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Performance Evaluation of SINR in 5G Urban Macro-Cells with Variable Parameters Under different path loss models

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Abstract

This research assesses the performance of Signal-to-Interference-plus-Noise Ratio (SINR) within urban macro-cells of 5G, comparing two different path loss models—Free-Space Propagation Model (FSPM) and Close-In (CI) model—to evaluate their effects on signal quality and network dependability. Concentrating on densely populated urban areas in Bhubaneswar, India, the study utilizes a hexagonal cell setup with 19 sites to investigate how crucial factors such as antenna height, inter-site distance, and transmission power affect SINR distribution. The simulations demonstrate that the CI model, which accounts for practical propagation effects such as shadowing and multipath fading, offers more accurate SINR predictions than the idealized FSPM. The results suggest that varying antenna heights enhances SINR by diminishing interference. The RSS analysis reveals that the Free-Space model often predicts higher signal strength than actual, whereas the Close-In model yields more precise outcomes for given environments. These findings highlight the necessity of refined deployment strategies and realistic modelling to strike a balance between coverage and performance in urban 5G networks.

I. INTRODUCTION

At present, 4G wireless communication is in use worldwide, yet it has its limitations. The advent of fifth-generation (5G) wireless networks has established new standards for data speeds, latency, reliability, and user capacity, especially in densely populated urban regions. Urban macro-cells, which form the core of 5G coverage, need to tackle a variety of propagation challenges posed by the intricate physical environment, such as tall buildings, diverse street layouts, and dynamic user movement. Among the crucial elements affecting network performance, the Signal-to-Interference-plus-Noise Ratio (SINR) is a significant factor in determining communication quality, impacting throughput, spectral efficiency, and overall system reliability. Evaluating SINR performance in urban settings necessitates the use of dependable path loss models that forecast how signals weaken over distance and through various obstacles. The choice of an appropriate path loss model significantly influences the precision of performance analysis. This study examines two different path loss models: the Free Space Propagation Model and the Close-In (CI) Reference Distance Model. The Free Space Model presumes an ideal environment without obstructions, offering a baseline for signal attenuation under line-of-sight (LOS) conditions. Conversely, the Close-In Model provides a more realistic framework by considering path loss relative to a reference distance, thus accounting for environmental factors like building density and signal obstruction. Various configurations are mentioned further in this paper, such as antenna height, ISD (Inter-Site Distance), transmitter power, and carrier frequency, along with some fixed parameters to observe changes in coverage area and SINR values. Additionally, this research paper focuses on the signal strength between the transmitter and receiver antennas. The different configurations for signal strength are further discussed below, providing insights into how various parameters affect the strength at the location. The location chosen for our analysis is Bhubaneswar, India. The insights gained from this research aim to aid network designers and engineers in selecting suitable propagation models for specific deployment scenarios. By understanding how SINR performance varies across different models and system parameters, more efficient and reliable 5G network infrastructures can be developed,

ultimately leading to improved Quality of Service (QoS) for users in urban macro-cell environments. The simulation block diagram for the research paper is illustrated below, offering a comprehensive overview and summary of the entire simulation process.

TABLE I Evolution of Mobile Network Generations with Enhanced Features and Capabilities

Generation	Dara rate	Innovations used	Major Attributes
1G (1970-1980s)	14.4 Kbps	AMPS,NMT,TACS	Basic mobility, no data, poor security
2G (1990–2000)	9.6/14.4 Kbps	TDMA,CDMA	Voice and Data services
3G (2004–2005)	3.1 Mbps	CDMA2000 (1xRTT,EVDO) UMTS And EDGE	Mobile broadband, multimedia support
4G (2010 onwords)	100–300 Mbps	High-speed internet,HD streaming, VoIP	All-IP network, low latency,enhanced multimedia
5G (2020s)	1 to 10 Gbps	IoT,automation, ultra-fastmobile broadband	Ultra-low latency, high reliability, massive connectivity

II. EXPERIMENTAL SECTION

In general, raising the BS antenna height expands the service area by enhancing line-of-sight and decreasing signal obstruction, particularly in urban settings.However, if improperly handled, it might potentially increase interference.

The simulation of 5G urban macrocell SINR uses four configuration scenarios (Configs A through D). A number of important parameters differ between these arrangements. The (BS) antenna height is fixed at 25 meters for the other configurations and varies from 10 to 100 meters in Config A. Config D use a fixed inter-site distance of 200 meters, but Config A and C utilize a variable of 200 meters, while Config B uses a wider range of 100 to 500 meters. Configs A, B, and D have a total transmit power of 44 dBm, but Config C has a range of 30 to 47 dBm. With the exception of Config D, which has a far larger frequency range of 0.9 GHz to 28 GHz, the carrier frequency is fixed at 4 GHz for all configurations. Thetransmit power $\mathrm{P_t}$ is given as:

$$\mathrm{P_t\,(dBm)} = 10\log_{10}\left(\mathrm{Power\,(W)}\right) + 30$$

Let Tx power = 25 Watt

Then $\mathrm{P_t\,(dBm)} = 10\log_{10}(25\ \mathrm{Watt}) + 30$

$\mathrm{P_t\,(dBm)}$ =44 dBm

Now the received signal power P_r at a distance d is given as:

$$\mathrm{P_r\,(dBm)} = \mathrm{P_t} + \mathrm{G_t} + \mathrm{G_r} - \mathrm{FSPL}$$

Where, $\mathbf{FSPL\,(dB)} = 20\mathbf{log_{10}}(\mathbf{d}) + 20\mathbf{log_{10}}(\mathbf{f}) - 147.55$

Let,

distance = 200m

frequency = 4Ghz= 4×10^9 Hz

transmitter gain = 0 dBi(isotropic)

receiver gain = 0 dBi(isotropic)

transmit power = 44 dBm

Then,

$$\mathrm{FSPL\,(dB)} = 20\log_{10}(200) + 20\log_{10}\left(4 \times 10^9\right) - 147.55$$

FSPL (dB) = 90.51 dB

Now $\mathrm{P_r\,(dBm)} = 44 + 0 + 0 - 90.51 = -46.51\ \mathrm{dBm}$

III. METHODOLOGY-PROPOSED PATH LOSS MODEL

A. *Free-Space Model*

A basic model for wireless communication, the Free-Space Propagation Model (FSPM) describes how electromagnetic signals move across a perfect environment devoid of obstructions, reflection, scattering, and absorption. It provides an upper bound on performance under optimal circumstances and is used as a baseline model in simulation-based investigations of wireless systems, such as 4G and 5G networks. Understanding the optimal signal behaviour and separating the effects of system characteristics like frequency, antenna height, and transmit power are the main objectives of academic research and early-stage system evaluations, where this model is most helpful.The FSPL is the reduction in power density of a signal as it propagates through free space. The log-distance formula for FSPL in decibels (dB) is:

$$\mathbf{FSPL\,(dB)} = 20\mathbf{log_{10}\,(d)} + 20\mathbf{log_{10}\,(f)} - 147.55$$

