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5G MMWave Network Performance Evaluation with Blockage Simulation

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Abstract: The fifth-generation (5G) technology is to support more wireless connections for a wider range of applications. The new characteristics employed in 5G wireless access networks, such as the millimeter wave (mmWave) network, make this activity possible. The mmWave network enables the transmission of enormous amounts of data in a shorter amount of time. 5G technology is expected to be the new infrastructure for wireless networks. Nevertheless, the mmWave frequency band cannot withstand interference or obstruction. Due to environment of no line of sight (NLOS), high-frequency wave energy is quickly lost in humid air and does not pass-through objects like trees, buildings, or people. As a result, in this study, the effectiveness of mmWave was assessed in an urban micro area (UMi) by taking into account the impact of the NLOS environment brought on by obstructions from objects like structures, trees, or people. The SINR as a measure for the network channel quality was evaluated through a series of simulations. The simulation results confirm that the SINR values were affected by blockages. Blockages such as trees, buildings, or humans had a significant impact to reduce the SINR (Signal Interference plus Noise Ratio) value, hence decrease signal quality.

Keywords: 5G, millimeter wave, performance evaluation, blockage, ns-3, SINR

1. Introduction

The human need for cellular communication continues to grow. Starting with the 1G system, the data rate continues to increase up to several Gbps in the 4G system. The 5th generation (5G) technology is expected to provide a bandwidth of more than 50Gbps [1)]. The next focus for ubiquitous smart-devices and diverse applications in 5G networks will be on immense prospects for optimization and efficiency gains. [26)].

The 5G technology is intended to accommodate a greater number of wireless connections for better support various applications such as cloud based application, and e-learning [18), 19)]. This action can be applied because of the new features used in 5G wireless access networks, such as the millimeter wave (mmWave) network [1), 5)]. These waves that are also known as Extremely High Frequencies are in the 30 GHz and 300 GHz spectrum bands.

The mmwave propagation is heavily affected by line of sight blockage although microwave systems (sub-6Ghz) are not much impacted by those things [10)]. This blockage can be produced by human physicals, buildings, trees, raindrops, or vehicles [2), 3), 4), 20), 25)]. Shadow losses caused by blockage need to be taken into account for accurate analysis [10)].

In combined, indoor and outdoor environments, such as commercial buildings with a pedestrian, the possibility of blockage by the human physical building, or tree is higher because BS (Base Station) antennas cannot be installed in high places because they must cover both indoor and outdoor areas [12)]. In addition, the user equipment (UE) movement path and the density of people in the crowd affect the likelihood of blockage dynamically in such an environment. [11)]. There is more signal interference and worse throughput when NLOS (No Line Of Sight) is more likely to occur [13)]. Therefore, quality of service control (QoS) is required to maintain the level of communication by taking into account the external environmental conditions, particularly the placement of the impediments.

To address this situation, the mmWave performance in urban micro (UMi) environment was evaluated.

This paper evaluated the impact on SINR of obstructions such as buildings, trees, and the human physical. To simulated real-life situations, It was UMi situation. In the circumstance known as UMi (Street canyon, open area), the BSs are positioned below the rooftop levels of the nearby structures. The UMi open area is meant to represent actual settings, such a city or a train station plaza. The average open area is between 50 and 100 meters wide.[6)].

The evaluation was constructed as follows:

1) Human-physical obstruction simulation
2) Human- physical and tree obstruction simulation
3) Human- physical and building blockage simulation
4) Changing of BS Antenna height

In section II, the research from other papers that were used in this study will be explained. The simulation scenario was explained in section III. In section IV, the simulation setup was explained. In Section V, the results and analysis of this article were discussed. Section VI concludes the paper.

