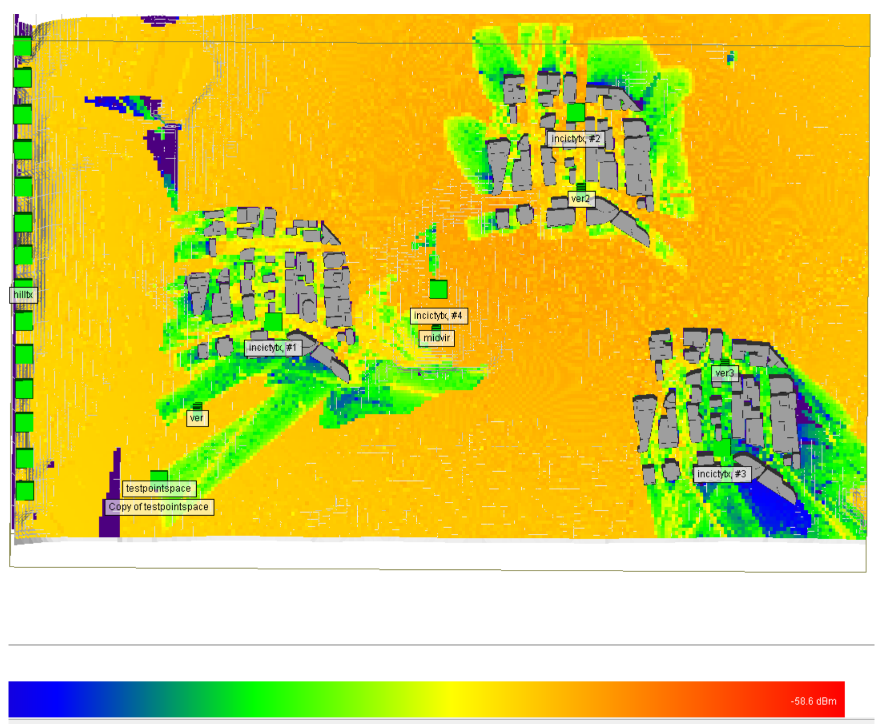


Figure 45: antenna heigth=200m

7.3.2 Throughput:

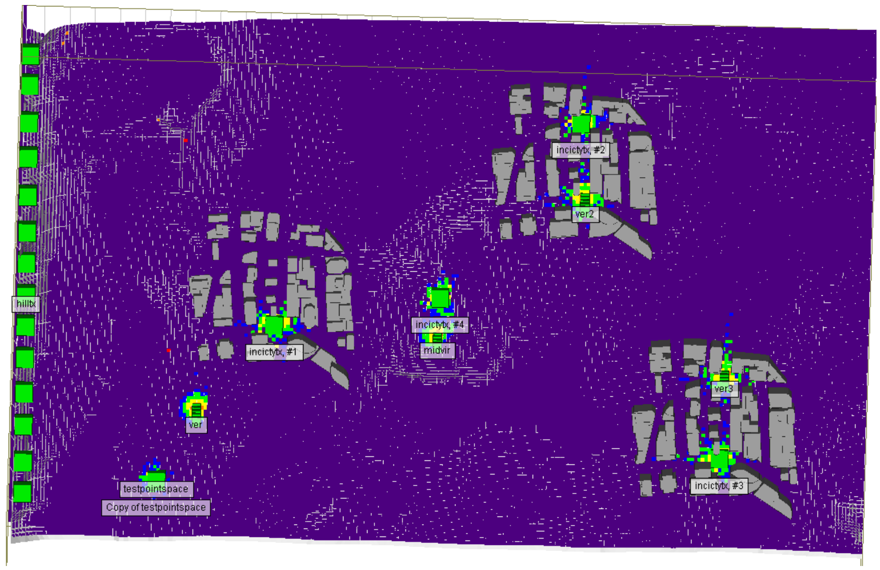


Figure 46: antenna heigth=200m

7.4 General result:

In this section, we will display the outcomes of throughput versus distance and received power versus distance, comparing scenarios with and without obstacles.