1

Alternatively, in terms of wavelength λ , the Friis Transmission Equation becomes:

$$\mathbf{FSPL\,(dB)} = 20\mathbf{log_{10}}\left(\frac{4\backslash\mathbf{varvec}\pi\,\mathbf{d}}{\backslash\mathbf{varvec}\lambda}\right)$$

2

where λ denotes wavelength of transmitted light in meters, f is the frequency in hertz, and d is the transmitter-to-receiver distance in meters.This demonstrates that FSPL rises with frequency and distance, indicating that attenuation is greater at higher frequencies (e.g., 4 GHz) than at lower ones within the same range [2].The received signal power $\mathrm{P_r}$ at a distance d is given as:

$$\mathrm{P_r\,(dBm)} = \mathrm{P_t} + \mathrm{G_t} + \mathrm{G_r} - \mathrm{FSPL}$$

3

In this case, $\mathrm{P_t}$ stands for transmit power in dBm, $\mathrm{G_t}$ for transmitter antenna gain (dBi), and $\mathrm{G_r}$for receiver antenna gain (dBi).For our simulation parameters the antenna gains are assumed to be zero (isotropic antennas) so:

$$\mathrm{P_r\,(dBm)} = \mathrm{P_t} - \mathrm{FSPL}$$

4

An essential metric in wireless communication systems for assessing a network's performance and quality is the Signal-to-Interference-plus-Noise Ratio (SINR). Interference is frequently overlooked while estimating the highest attainable SINR in the free-space model. The noise power is assumed to be main issue in this simplification. Thus, the SINR is defined as:

$$\mathrm{SINR} = \frac{\mathrm{P_s}}{\mathrm{P_i} + \mathrm{P_n}}$$

5

Here, the SINR is a logarithmic indicator of signal quality and is given in decibels (dB). Where $\mathrm{P_s}$the power of the desired signal is, $\mathrm{P_i}$ is power of the interference of the signal and $\mathrm{P_n}$ is the power of background noise. Understanding the upper bounds of network performance under optimal circumstances is made easier by this approximation, which focuses on the difference between the received signal power and the noise power. But in practice, environmental influences and other cell interference can greatly affect SINR, therefore sophisticated methods like noise reduction and interference management are needed to maximize network efficiency.

B. *Close-In Model*

One important and reliable model for analyzing large-scale signal loss in wireless channels is the Close-In (CI) Free Space Reference Distance Path Loss Model.It is especially proficient in showcasing signal performance throughout a varied frequency range, from sub-6 GHz to millimeter-wave (mmWave) bands, and has been recognized by 3GPPand IEEE for its effectiveness in modeling 5G scenarios in urban, suburban, and indoor environments. Introduced as a more straightforward option compared to the Alpha-Beta-Gamma (ABG) and floating intercept (FI) models, the CI model avoids the pitfalls of overfitting and ambiguous physical interpretation [12]. By linking the model to a specific physical reference—the free space path loss at 1 meter—it ensures both reliability and clarity in its application. The equation representing the CI model with a reference distance of d_0 meters is articulated as:

$$\mathrm{PL_{CI}\left(f,d\right)=FSPL\left(f,d_0\right)+10nlog_{10}\left(\frac{d}{d_0}\right)+X_\sigma}$$

6

Where n is the Path loss exponent, characterizing the rate of signal decay and X_σ is the Log-normal shadow fading (in dB).In contrast to the FSPL model, the CI path loss model takes into greater consideration the real-life conditions in which signals are transmitted. While the FSPL model considers conditions using the Friis transmission equation, it is based on ideal conditions like clear line of sight with no obstructions. Obstacles, multipath fading, and environmental changes are challenges neglected by the FSPL. The CI model addresses shortcomings of the FSPL model relay focuses on the distance range greater than the reference distance, typically 1 meter in our case, while also providing flexibility based on the environment through path loss exponent. Unlike CI, FSPL does not consider urban, rural suburbs, or indoors.

Alongside other innovations, CI has also built upon the foundation of shadow fading making it more effective at dealing with random signal fluctuations caused by environmental interruptions. CI however is quite effective when assuming NLOS conditions which are more frequent in everyday scenarios. In modern technology including 5G and mmWave communications which are more prone to high frequencies, CI has proven to work well as unlike other models, it maintains the dependence of frequency in its formulation[4–5].

IV. 5G NETWORK COVERAGE PLANNING

Planning for 5G network coverage involves the strategic design and installation of base stations, antennas, and associated infrastructure to guarantee optimal wireless signal reach, capacity, and quality. Unlike earlier generations, 5G presents new challenges due to its use of higher frequency bands like mmWave, smaller cell sizes, and advanced technologies such as beamforming and massive MIMO. Successful coverage planning is crucial to fully realize the advantages of 5G, consisting of massive machine-type communication (mMTC), ultra-reliable low latency communication (URLLC), and enhanced

mobile broadband (eMBB). The fundamentals of network coverage are covered in this section, along with specifics of the thorough 5G planning, such as transmitter site design and network topology.

A. Understanding Network Coverage

In the realm of wireless communication, network coverage refers to the specific geographical areas where a wireless network can connect its users. This coverage is shaped by the location and capabilities of network infrastructure, including cell towers and antennas. The quality of coverage is impacted by elements such as signal strength, frequency bands, and environmental factors. With the rise of 5G technology, achieving superior coverage is essential for enabling rapid data transfer, low latency, and uninterrupted connectivity across various environments. Wireless communication often employs a cell-based structure, where each cell corresponds to a particular geographic area served by a base station that facilitates communication with mobile devices within its range. This design allows for efficient frequency reuse, minimizes interference, and maximizes coverage. Cell sizes can vary, with smaller cells typically found in densely populated urban areas and larger cells in rural settings. This cell structure is integral to the management of network resources, ensuring smooth transitions between cells, and sustaining reliable connectivity as users move through different regions. In 5G networks, enhancements such as small cells and beamforming technology are utilized to further improve coverage and capacity.

