

Sample Lab Experiments

Wireless Communication (using BWSim-5G)



Lab Experiments using BWSim5G-R23 a



Document version v1.0.0



Wireless Research Team
BWSim-5G (R23.a) Product
Email: support@gigayasa.com

Contributors:

Editor: Simulator Design Team, Gigayasa

Contributing Authors: Vikram Singh, Gigayasa

Grants and Funding:

Our startup is being supported by:

- Ministry of Electronics and Information Technology, Government of India.
- Center of Excellence in Wireless Technology (CEWiT), IITM.
- Indian Institute of Technology, Madras Incubation Center (IITM-IC).
- Tamil Nadu Startup and Innovation Mission.

© 2022 Gigayasa Wireless Private Limited. All rights reserved.

Gigayasa/GigaYasa (name and logo), BWSim/BWSim5G-T22a/BWSim5G-R22a, and related trade dress used in this publication are the trademark or registered trademarks of GigaYasa and its affiliates in India and other countries and may not be used without express written consent of GigaYasa Wireless. All other trademarks used in this publication are property of their respective owners and are not associated with any of GigaYasa Wireless's products or services. Rather than put a trademark or registered trademark symbol after every occurrence of a trademark name, names are used in an editorial fashion only, and to the benefit of the trademark owner, with no intention of infringement of the trademark. The content in this document is for education and research purposes and not to be shared to persons or organized without license or consent of Gigayasa.

TABLE OF CONTENTS

Objective of this Documentation.....	4
Experiment-1: Study path-loss in wireless channel model	5
1.1. Path loss models in wireless Communication.....	5
1.2. Results and Observations	9
1.3. References	10
Experiment-2: Line of sight models for Wireless Channel.....	11
2.1. Line of Sight Probability Models.....	11
2.2. Results and Observations	13
2.3. References	14
Experiment-3: Interferences In 5G-NR Multicell Systems.....	15
3.1. Interference in 5G System	15
3.1.1. Inter-user Interference	15
3.1.2. Inter-cell Interference	17
3.2. Results and Observations	18
3.3. References	19
Experiment-4: Studying Outdoor Terrains and their characteristics	20
4.1. Modelling the Outdoor Terrains	20
4.1.1. Urban Macro cell.....	20
4.1.2. Urban Micro cell	21
4.1.3. Rural Macro cell.....	21
4.1.4. Coverage in Outdoor terrains.....	21
4.2. Results and Observations	22
4.3. References	24
Experiment-5: Studying Indoor Terrains and their characteristics.....	25
5.1. Modelling the Indoor Terrains	25
5.1.1. Indoor Hotspot	25
5.1.2. Indoor Factory.....	26
5.1.3. Coverage in Indoor terrains	28
5.2. Results and Observations	28
5.3. References	29
Experiment-6: Cellular Concept, Geometry and Deployment in Mobile Networks	30
6.1. Cellular Concept	30
6.2. Cellular Geometry.....	30
6.3. Network Deployment and Inter-site Distance.....	31

6.3.1.	Network Deployment in Outdoor Terrains	32
6.3.2.	Network Deployment in Indoor Terrains.....	32
6.4.	Results and Observations	32
6.5.	References	33
Experiment-7: AAS and Beamforming in 5G networks.....		34
7.1.	Beamforming using AAS	34
7.1.1.	Basics: Linear Arrays	34
7.1.2.	Uniform Planner Arrays	36
7.1.3.	Dual Polarized Antenna Arrays	36
7.1.4.	AAS in 5G and RF chains	37
7.2.	Results and Observations	37
7.3.	References	37
Experiment-8: Antenna Tilt angle selection in 5G and Beyond networks.....		39
8.1.	Antenna Tilts angle	39
8.1.1.	Basics and definitions.....	39
8.1.2.	Implementation of down-tilt angle in advanced antenna arrays.....	40
8.1.3.	Methods of calculating down-tilt angles.....	40
8.2.	Results and Observations	41
8.3.	References	41
Experiment-9: Modulation schemes in 5G-NR.....		42
9.1.	Modulation Schemes	42
9.1.1.	Symbol Mapping.....	42
9.1.2.	Symbol Decoding.....	43
9.2.	Results and Observations	44
9.3.	Further Reading	45
Experiment-10: Forward Error Correction in 5G-NR		46
10.1.	Channel Codes in 5G-NR	46
10.1.1.	LDPC Codes	47
10.1.2.	Polar Codes.....	48
10.2.	Results and Observations.....	50
10.3.	Further Reading.....	50
Experiment-11: System-level Simulations for 5G Networks.....		51
11.1.	Elements of system level simulation	51