2. Related works

TR 38.901 provides information on 3GPP modeling of the physical layer of both mobile equipment and the access network.[6)]. It captures the channel model(s) at frequencies ranging from 0.5 GHz to 100GHz. For the purpose of simulating signal transmission in various contexts, it outlines four cases with distinct values for the randomized distributions underlay the channel. [2), 6)]:

- RMa (Rural Macro), which focuses on rural deployments with continuous coverage across a vast area.
- UMa (Urban Macro) is designed to represent urban environments using macrocells positioned above the neighboring buildings' rooftops.
- UMi (Urban Micro) Street Canyon, designed to simulate real-world environments like a city or station square. The normal width of an open area is between 50 and 100 meters, and the BSs are positioned below the roof levels of surrounding structures..
- Interior Hotspot (InH) is designed to encompass a variety of indoor deployment scenarios, such as office spaces and shopping malls. The usual office setting consists of open cubicle areas, enclosed offices, open areas, corridors, and so forth. The BSs are fixed on the ceilings or walls at a height of 1-2 m. Typical retail malls range in height from one to five stories and may feature an open space (or "atrium") shared by many floors. The BSs are fixed on the walls or ceilings of the corridors and stores at a height of roughly 3 meters.

In [2)], the ChannelCondition class was created, which contains state information pertaining to a specific channel. To accommodate the channel condition models outlined in 3GPP TR 38.901, five distinct categories were constructed,i.e., ThreeGppRmaChannelConditionModel, ThreeGppUmaChannelConditionModel, ThreeGppUmi-StreetCanyonChannelConditionModel, ThreeGppIndoor-OpenOfficeChannelConditionModel and ThreeGpp-IndoorMixedOfficeChannelConditionModel, each addressing a distinct scenario. All of the new categories inherit from the ThreeGppChannelConditionModel base class, which expands the ChannelConditionModel interface and offers caching capabilities for the regular update of state values.

To incorporate the path loss and shading model defined in 3GPP TR 38.901, in [2)] ThreeGppRmaPropagation-LossModel, ThreeGppUma-PropagationLossModel, ThreeGppUmaStreetCanyon-PropagationLossModel, and ThreeGppIndoorOffice-PropagationLossModel, which specify the models for the various channel instances, were developed. As the transmission loss is dependent on the LOS/NLOS channel state, the ThreeGppPropagation-LossModel interface is linked with a channel condition model.

In earlier research, the impact of the LoS blockage is studied by establishing that the blocked condition lasts between 400 and 1000 milliseconds for typical input parameters. [3)].

The NYUSIM channel model was expanded to include geographical consistency, human obstruction, and O2I (Outside to Inside) transmission loss. The multiple reflection surfaces method was employed to update the spatial consistency procedure's small-scale parameters. A parabola model for O2I transmission loss was constructed, which will be relevant for the forthcoming expanded model. On the basis of the user-specified UT trajectory, [10)].

The prior study [7) 13)] describes the characteristics of human physical obstruction at an indoor railway station. Signal-to-noise ratio and throughputs in 5G are greatly affected by the transmission losses resulting from human obstructions in addition to the distance of the user equipment to the base station. In [15), 16), 17)] the author showed that with increasing length, density, and size of the blockers, latency increases significantly. Authors in [21)] provide a new method to compute estimates of line-of-sight (LOS)/non-LOS (NLOS) maps. The effect of rainfall rate upon this SINR was examined. Medium rain decreases the performance of the mmWave band and the combined mechanism by approximately 20% compared to the no-rain scenario. Approximately 41% of performance is diminished with the severe rainfall [23)].

The authors in [7)] provide measurements of human blockage in an anechoic chamber at 15, 28, and 60 GHz using 15 people of various sizes and weights. Concerning the radio link, the results indicated that the losses are proportional to the human physical cross-section.. In addition, the blockage loss diminishes as the transmitting antenna rises in height.

The authors of [22)] construct a model to estimate the LoS probability for the BS-to-UAV link working within mmWave network in 3D normal urban network deployments. In the meantime, the authors of [24)] develop a novel sum of Markov chains (MC) to describe blockage in mmwave vehicle-to-infrastructure (V2I) communications.