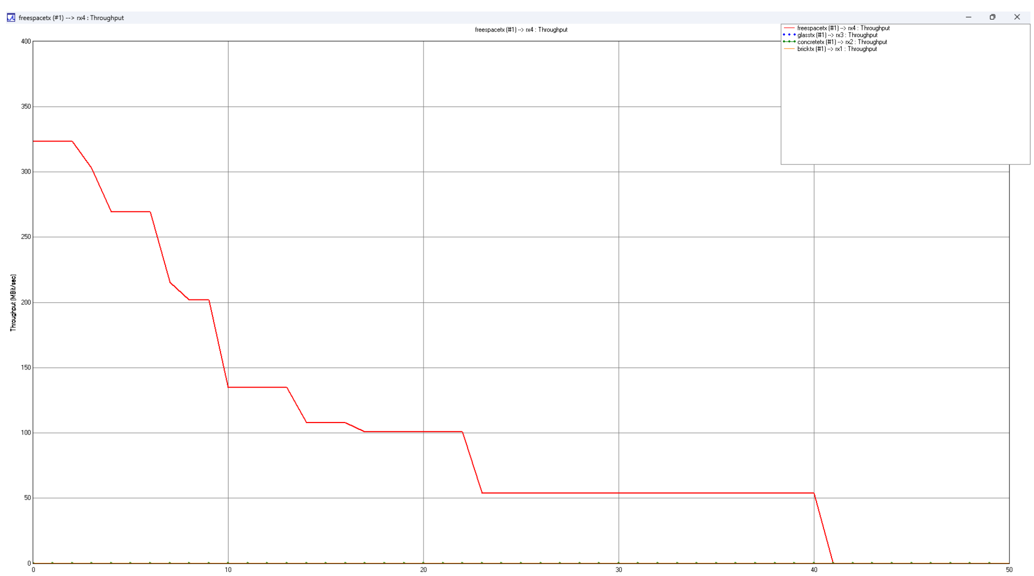


Figure 47: throughput vs distance

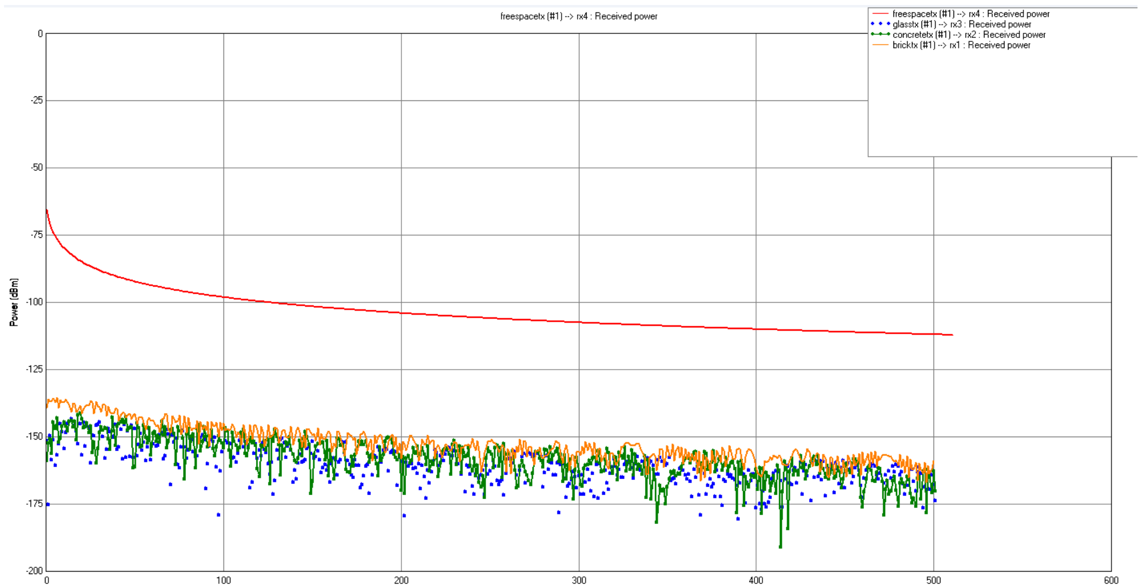


Figure 48: throughput vs distance

8 conclusion

In the context of this project, we simulated three distinct environmental models to assess their impact on communication networks, focusing on metrics such as received power, propagation paths, and throughput. An illustrative example is seen in the investigation of the influence of different material obstacles on received power and throughput, showcased in Fig. 48 and Fig. 47. Furthermore, we explored the effects of transmitter height in an outdoor scenario, revealing in Fig. 44 and Fig. 45 that a transmitter at a height of 200 provides superior propagation or coverage.

Examining the indoor scenario, it is evident that the coverage of tx2 fig30, positioned in the middle of a wall, is suboptimal. However, the study also indicates that tx1 exhibits better coverage than tx2, as it is placed in a corner. Applying the same principle, we improved coverage by relocating tx2 to a corner, as demonstrated using ”tes” fig31 transmitters. Nevertheless, tx1’s vertical coverage is limited, with minimal power reception on the 1st, 2nd, and 3rd floors of the e-library. In contrast, tx2 performs better than tx1 in this specific aspect.

Examining the urban scenario, we observe the impact of dense tall buildings on throughput and coverage, as depicted in Fig. 34 and Fig. 35. Additionally, the complexity of propagation paths in this scenario is evident. In Fig. 37, we gain insights into the combined throughput of four transmitters, providing a holistic view of network performance in this urban environment. In this context, we gathered an extensive dataset, including approximately 3 sets of 8500 channel impulse response samples solely from the indoor environment. For outdoor scenarios, we accumulated over 40,000 samples for each transmitter. In the urban environment, we collected 2653 samples for each transmitter. This rich dataset serves as a valuable foundation for training and testing machine learning models, enabling robust analysis and prediction capabilities in the context of the studied communication scenarios. From the above collected urban dataset we have implemented an OFDM system from which we used QPSK,QAM16,QAM32 and QAM64 as modulation we have got BER vs SNR result from which we can with low power of ¡15dBi we can send aQPSK signal with acceptable ber.

9 Future works

1. In future endeavors, our focus will be on constructing a CP-OFDM (Cyclic Prefix Orthogonal Frequency Division Multiplexing) model for a comprehensive analysis of Bit Error Rate (BER) and throughput. This model will be developed in MATLAB, leveraging our extensive dataset that encompasses various scenarios. This approach aims to provide detailed insights into the performance of communication systems under diverse conditions, contributing to a more nuanced understanding of the studied scenarios and facilitating informed decision-making in wireless communication

2. In our ongoing efforts, we are actively exploring the integration of machine learning models to mitigate the complexity inherent in multi-environment scenarios. The objective is to enhance computational efficiency and improve the efficacy of channel estimation techniques. By leveraging machine learning algorithms, we aim to streamline the analysis process, reduce computational time, and achieve optimized results in the estimation of channel characteristics across diverse environmental scenarios. This strategic integration holds the potential to significantly improve the overall efficiency of our simulations and analyses.

10 References

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