OBJECTIVE OF THIS DOCUMENTATION

This document present some, non-exhaustive, use-cases of BWSim-5G (R23.a) for the purpose of teaching and research. It introduces the user to the **Broadband Wireless Simulator for 5G** which is system level simulator for 5G networks. The meaning of system level simulations, for the convenience of users, is defined below.

System level Simulation:

It is a method/mechanism of mimicking a practical real-time system or scenario with the help of computer simulation. It implements all the physical phenomena using realistic mathematical models parameterized based on the real-data collected during field trials. The system and algorithms are implemented as software in the same fashion as on the actual system. The system level simulations are often non-real time and allows the researchers and designers to test the performance of their algorithms and methods before deploying them on the actual system.

5G Wireless System level Simulation:

5G Wireless communication system consists of layer-1 (Physical layer), layer-2 (MAC, RLC, PDCP and SDAP), layer-3 (Radio resource control), which are implemented on software stacks, firmware, and hardware units inside the user equipment and base-stations. An actual network consists of many UEs, located at random locations, and BSs deployed strategically. These devices co-operate, co-ordinate and sometimes compete for resources and performance optimization. The user equipment and base-station exchanges data through wireless channel, which is influenced by buildings, scatterers, user mobility, environmental conditions etc. A system level simulation implements the layers and modules constituting a UEs and BSs on a software and allows the user to customize these entities to suit the purpose of their simulations. Furthermore, it implements the mathematical models designed to replicate the effects caused by physical phenomena such wireless channel, hardware impairments, UEs-BS relative motions etc.

It contains 11 experiments which has been performed using BWSim-5G (R23.a) and no external source or 3rd party tool has been used for generating these results.

EXPERIMENT-1

STUDY PATH-LOSS IN WIRELESS CHANNEL MODEL

The path-loss is a random phenomenon in wireless channels which changes with carrier frequency, Tx-Rx separation, and terrain. This experiment demonstrates the path-loss variation as a function of distance between the transmitter and receiver using state of the art path-loss models. These models are crucial for understanding the wireless channels to combat path-loss experienced by the signal while propagating over the wireless channel. Furthermore, these models help in designing robust practical wireless systems and analyze their performance in different terrains. This chapter introduces path-loss models which are commonly used for research and development and discusses their limitation and characteristics. Finally, we demonstrate the 3GPP path-loss models [1] and the effect of different parameters on system performance using 3GPP 3D spatial channel model.

2.1. PATH LOSS MODELS IN WIRELESS COMMUNICATION

Path loss defines the amount of power lost by transmitted signal while propagating over the channel. Empirically, it is calculated using,

$$L = \frac{P_r}{P_t}, \quad (1.1)$$

where P_r is the power received at the receiver antenna terminal, P_t is the power transmitted by transmit antenna, and L is the propagation power loss. The path-loss on decibel scale can be represented as:

$$L_{dB} = 10 * \log_{10}(L) \quad (1.2)$$

$$= 10 * \log_{10} \frac{P_r}{P_t} \quad (1.3)$$

$$= 10 * \log_{10} P_r - 10 * \log_{10} P_t \quad (1.4)$$

$$= P_r(dB) - P_t(dB) \quad (1.5)$$

The path loss for free space is computed using Poynting theorem from electromagnetic field theory as

$$L = \left(\frac{4\pi d}{\lambda}\right)^2 \quad (1.6)$$

$$L_{dB} = 20 * \log_{10} \frac{4\pi}{\lambda} + 20 * \log_{10} d \quad (1.7)$$

$$= \alpha + \beta * \log_{10} f_c + \gamma * \log_{10} d \quad (1.8)$$

where d is the separation between transmitter and receiver antenna, λ is wavelength of the carrier used for transmitting the signal by transmitter antenna, and f_c is the carrier frequency. This equation can be generalized as