3GPP considers people and vehicles to be one of the most significant impediments to mmWave propagation, and the blockage model was included in their technical report. [6), 12)].

3. Simulation setup

3.1 Simulation Parameters

Table 1. Simulation parameters

Parameter		Value	
Antenna type		Isotropic: an antenna that radiates equal signal power in all directions	
BS antenna height		10m and 5m	
BS position (x,y,z)		(0,20,10)	
Number of BS		1	
UE location	Outdoor/indoor	Outdoor and indoor	
	LOS/NLOS	LOS and NLOS	
	Height	1 m	
	Position (x,y,z)	(-5,60,1), (5,60,1), (1,20,1)	
Number of humans		250, 500, 1000	
Building position		(Box (-20.0, 0.0, 20.0, 100.0, 0.0, 30.0))	
Trees position (x,y,z)		(2.5, 10, 4) (2.5, 20, 4) (2.5, 30, 4) (2.5, 40, 4) (2.5, 50, 4)	(20, 10, 4) (20, 20, 4) (20, 30, 4) (20, 40, 4) (20, 50, 4)

3.2 NS-3 Parameters

To support the uMI scenario, the ns-3 coding below is used:

1) Pathloss Model: Define the signal attenuation between a transmitting and receiving antenna in terms of propagation distance and other parameters.
   Config::SetDefault ("ns3::MmWaveHelper:: PathlossModel", StringValue ("ns3:: ThreeGpp-UmiStreetCanyonPropagationLossModel"));
   2) Channel Model: predict the behavior of radio signal transmission for all similar channels subject to the same barriers (environment, channel fading, multi-path, etc). Config::SetDefault ("ns3::ThreeGpp-ChannelModel::Scenario", StringValue ("UMi-StreetCanyon"));
3) Enable Blockage: enable blockage model in the simulation.
   Config::SetDefault ("ns3:: ThreeGppChannelModel:: Blockage", BooleanValue (true));
4) Blockage Model: Portrait. In this simulation, the portrait model was used to represent humans.
   Config::SetDefault ("ns3:: ThreeGppChannelModel:: PortraitMode", BooleanValue (true));
5) Number of Blockages: total number of blockages. In this simulation, this value was used to represent density patterns.
   Config::SetDefault ("ns3:: ThreeGppChannelModel:: NumNonselfBlocking", IntegerValue (250));
6) Blocker Speed: velocity of blockage.
   Config::SetDefault ("ns3:: ThreeGppChannelModel:: BlockerSpeed", DoubleValue (1));
7) Antenna Model=Isotropic: an antenna that having the same radiation in all directions.
   Config::SetDefault ("ns3:: ThreeGppAntennaArray-Model::IsotropicElements", BooleanValue (true));
8) Building object (width: 20m, length: 80 m, height: 30m).
   building1->SetBoundaries (Box (-20.0, 0.0,
   20.0, 100.0,
   0.0, 30.0));
   building1->SetBuildingType (Building::Commercial);
   building1->SetExtWallsType (Building::ConcreteWithWindows);
9) Tree object: building object was used to mimic tree object. (width 0.5m, length:0.5m, height:4m).
   building2->SetBoundaries (Box (2.5, 3.0,
   10.0, 10.5,
   0.0, 4.0));
   building2->SetExtWallsType (Building::Wood);

3.3 Data Analysis Tools

Panda and matplotlib modules in Python were used to generate a graph from simulation results.

4. Simulation scenarios

An important factor affecting mmWave performance is LoS (Line Of Sight). It is because of the sensitivity of mmWave to obstacles such as human bodies, trees, and buildings. This research used the uMi (Urban Micro) - Street Canyon scenario to simulate the performance of 5G mmWave. Based on the Technical Report in paper[6)], uMi has the following parameters:

In this paper, the Urban Micro scenario includes a commercial building and pedestrian area with 100 m in length and 50 m in width. The street is 100 m long, has a width of approximately 10 m, and is bordered by a 15-floor commercial building. The Radio Base Station was placed under the rooftop at 10 m in height. The UE was placed at a height of 1m and moved along across the street, following the street and walk into the commercial building with constant speeds of 1 m/s. The simulation was evaluated under several conditions such as the speed of UE, the number of humans (lowly, medium, and high density), and UE walking direction.