B. Defining Network Layout

In contemporary 5G networks, particularly in densely populated urban regions with high user demand and interference, cell sites employ sectorization rather than omnidirectional antennas. Each site is segmented into three 120-degree sectors, enhancing performance through directional signal transmission, minimized interference, and frequency reuse. In a 19-site hexagonal configuration, this results in 57 sectors (19 × 3), ensuring effective coverage and smooth user transitions. Sectorization increases capacity by allowing each sector to utilize independent radio resources, accommodating more concurrent users [5]. Technologies such as massive MIMO and beamforming excel in this environment, enabling precise signal targeting for improved data rates and reduced interference. Furthermore, energy efficiency is improved, as sectors can dynamically adjust power based on traffic load, even shutting down during periods of low demand to conserve energy. Sectorization also streamlines network optimization, with adjustable parameters like antenna tilt and power per sector, ensuring robust performance in complex settings. In conclusion, a 57-sector, 19-site design is a strategic approach that optimizes coverage, capacity, efficiency, and spectral utilization, making it ideal for high-density 5G networks.

C. *Designing Transmitter Sites*

Three transmitters can be installed at each cell location. An array of antenna elements or a single antenna element can be used to create transmitters. Given the usage of higher frequency bands (millimetre-wave bands) in 5G, the incorporation of numerous antennas into one arrayis feasible, for example, an 8-by-8 rectangular array with an operating frequency of 30 GHz, according to IMT-2020 [6].

V. SIMULATION PARAMETERS

TABLE II Simulation Parameters For 5G Network Coverage And Sinr

Parameters	Value
Bandwidth	80 Mhz
BS Antenna gain	10 dBi
BS Antenna noise figure	7 dB
Receiver height	1.5m
Receiver noise figure	7dB
Receiver gain	8 dBi
No. of cell sites	19

VI. RESULTS, DISCUSSION AND PERFORMANCE ANALYSIS

To analyse the SINR (Signal-To-Interference-Noise-Ratio) iterations are made on antenna height, Inter-site distance and transmitter power by keeping the different parameters fixed for each case mentioned Table III. Recognizing that actual coverage can vary greatly depending on deployment location, this paper estimates 5G network coverage using the close in model and the free space propagation model. We have supplied the geographical latitude and longitude coordinates of the rectangle antenna that we use in our design. Bhubaneswar has been chosen as the venue. The transmitter is located at latitude 20.296059 N and longitude 85.824539 E. The different cases for the SINR simulations are depicted in Figs. 5–10. The simulation complies with the IMT 2020 standards for planning and simulating coverage in 5G networks. A comprehensive list of all simulation parameters for different configurations can be found in Table III.

TABLE III Parameter Configurations for 5G Urban Macrocell SINR Simulation Scenarios

Parameters	ConfigA	Config B	Config C	Config D
BS antenna height	10m-100m	25m	25m	25m
Inter-site distance	200m	100m-500m	200m	200m
Total transmit power	44dBm	44dBm	30dBm-47dBm	44dBm
Carrier frequency	4Ghz	4Ghz	4Ghz	0.9Ghz-28Ghz

A. *Results For Free-Space Model*

Figure 5 illustrates the SINR distribution within a 5G urban macrocell setting for antenna heights of 10 meters (left) and 100 meters (right), maintaining a consistent inter-site distance of 200 meters. At a height of 10 meters, the signal coverage is more concentrated, leading to higher SINR and reduced interference due to limited propagation and minimal overlap with adjacent cells [10]. However, this can result in coverage gaps in densely populated urban areas. Conversely, the 100-meter antenna height offers broader coverage but also increases inter-cell interference, which reduces the overall SINR. This comparison underscores the balance between signal quality and coverage when selecting antenna heights.

Figure 6 depicts a comparison of SINR distributions for two distinct inter-site distances (ISD) within a 5G urban macrocell setting, maintaining a constant base station antenna height of 25 meters. The left map depicts an ISD of 500 meters, while the right map illustrates an ISD of 100 meters. In the scenario with a 500 m ISD (left), coverage is less comprehensive, and SINR performance is diminished, particularly in outer regions such as Jayadev Vihar, due to the greater distance between base stations. As a result, signal strength is weaker, leading to potential performance issues for users located at the periphery. Conversely, the 100 m ISD scenario (right) reveals a marked enhancement in SINR across the area, including Jayadev Vihar, attributed to the closer placement of base stations.

Figure 7 illustrate the effects of different transmit power levels in a 5G urban macrocell setting. The left image corresponds to a transmit power of 30 dBm, while the right image reflects a power level of 47 dBm, with all other parameters remaining unchanged. It is apparent that a higher transmit power significantly improves both signal quality and coverage area, as evidenced by the more extensive high SINR regions in the right image. In this scenario increasing the transmitter power might also increase interference to neighbouring cells, but this is often outweighed by the strong signal. The design of the SINR map, characterized by hexagonal patterns from the cell layout, will remain unchanged, but the colour gradients that reflect SINR values will be adjusted.

B. *Result For Close-In Model*

Figure 8 illustrate the SINR distribution according to the Close-In model for antenna heights of 10 meters (left) and 100 meters (right). At 10 meters, the SINR is higher because of less interference and more concentrated coverage. However, at 100 meters, the wider coverage results in greater inter-cell interference, leading to a lower overall SINR across the region. Thus, by comparing the free space model and close in model we can clearly depicts that the coverage gaps are reduced in the SINR map and the SINR values are reduced due to large interference.

Figure 9 presents a comparison of SINR distributions for two different inter-site distances (ISD) in a close-in model, with the base station antenna consistently set at a height of 25 meters. The map on the left shows an ISD of 100 meters, whereas the map on the right displays an ISD of 500 meters. These maps suggest a similar analysis, indicating that coverage gaps are minimized compared to the free space model.

Figure 10 is expected to undergo a similar analysis. Therefore, from the comparison above, we can confirm that the close-in model enhances coverage gaps, although it does so by diminishing signal strength and other parameters.

C. *Result of Signal Strength for Free-space and Close-In Models*

Table IV illustrate, the received signal strength (RSS) in dBm is displayed for various transmit power levels, contrasting the Free-Space and Close-In propagation models in Bhubaneswar. As the transmit power rises from 1W to 50W, both models demonstrate an increase in RSS, signifying stronger signals. The Free-Space model consistently provides higher RSS values compared to the Close-In model, which is due to its idealized assumptions that minimize environmental losses [11]. On the other hand, the Close-In model takes into account real-world urban barriers, resulting in greater path loss and diminished signal strength. For example, at a transmit power of 1W, the Free-Space model shows an RSS of -74.39 dBm, whereas the Close-In model reflects a lower − 90.76 dBm. Even at 50W, the Close-In model's RSS of -73.46 dBm is still less than the Free-Space model's -57.41 dBm. This indicates that the Free-Space model may overestimate signal strength, while the Close-In model provides a more realistic view of signal degradation in urban environments such as Bhubaneswar.