$$L_{dB} = \alpha + \beta * \log_{10} f_c + \gamma * \log_{10} d$$

where α , β and γ are path-loss co-efficient which are calibrated to model the path-loss for different terrains and propagation conditions. This equation can be further simplified as

$$L_{dB}(d) = L_{dB}(d_0) + 20 * \log_{10} \frac{d}{d_0} \quad (1.9)$$

$$= \alpha_0 + \beta_0 * L_{dB}(d_0) + \gamma_0 * \log_{10} \frac{d}{d_0} \quad (1.10)$$

where d_0 is the distance of a reference point from transmitter antenna where power is known. In real channel point studies, the received power is measured at many such reference points to compute the path-loss $L_{dB}(d_0)$. The path-loss measurements at many such reference points help in computing the path-loss model parameters $(\alpha_0, \beta_0, \gamma_0)$ for the terrains under study. The free space path loss equation clearly reveal that the path loss increases with the distance between transmitter and receiver. Moreover, the path-loss is higher for signal transmitted at higher carrier frequency compared to a signal modulated over lower frequency carrier. However, the above path loss model is overly simplistic and doesn't capture many practical aspects, such as height of the transmitter and the receiver, shadowing etc.

In real scenarios, the surrounding of two receivers equidistant from a transmitter can be vastly different resulting in vastly different received powers even for signals transmitted with equal power.

The 3GPP pathloss models are summarized in Table 7.4.1-1 and the of 2D and 3D distances are defined in equation (1-11) and illustrated in Figure 7.4.1-1 and Figure 7.4.1-2 respectively. Note that the distribution of the shadow fading is log-normal, and its standard deviation for each scenario is considered based on the Table 7.4.1-1. All these parameters are computed based on real wireless propagation data collected by different companies and research institutes [1].

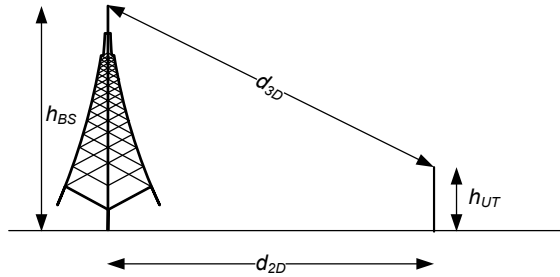


Figure 1-1: Definition of d_{2D} and d_{3D} for outdoor UTs

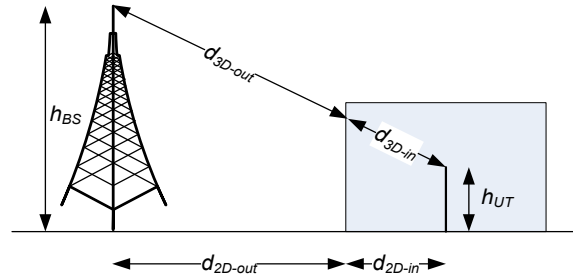


Figure 1-2: Definition of d_{2D-out} , d_{2D-in} and d_{3D-out} , d_{3D-in} for indoor UTs.

Note that

$$d_{3D-out} + d_{3D-in} = \sqrt{(d_{2D-out} + d_{2D-in})^2 + (h_{BS} - h_{UT})^2} \quad (1-11)$$