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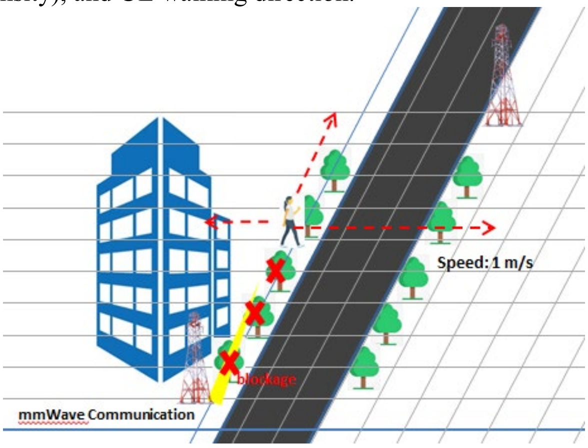


Fig.1 Micro Urban Area Scenario that used in the simulation

Three distinct population density patterns (lowly, medium, and high density) were utilized. At every sequence, there were 250 people (lowly-density: 0.005 people/m2), 500 people (medium-density: 0.1 people/m2), and 1000 people (high-density: 0.2 people/m2). The crowd moves at a steady speed of 1 m/s throughout the outdoor and indoor areas. The assumption was made that the UE moves along a fixed path, just like depicted by the red line in Figure 1. In the simulation, the UE moves at 1 m/s along the x- or y-axis. Changing speed was deployed in one of the simulations to see the effect of higher speed against signal interference.

Performance of 5G mmWave was evaluated in urban micro environment under the following conditions:

1) Human-physical obstruction. This step involved simulating the characteristics of human-physical obstruction by altering the population size.
2) Human-physical and trees blockage. Changing the number of people simulated the human- physical and tree blockage characteristics in an indoor-to-outdoor (I2O) transition.
3) Human- physical and building blockage. Changing the number of people simulated the human-physical and building blockage characteristics in an outdoor-to-indoor (O2I) transition.
4) Changing BS antenna height. In this step, human-physical and building blockage characteristics were modeled by reducing the antenna height from 10 m to 5 m and varying the number of people.

The output of the ns-3 simulation with the mmwave module was then used to evaluate SINR values. Python was used to generate the graph of simulation results.

5. Results and analysis

The impact of UE movement, density patterns, and obstructions on the SINR value was simulated in this section.

5.1. Simulation results

5.1.1 Scenario A. Human-physical blockage

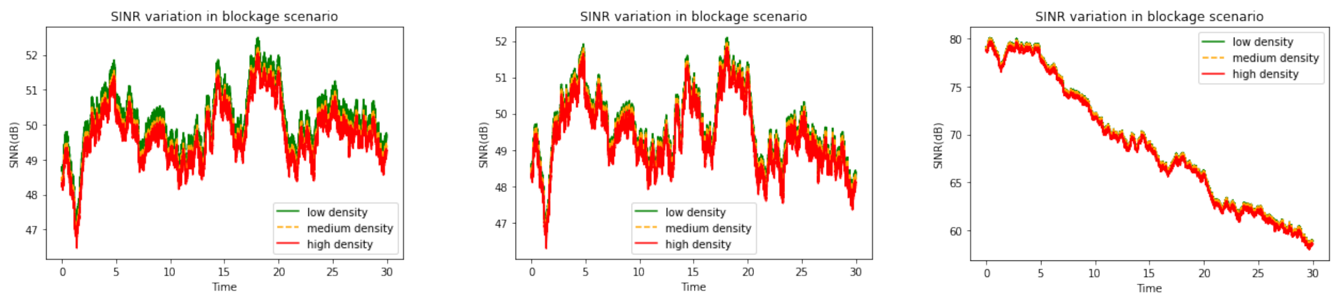
To evaluate the SINR value in this scenario, the human physical blockage was simulated by varying the number of people in three distinct density patterns (lowly, medium, and high). The BS antenna height was 10m.