TABLE IIIV Received Signal Strength (in dBm) vs Tx Power using Free Space and Close-In Models in Bhubaneswar

Power (Watt)	Free-Space (dBm)	Close-In(dBm)
1	-74.3973132323568	-90.7571545084454
5	-67.4076131889966	-83.5292681390751
10	-64.3973132323568	-80.5990250137152
20	-61.387013275717	-77.6838635506857
50	-57.4076131889966	-73.4620595914008

Table IV demonstrates that in the urban setting of Bhubaneswar, increasing the height of antennas enhances signal strength, though the extent of improvement varies across different models. The free space model forecasts stronger signals, reaching − 58 dBm at a height of 10 meters. In contrast, the more realistic close-in model indicates weaker reception at -74 dBm at the same height, with smaller enhancements due to urban obstructions. The disparity between the models underscores the impact of Bhubaneswar's buildings and vegetation on signal degradation, emphasizing the importance of raising tower heights to 10–100 meters to counteract real-world path loss.

TABLE V Received Signal Strength (in dBm) vs Antenna Height using Free Space and Close-In Models in Bhubaneswar

Antenna Height (m)	Free-Space (dBm)	Close-In(dBm)
10	-58.1914977032885	-74.1145716954686
25	-58.1924812209569	-74.1526033111467
40	-58.1943076595538	-74.5491439742817
55	-58.1969759560513	-74.4373383560491
100	-58.2100140600042	-74.9830746535056

Table V demonstratesthat higher frequencies exhibit a more drastic reduction in signal strength in real-world applications than theoretical models suggest for free space. The sub-6GHz bands (700MHz-3.5GHz) ensure better coverage, while mmWave frequencies (24GHz and above) encounter severe losses, limiting their feasibility for widespread deployment. In urban areas, signal strength decreases by 25-30dB per decade in close-in models, in contrast to a 20dB decrease in free space, with the performance gap increasing at higher frequencies.

TABLE VI Received Signal Strength (in dBm) vs Carrier Frequency using Free Space and Close-In Models in Bhubaneswar

Carrier Frequency (Ghz)	Free-Space (dBm)	Close-In(dBm)
0.9	-52.1723965050871	-61.1073046095007
1.8	-58.1929964183668	-75.6132366801209
3.5	-63.9689072033061	-97.5137072126748
26	-81.387013275717	-329.708468687703
28	-82.030706943145	-349.605752587733

VII. ANALYSIS OF CHALLENGES

The Free Space Model is based on the premise of a direct line-of-sight (LOS) and the absence of obstacles, which makes it ideal for open spaces but problematic in urban environments. It often overestimates coverage since it overlooks the effects of reflection, diffraction, and scattering. In non-line-of-sight (NLOS) conditions, it predicts unrealistically high SINR values. Furthermore, it fails to consider shadowing and multipath phenomena that are significant in city landscapes, resulting in inaccuracies for scenarios involving street canyons, indoor users, or areas with obstructions.

The Close-In model enhances realism by using a reference distance but has limitations: it's a single-parameter model that may oversimplify multi-slope urban path loss [14]. Accurate performance requires careful tuning of the path loss exponent (PLE) for specific environments (urban macro/micro, indoor).

Additionally, it doesn't model fast fading and must be combined with stochastic models for complete channel characterization.

Urban SINR modelling presents significant challenges due to factors like multipath fading from closely packed infrastructure, shadowing effects, frequent non-line-of-sight (NLOS) scenarios, fluctuating interference patterns, and channel variations driven by mobility. To achieve accurate predictions in cities like Bhubaneswar, it is crucial to have detailed 3D antenna characteristics and extensive geospatial information, which are often not readily available. Consequently, advanced modelling strategies that include real-world calibration are required [15].

VIII. CONCLUSIONS AND FUTURE WORK

This research illustrates the impact of antenna height, inter-site distance (ISD), transmission power, and propagation models on SINR and signal strength in 5G urban macrocells. Antennas positioned at lower heights (10 m) yield higher SINR but can lead to coverage gaps, whereas taller antennas (100 m) extend coverage but introduce more interference. Shorter ISDs (100 m) help reduce coverage gaps, facilitating dense urban deployment. The RSS analysis indicates that the Free-Space model tends to overestimate signal strength, while the Close-In model provides more accurate results for environments such as Bhubaneswar. These results underscore the importance of optimized deployment strategies and realistic modelling to achieve a balance between coverage and performance in urban 5G networks.

Abbreviations

MIMO
Multiple–input–Multiple–output
SINR
Signal to Interference Noise Ratio
FSPL
Free space path loss
CI
Close–in model
LOS
Line of sight
NLOS
Non–line of sight
RSS
Received Signal Strength
QOS
Quality of Service
5G
5th Generation

ABG
Alpha–Beta–Gamma
MMTC
Massive machine type communication
URLLC
Ultra–reliable low latency communication
EMBB
Enhanced mobile broadband

Declarations

- Availability of data and material

“Not Applicable”

- Competing interests

“The authors declare that they have no competing interests"

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- Authors' contributions

"1st Author analyzed and done whole literature review. 2nd and 3rd was a major contributor in carrying out the work and writing the manuscript. All authors read and approved the final manuscript."