Table 1-1: Pathloss models

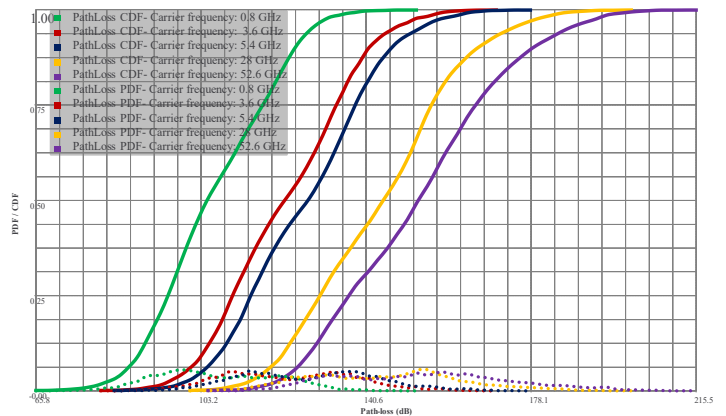
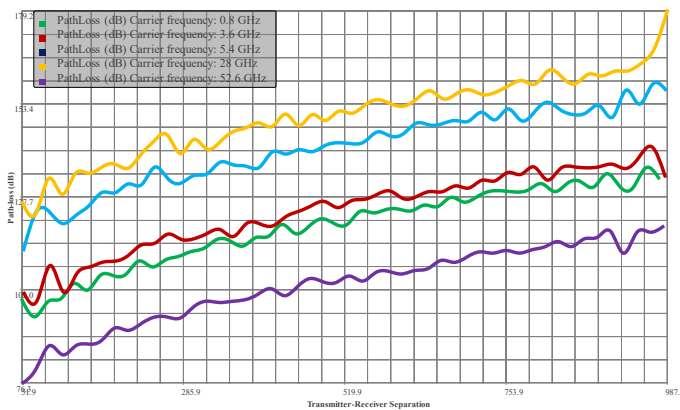
Scenario	LOS/NLOS	Pathloss [dB], f_c is in GHz and d is in meters, see note 6	Shadow fading std [dB]	Applicability range, antenna height default values
RMa	LOS	$PL_{\text{RMa-LOS}} = \begin{cases} PL_1 & 10\text{m} \leq d_{2\text{D}} \leq d_{\text{BP}} \\ PL_2 & d_{\text{BP}} \leq d_{2\text{D}} \leq 10\text{km} \end{cases}, \text{ see note 5}$ $PL_1 = 20 \log_{10}(40\pi d_{3\text{D}} f_c / 3) + \min(0.03h^{1.72}, 10) \log_{10}(d_{3\text{D}}) - \min(0.044h^{1.72}, 14.77) + 0.002 \log_{10}(h) d_{3\text{D}}$ $PL_2 = PL_1(d_{\text{BP}}) + 40 \log_{10}(d_{3\text{D}} / d_{\text{BP}})$	$\sigma_{\text{SF}} = 4$ $\sigma_{\text{SF}} = 6$	$h_{\text{BS}} = 35\text{m}$ $h_{\text{UT}} = 1.5\text{m}$ $W = 20\text{m}$ $h = 5\text{m}$ h = avg. building height W = avg. street width The applicability ranges:
	NLOS	$PL_{\text{RMa-NLOS}} = \max(PL_{\text{RMa-LOS}}, PL'_{\text{RMa-NLOS}})$ for $10\text{m} \leq d_{2\text{D}} \leq 5\text{km}$ $PL'_{\text{RMa-NLOS}} = 161.04 - 7.1 \log_{10}(W) + 7.5 \log_{10}(h) - (24.37 - 3.7(h/h_{\text{BS}})^2) \log_{10}(h_{\text{BS}}) + (43.42 - 3.1 \log_{10}(h_{\text{BS}}))(\log_{10}(d_{3\text{D}}) - 3) + 20 \log_{10}(f_c) - (3.2(\log_{10}(11.75h_{\text{UT}}))^2 - 4.97)$	$\sigma_{\text{SF}} = 8$	$5\text{m} \leq h \leq 50\text{m}$ $5\text{m} \leq W \leq 50\text{m}$ $10\text{m} \leq h_{\text{BS}} \leq 150\text{m}$ $1\text{m} \leq h_{\text{UT}} \leq 10\text{m}$
UMa	LOS	$PL_{\text{UMa-LOS}} = \begin{cases} PL_1 & 10\text{m} \leq d_{2\text{D}} \leq d'_{\text{BP}} \\ PL_2 & d'_{\text{BP}} \leq d_{2\text{D}} \leq 5\text{km} \end{cases}, \text{ see note 1}$ $PL_1 = 28.0 + 22 \log_{10}(d_{3\text{D}}) + 20 \log_{10}(f_c)$ $PL_2 = 28.0 + 40 \log_{10}(d_{3\text{D}}) + 20 \log_{10}(f_c) - 9 \log_{10}((d'_{\text{BP}})^2 + (h_{\text{BS}} - h_{\text{UT}})^2)$	$\sigma_{\text{SF}} = 4$	$1.5\text{m} \leq h_{\text{UT}} \leq 22.5\text{m}$ $h_{\text{BS}} = 25\text{m}$
	NLOS	$PL_{\text{UMa-NLOS}} = \max(PL_{\text{UMa-LOS}}, PL'_{\text{UMa-NLOS}})$ for $10\text{m} \leq d_{2\text{D}} \leq 5\text{km}$ $PL'_{\text{UMa-NLOS}} = 13.54 + 39.08 \log_{10}(d_{3\text{D}}) + 20 \log_{10}(f_c) - 0.6(h_{\text{UT}} - 1.5)$	$\sigma_{\text{SF}} = 6$	$1.5\text{m} \leq h_{\text{UT}} \leq 22.5\text{m}$ $h_{\text{BS}} = 25\text{m}$ Explanations: see note 3
		Optional PL = $32.4 + 20 \log_{10}(f_c) + 30 \log_{10}(d_{3\text{D}})$	$\sigma_{\text{SF}} = 7.8$	