This scenario was divided into the following experiments:

1) One BS located at (0,20,10) and one UE located at (-5,60,1) cross the street at a speed of 1 m/s in the x-axis. Figure 2 (a) depicts the SINR result.
2) One BS located at (0,20,10), and one UE located at (-5,60,1) walks across the street at a speed of 1.2 m/s. in the x-axis. Figure 2(b) depicts the SINR result.
3) One BS located at (0,20,10), and one UE located at (1,20,1) walks away from the BS at a speed of 1 m/s. in the y- axis. Figure 2(c) depicts the SINR result.

Table 2. Simulation parameters for scenario A

Parameter	Value
UE Position	(-5,60,1) and (1,20,1)
UE Height	1 m
UE Speed	1.0 m/s and 1.2 m/s
UE Speed Direction	(1,0,0) and (0,1,0)
BS Position	(0,20,10)
Antenna Height	10 m
Blocker Speed	1.0 m/s



(a) (b) (c)

Fig. 2 Results of SINR characteristics in simulation with human- physical blockage, with 10m BS antenna height, 1 BS and 1 UE that walks following x- and y-axis

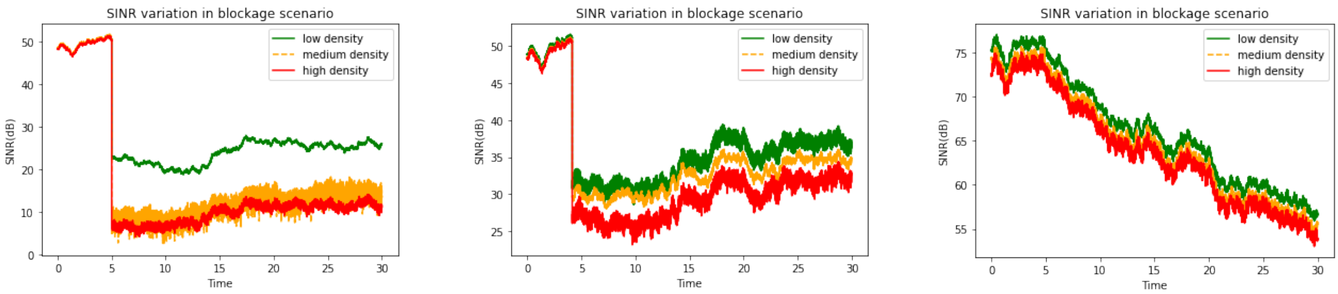
5.1.2 Scenario B. Human- physical and tree blockage

To evaluate SINR value, this scenario simulates human physical and tree blockage by varying the number of people in three distinct density patterns (lowly, medium, high). The BS antenna height was 10m. This scenario is divided into the following experiments:

1) There is one BS located at (0,20,10), and one UE located at (-5,60,1) cross the street at a speed of 1 m/s in the x-axis. Figure 3(a) depicts the SINR result.
2) There is one BS located at (0,20,10), and one UE located at (-5,60,1) walks across the street at a speed of 1.2 m/s in the x-axis. Figure 3(b) depicts the SINR result.
3) There is one BS located at (0,20,10), and one UE located at (1,20,1) walks away from the BS at a speed of 1 m/s in the y-axis. Figure 3(c) depicts the SINR result.