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Figures

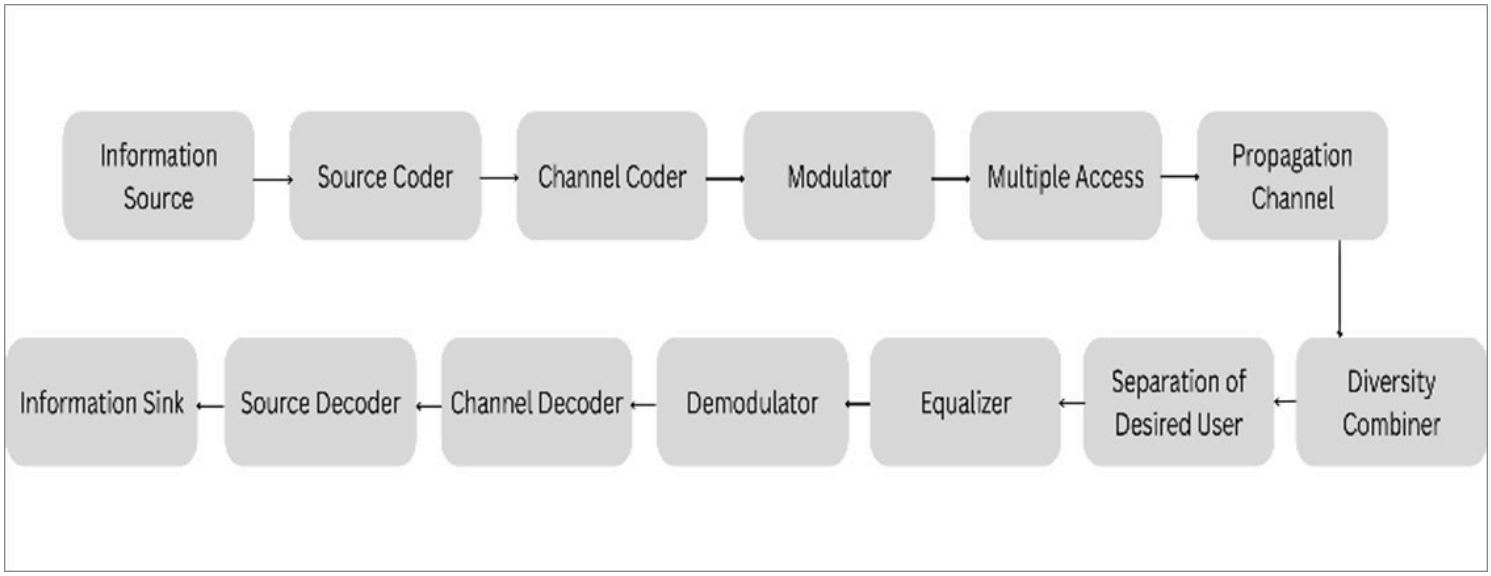


Figure 1

Simulation block diagram of the proposed communication system.

The figure illustrates whole digital communication system, emphasizing the digital information transmission and reception process. The information source, which creates the message to be conveyed, comes first. This data is compressed by the source coder, and redundancy is added for error correction by the channel coder. After the modulator transforms the digital signal into a transmittable format, the channel is shared via multiple access mechanisms. After that, the signal travels along the propagation channel. Separating the intended user isolates the signal, whereas diversity combining increases signal dependability at the receiver. The demodulator recovers the baseband signal while the equalization reduces channel distortions. The source decoder reconstructs the original message for delivery to the information sink, whereas the channel decoder fixes mistakes. This framework guarantees accurate and effective digital communication.

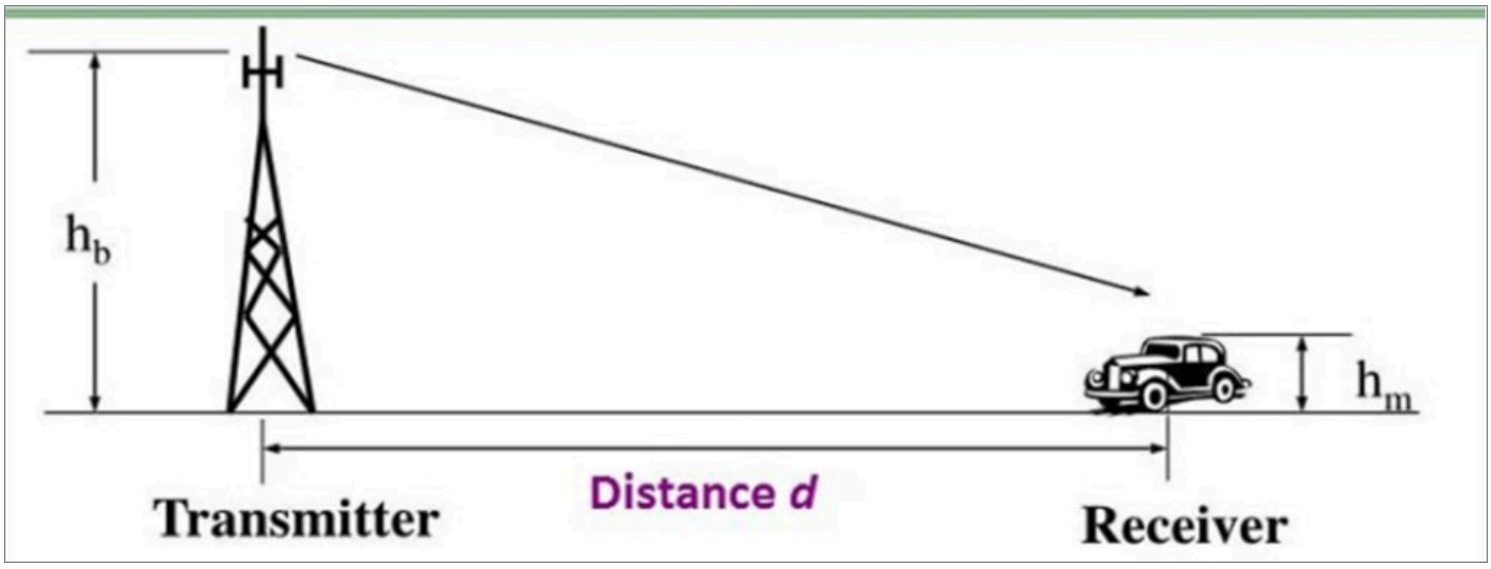


Figure 2

Free-space model with line-of-sight path over distance d between transmitter and receiver.

A simple line-of-sight (LOS) communication situation that is frequently employed in wireless communication models is depicted in the figure. It displays a receiver (like a moving car) on the right at a height hm and a transmitter (like a base station or cell tower) on the left, raised at a height hb. The direct path of signal propagation is shown by the straight line connecting the transmitter and receiver. The symbol "d" represents the horizontal distance between the transmitter and receiver. Path loss models, such as the free-space propagation model or the two-ray ground reflection model, frequently use this configuration to examine how signals behave over long distances in open spaces.