Scenario	LOS/NLOS	Pathloss [dB], f_c is in GHz and d is in meters, see note 6	Shadow fading std [dB]	Applicability range, antenna height default values
UMi - Street Canyon	LOS	$PL_{\text{UMi-LOS}} = \begin{cases} PL_1 & 10\text{m} \leq d_{2D} \leq d'_{\text{BP}} \\ PL_2 & d'_{\text{BP}} \leq d_{2D} \leq 5\text{km} \end{cases}, \text{ see note 1}$ $PL_1 = 32.4 + 21\log_{10}(d_{3D}) + 20\log_{10}(f_c)$ $PL_2 = 32.4 + 40\log_{10}(d_{3D}) + 20\log_{10}(f_c) - 9.5\log_{10}((d'_{\text{BP}})^2 + (h_{\text{BS}} - h_{\text{UT}})^2)$	$\sigma_{\text{SF}} = 4$	$1.5\text{m} \leq h_{\text{UT}} \leq 22.5\text{m}$ $h_{\text{BS}} = 10\text{m}$
	NLOS	$PL_{\text{UMi-NLOS}} = \max(PL_{\text{UMi-LOS}}, PL'_{\text{UMi-NLOS}})$ <p style="text-align: center;">for $10\text{m} \leq d_{2D} \leq 5\text{km}$</p> $PL'_{\text{UMi-NLOS}} = 35.3\log_{10}(d_{3D}) + 22.4 + 21.3\log_{10}(f_c) - 0.3(h_{\text{UT}} - 1.5)$	$\sigma_{\text{SF}} = 7.82$	$1.5\text{m} \leq h_{\text{UT}} \leq 22.5\text{m}$ $h_{\text{BS}} = 10\text{m}$ Explanations: see note 4
	NLOS	Optional $PL = 32.4 + 20\log_{10}(f_c) + 31.9\log_{10}(d_{3D})$	$\sigma_{\text{SF}} = 8.2$	
InH - Office	LOS	$PL_{\text{InH-LOS}} = 32.4 + 17.3\log_{10}(d_{3D}) + 20\log_{10}(f_c)$	$\sigma_{\text{SF}} = 3$	$1\text{m} \leq d_{3D} \leq 150\text{m}$
	NLOS	$PL_{\text{InH-NLOS}} = \max(PL_{\text{InH-LOS}}, PL'_{\text{InH-NLOS}})$ $PL'_{\text{InH-NLOS}} = 38.3\log_{10}(d_{3D}) + 17.30 + 24.9\log_{10}(f_c)$	$\sigma_{\text{SF}} = 8.03$	$1\text{m} \leq d_{3D} \leq 150\text{m}$
	NLOS	Optional $PL'_{\text{InH-NLOS}} = 32.4 + 20\log_{10}(f_c) + 31.9\log_{10}(d_{3D})$	$\sigma_{\text{SF}} = 8.29$	$1\text{m} \leq d_{3D} \leq 150\text{m}$
InF	LOS	$PL_{\text{LOS}} = 31.84 + 21.50\log_{10}(d_{3D}) + 19.00\log_{10}(f_c)$	$\sigma_{\text{SF}} = 4.3$	$1 \leq d_{3D} \leq 600 \text{ m}$
	NLOS	InF-SL: $PL = 33 + 25.5\log_{10}(d_{3D}) + 20\log_{10}(f_c)$ $PL_{\text{NLOS}} = \max(PL, PL_{\text{LOS}})$	$\sigma_{\text{SF}} = 5.7$	
		InF-DL: $PL = 18.6 + 35.7\log_{10}(d_{3D}) + 20\log_{10}(f_c)$ $PL_{\text{NLOS}} = \max(PL, PL_{\text{LOS}}, PL_{\text{InF-SL}})$	$\sigma_{\text{SF}} = 7.2$	
		InF-SH: $PL = 32.4 + 23.0\log_{10}(d_{3D}) + 20\log_{10}(f_c)$ $PL_{\text{NLOS}} = \max(PL, PL_{\text{LOS}})$	$\sigma_{\text{SF}} = 5.9$	
		InF-DH: $PL = 33.63 + 21.9\log_{10}(d_{3D}) + 20\log_{10}(f_c)$ $PL_{\text{NLOS}} = \max(PL, PL_{\text{LOS}})$	$\sigma_{\text{SF}} = 4.0$	