Table 3. Simulation parameters for scenario B

Parameter	**Value**	
UE Position	(-5,60,1) and (1,20,1)	
UE Height	1 m	
UE Speed	1.0 m/s and 1.2 m/s	
UE Speed Direction	(1,0,0) and (0,1,0)	
BS Position	(0,20,10)	
Antenna Height	10 m	
Blocker Speed	1.0 m/s	
Trees Position	(2.5, 10, 4)	(20, 10, 4)
	(2.5, 20, 4)	(20, 20, 4)
	(2.5, 30, 4)	(20, 30, 4)
	(2.5, 40, 4)	(20, 40, 4)
	(2.5, 50, 4)	(20, 50, 4)



(a) (b) (c)

Fig. 3 Results of SINR characteristics in simulation with human- physical and tree blockage, 10m BS antenna height, 1 BS and 1 UE that walks following x- and y-axis

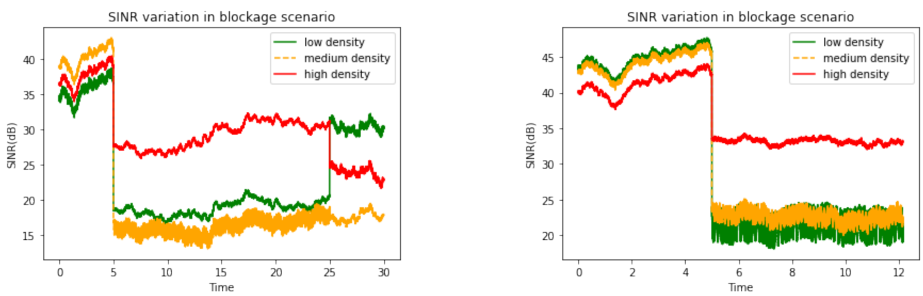
5.1.3 Scenario C. Human-physical and building blockage

To evaluate SINR value, this scenario simulates human physical and building blockage by varying the number of people in three distinct density patterns (lowly, medium, and high). The UE entered the building with constant speed. This scenario is divided into the following experiments:

1) There is one BS located at (0,20,10), and one UE located at (5,60,1) walks into the building at a speed of 1 m/s in the x-axis. Figure 4(a) depicts the SINR result.
2) There is one BS located at (0,20,10), and one UE located at (5,60,1) walks into the building at a speed of 1.2 m/s in x-axis. Figure 4(b) depicts the SINR result.

Table 4. Simulation parameters for scenario C

Parameter	**Value**
UE Position	(5,60,1)
UE Height	1 m
UE Speed	1.0 m/s and 1.2 m/s
UE Speed Direction	(-1,0,0) and (-1.2,0,0)
BS Position	(0,20,10)
Antenna Height	10 m
Blocker Speed	1.0 m/s
Building Position	(Box (-20.0, 0.0, 20.0, 100.0, 0.0, 30.0))



(a) (b)

Fig. 4 Results of SINR characteristics in simulation with human- physical and building blockage, 10m BS antenna height, 1 BS and 1 UE that walks following x-axis

5.1.4 Scenario D. Changing BS antenna height

To evaluate SINR value, this scenario simulates human physical and building blockage by varying the number of people in three distinct density patterns (lowly, medium, high). The BS antenna height was 5m. This scenario is divided into the following experiments:

1) There is one BS located at (0,20,5), 1 UE located at (5,60,1) walks into the building at a speed of 1 m/s. in the x-axis. Figure 5(a) depicts the SINR result.
2) There is one BS located at (0,20,5), 1 UE located at (-5,60,1) walks across the street at a speed of 1.2 m/s in the x-axis. Figure 5(b) depicts the SINR result.
3) There is one BS located at (0,20,5), 1 UE located at (1,20,1) walks away from the BS at a speed of 1 m/s in the y-axis. Figure 5(c) depicts the SINR result.