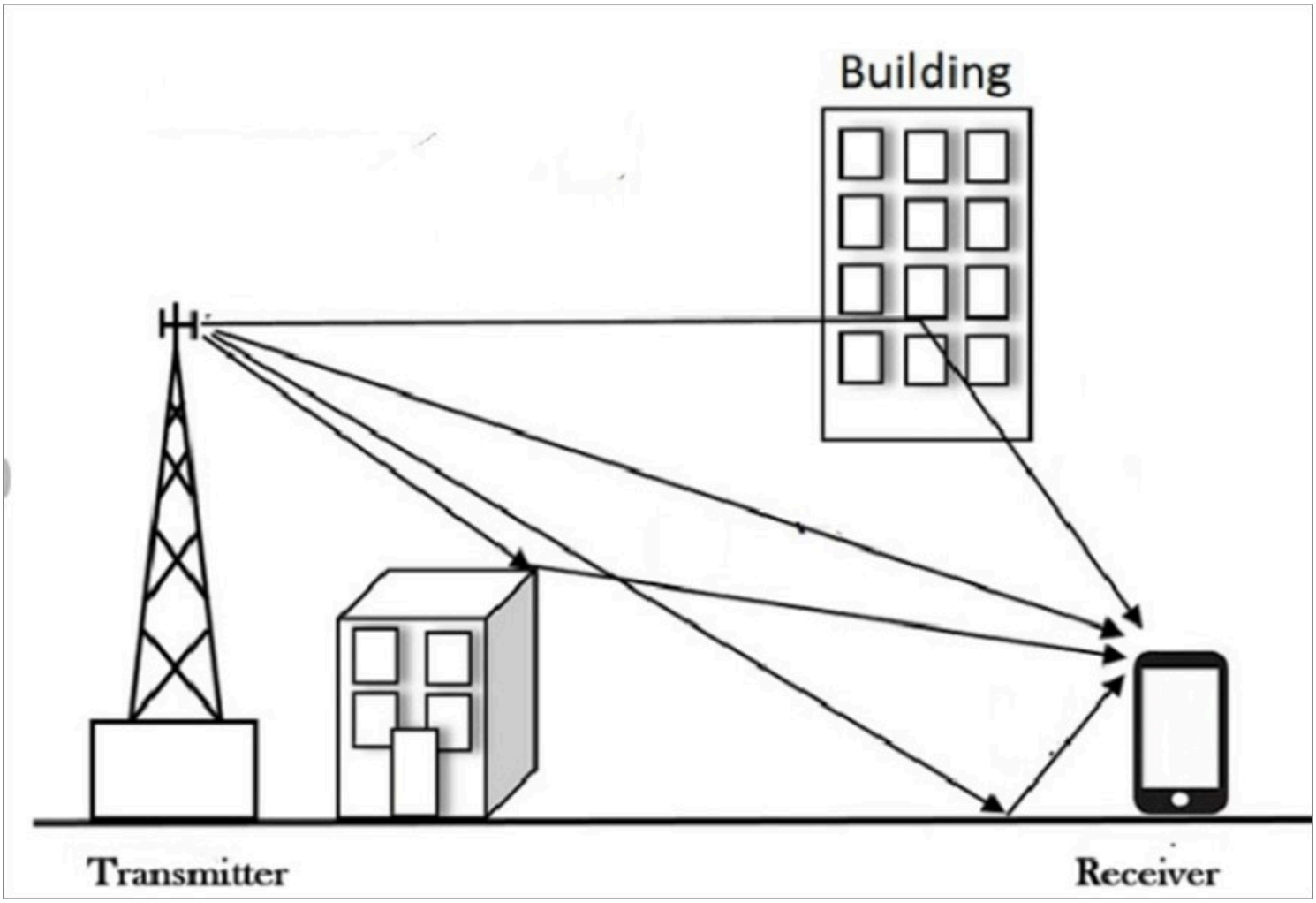


Figure 3

Close-in model showing signal reflections and diffractions between transmitter and receiver

Signal transmission in urban settings with obstructions like buildings is shown by the close-in propagation model. Multipath propagation results from the reflection, diffraction, and scattering of signals. Compared to free-space models, this model more accurately estimates route loss by taking into consideration obstacles between the transmitter and receiver, particularly in urban and mobile settings.

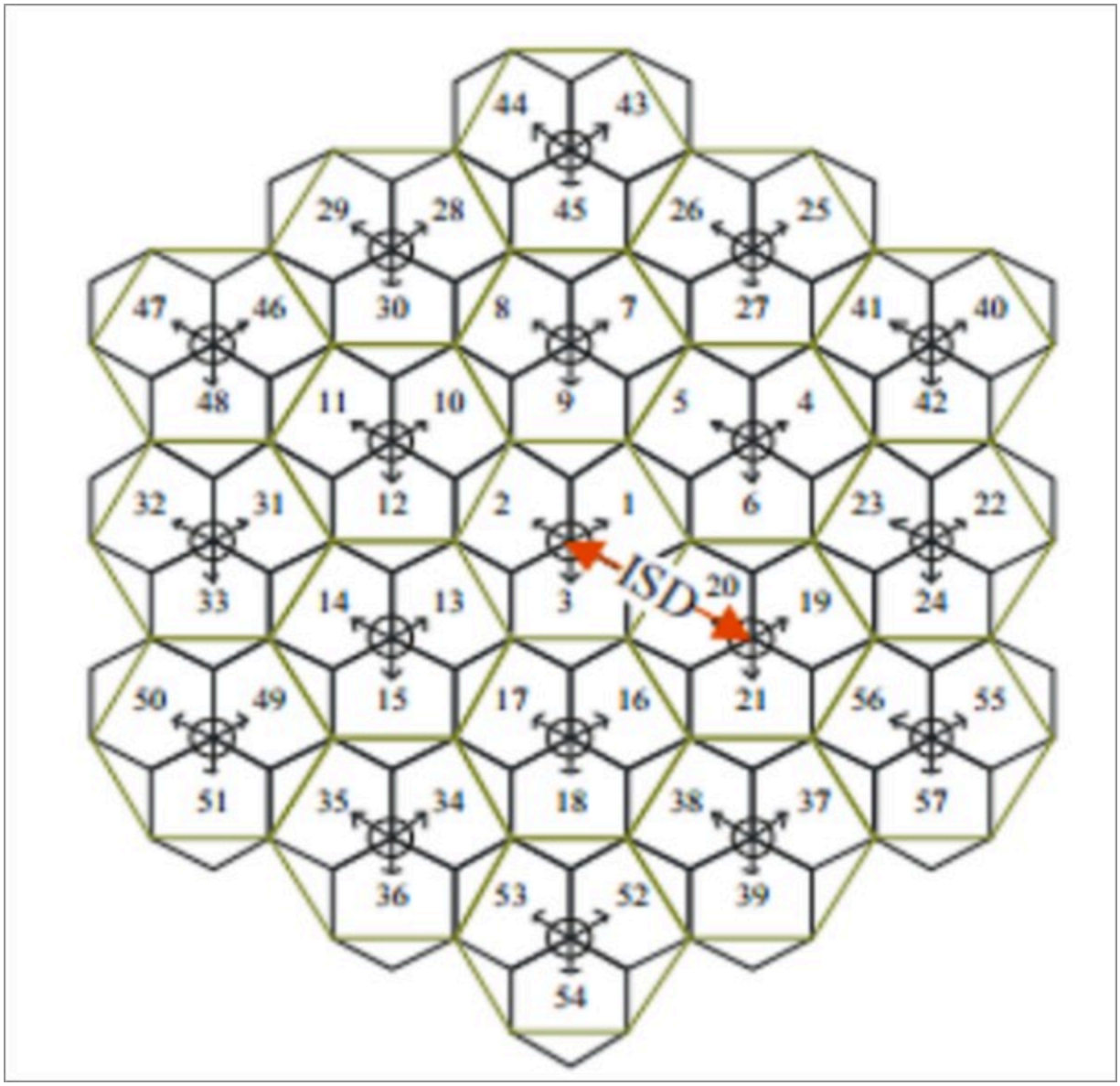


Figure 4

Hexagonal Cellular Network Layout with Inter-Site Distance (ISD).