Scenario	LOS/NLOS	Pathloss [dB], f_c is in GHz and d is in meters, see note 6	Shadow fading std [dB]	Applicability range, antenna height default values
Note 1:		<p>Breakpoint distance $d'_{BP} = 4 h'_{BS} h'_{UT} f_c/c$, where f_c is the centre frequency in Hz, $c = 3.0 \times 10^8$ m/s is the propagation velocity in free space, and h'_{BS} and h'_{UT} are the effective antenna heights at the BS and the UT, respectively. The effective antenna heights h'_{BS} and h'_{UT} are computed as follows: $h'_{BS} = h_{BS} - h_E$, $h'_{UT} = h_{UT} - h_E$, where h_{BS} and h_{UT} are the actual antenna heights, and h_E is the effective environment height. For UMi $h_E = 1.0$m. For UMA $h_E = 1$m with a probability equal to $1/(1+C(d_{2D}, h_{UT}))$ and chosen from a discrete uniform distribution $uniform(12, 15, \dots, (h_{UT}-1.5))$ otherwise. With $C(d_{2D}, h_{UT})$ given by</p> $C(d_{2D}, h_{UT}) = \begin{cases} 0 & , h_{UT} < 13\text{m} \\ \left(\frac{h_{UT} - 13}{10}\right)^{1.5} g(d_{2D}) & , 13\text{m} \leq h_{UT} \leq 23\text{m} \end{cases}$ <p>where</p> $g(d_{2D}) = \begin{cases} 0 & , d_{2D} \leq 18\text{m} \\ \frac{5}{4} \left(\frac{d_{2D}}{100}\right)^3 \exp\left(\frac{-d_{2D}}{150}\right) & , 18\text{m} < d_{2D} \end{cases}$ <p>Note that h_E depends on d_{2D} and h_{UT} and thus needs to be independently determined for every link between BS sites and UTs. A BS site may be a single BS or multiple co-located BSs.</p>		
Note 2:		The applicable frequency range of the PL formula in this table is $0.5 < f_c < f_H$ GHz, where $f_H = 30$ GHz for RMa and $f_H = 100$ GHz for all the other scenarios. It is noted that RMa pathloss model for >7 GHz is validated based on a single measurement campaign conducted at 24 GHz.		
Note 3:		UMA NLOS pathloss is from TR36.873 with simplified format and $PL_{UMA-NLOS} = \text{Pathloss of UMA LOS outdoor scenario}$.		
Note 4:		$PL_{UMi-LOS} = \text{Pathloss of UMi-Street Canyon LOS outdoor scenario}$.		
Note 5:		Break point distance $d_{BP} = 2\pi h_{BS} h_{UT} f_c/c$, where f_c is the centre frequency in Hz, $c = 3.0 \times 10^8$ m/s is the propagation velocity in free space, and h_{BS} and h_{UT} are the antenna heights at the BS and the UT, respectively.		
Note 6:		f_c denotes the center frequency normalized by 1GHz, all distance related values are normalized by 1m, unless it is stated otherwise.		

2.2. RESULTS AND OBSERVATIONS

Observation-1: The path-loss a transmitted signal experience while propagating over a wireless channel increase with the transmitter receiver separation.



Observation-2: As the carrier frequency of the transmitter signal increases the path loss experienced by the signal also increases.