Table 5. Simulation parameters for scenario D

Parameter	Value	
UE Position	(5,60,1), (-5,60,1), and (1,20,1)	
UE Height	1 m	
UE Speed	1.0 m/s and 1.2 m/s	
UE Speed Direction	(1,0,0), (1.2,0,0) and (0,1,0)	
BS Position	(0,20,5)	
Antenna Height	5 m	
Blocker Speed	1.0 m/s	
Trees Position	(2.5, 10, 4)	(20, 10, 4)
	(2.5, 20, 4)	(20, 20, 4)
	(2.5, 30, 4)	(20, 30, 4)
	(2.5, 40, 4)	(20, 40, 4)
	(2.5, 50, 4)	(20, 50, 4)

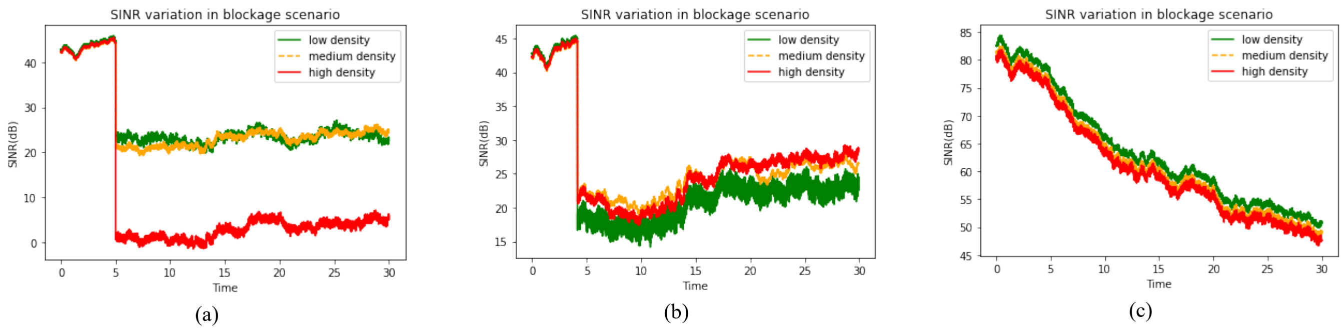


Fig. 5 Results of SINR characteristics in simulation with human- physical and tree blockage, 5m BS antenna height, 1 BS and 1 UE that walks following x- and y-axis

5.2 Simulation Analysis

The simulation result shows the effect of blockages on the SINR value. The following table describes the relationship between the mean value of SINR from various scenarios:

Table 5. Simulation results

SINR Mean Value	Density Pattern		
	Low	**Medium**	**High**
Scenario A.1	50.165	49.872	49.717
Scenario A.2	49.630	49.520	49.366
Scenario A.3	69.053	69.035	68.730
Scenario B.1	28.172	18.014	16.273
Scenario B.2	36.410	34.718	32.147
Scenario B.3	66.269	64.575	63.858
Scenario C.1	23.590	20.532	29.792
Scenario C.2	26.383	28.439	33.994
Scenario D.1	26.751	26.343	9.588
Scenario D.2	23.897	26.685	26.662
Scenario D.3	63.612	61.910	60.942

In Scenario A there was only people density as obstacles while in scenario B and scenario C there were additional trees and a building as obstacles. Simulation results showed that the SINR value decreased with an increasing number of obstacles.

In Scenario B and scenario D, there was a difference in BS antenna height. Simulation results showed that a higher antenna had a better SINR value.

The results confirmed that the value of SINR (signal interference plus noise ratio) was decreased with lower BS antenna height and an increasing number of obstacles and distance between UE and BS.

6. Conclusion

In this paper, the 5G mmWave signal quality performances in an UMi-Street Canyon scenario were evaluated by using the mmWave module from ns-3 library and python to generate a graph from simulation results. Four simulations were used to conduct the evaluation:

1) Human-physical obstruction simulation
2) Human-physical and tree obstruction simulation
3) Human-physical and building blockage simulation
4) Change BS antenna height

The simulation results indicate that the quantity of obstacles surrounding the BS and UE, the height of the BS antenna, and the user equipment's distance from the base station impact the 5G mmWave signal quality significantly. The signal quality decrease with an increasing distance, number of obstacles, and decreasing antenna height.

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