A multi-cell hexagonal cellular network structure, which is frequently used to simulate wireless communication situations, is depicted in this figure. The Inter-Site Distance (ISD) shows the distance between adjacent base stations, and each hexagon represents a cell that a base station serves.



Figure 5

Configuration A-SINR Map Comparison for Different Antenna Heights (ISD=200m).

SINR distributions at antenna heights of 10 m (left) and 100 m (right) with a fixed inter-site distance of 200 m are shown in this picture. Taller antennas offer greater coverage but increase inter-cell interference, which lowers total SINR. In contrast, lower antennas produce better SINR and less interference.

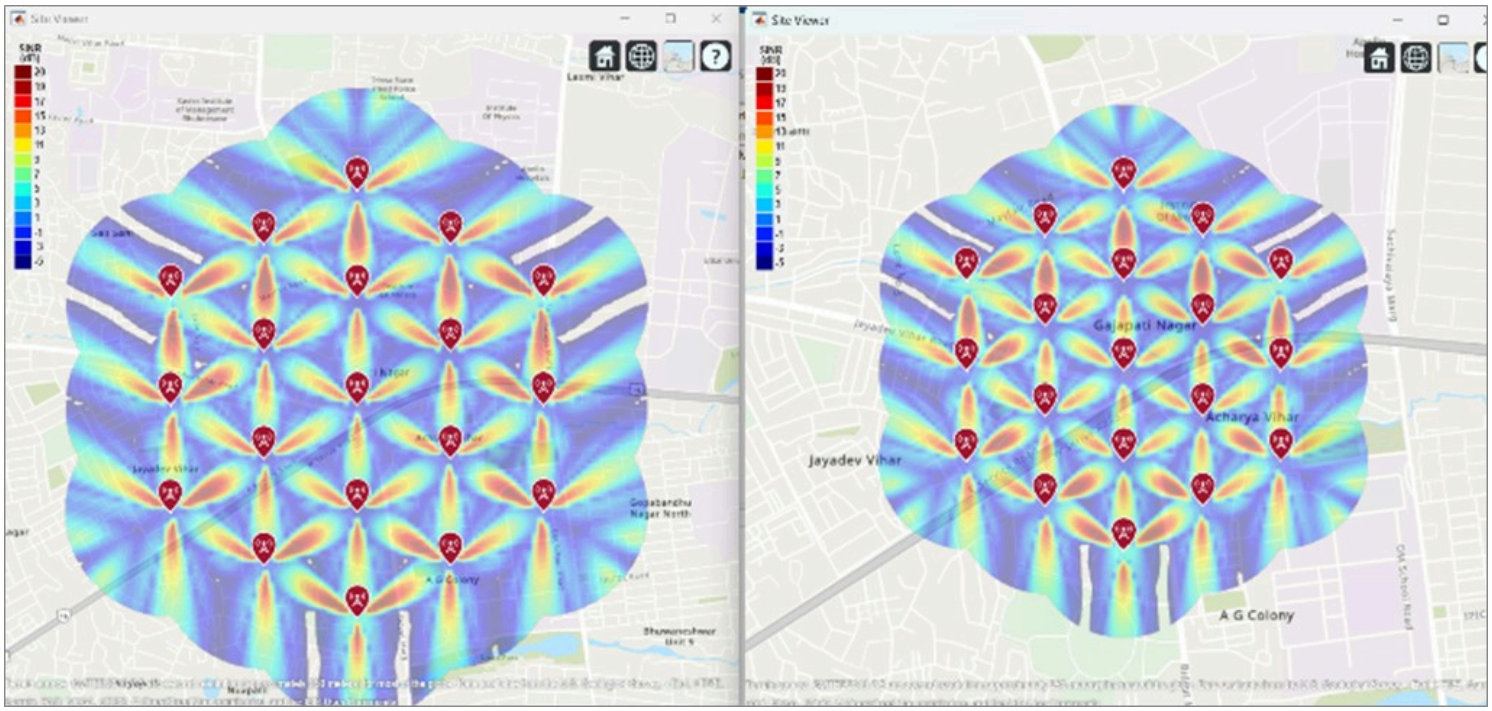


Figure 6

Configuration B-SINR Map Comparison for Different Inter-site distance (BS Antenna height=25m).

SINR distributions for ISDs of 500 m and 100 m in a 5G urban macrocell configuration with a 25 m antenna height are contrasted in the figure. Due to denser base station deployment, the 100 m ISD offers noticeably better SINR than the 500 m ISD, which exhibits poorer coverage and SINR, particularly near edges.

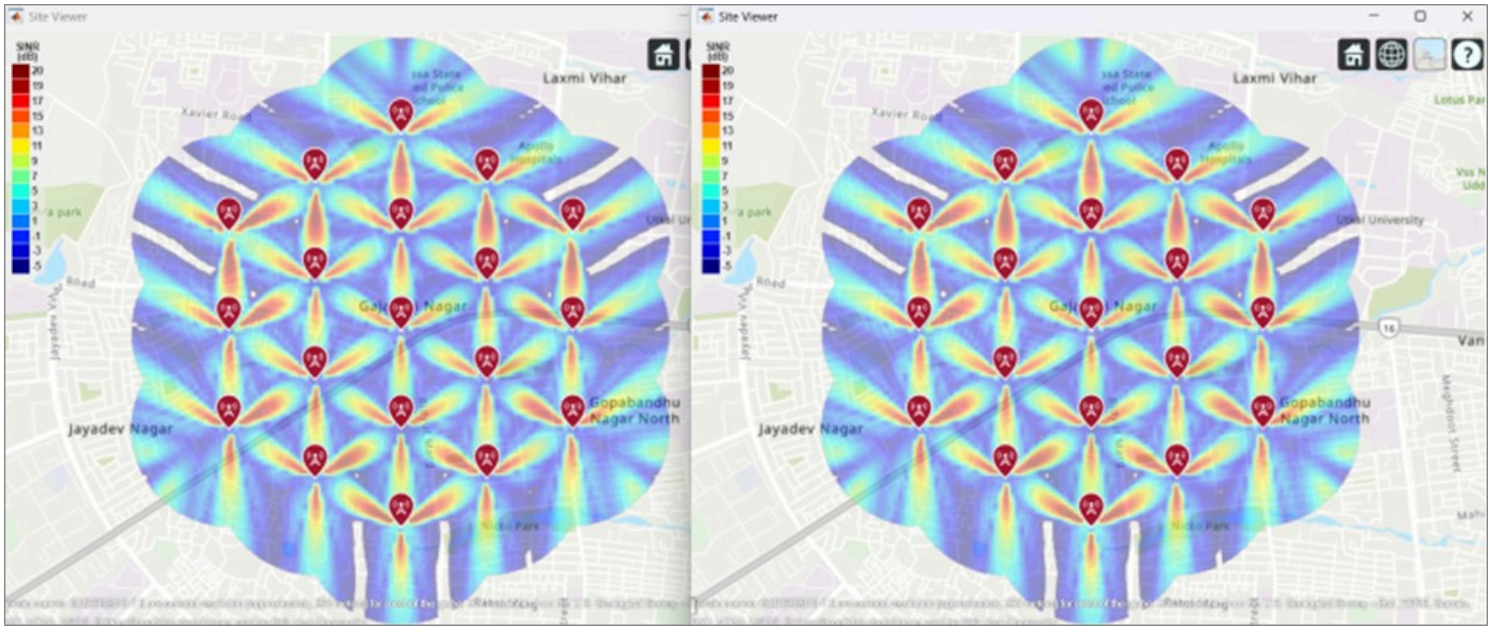


Figure 7

Configuration C-SINR Map Comparison for Different transmitter power.

SINR distributions for transmit powers of 30 dBm (left) and 47 dBm (right), with constant parameters, are displayed in this figure. High SINR regions are increased by higher transmit power, which also improves signal quality and coverage. The stronger signal usually improves overall performance without changing the hexagonal layout pattern, even if interference may increase.



Figure 8

Configuration A- SINR Map Comparison for Different antenna height (ISD=200m) for Close-In model.

Based on the Close-In path loss model, SINR distributions for antenna heights of 10 and 100 meters are shown in this image. Higher antenna height increases coverage but decreases SINR because of more inter-cell interference, whereas lower antenna height results in higher SINR because of less interference. The Close-In model has less coverage gaps than the Free Space model, but because of greater interference, the SINR levels are also lower.



Figure 9

Configuration B- SINR Map Comparison for Different Inter-site distance (BS Antenna height=25m) for Close-In model.

With a fixed antenna height of 25 m, this figure contrasts SINR distributions for inter-site distances of 100 m and 500 m under the Close-In model. While SINR effectiveness still varies with ISD, the results demonstrate fewer coverage gaps as compared to the Free Space model.

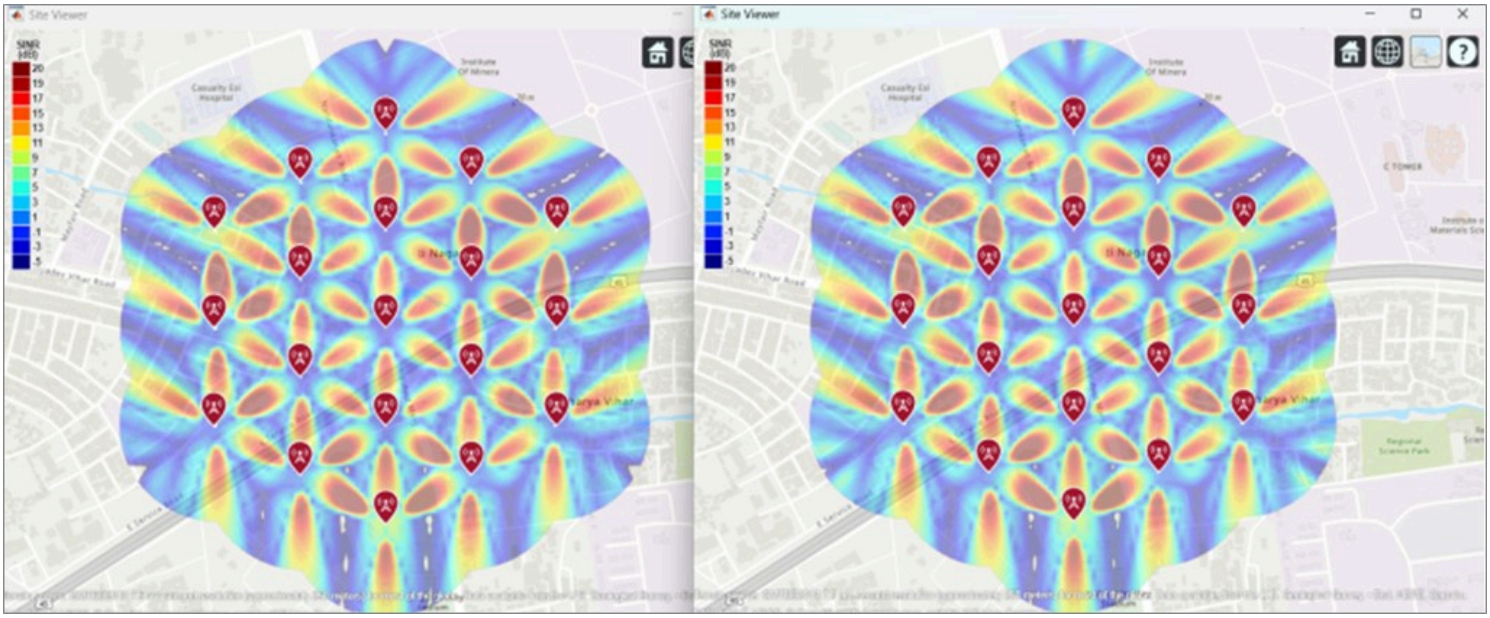


Figure 10

Configuration C- SINR Map Comparison for Different transmitter power for Close-In model.

This figure is anticipated to go through a comparable analysis. Thus, it is evident from the comparison above that the close-in model increases coverage gaps, albeit by reducing signal strength and other factors.