GIGAYASA

Sample Lab Experiments

Wireless Communication (using BWSim-5G)

Lab Experiments using BWSim5G-R23 a

Document version v1.0.0

GIGAYASA

Wireless Research Team

BWSim-5G (R23.a) Product

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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.

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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 **B**roadband **W**ireless **Sim**ulator 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,

$$L = \frac{P_r}{P_t}, \tag{1.1}$$

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:

$$\begin{aligned} L_{dB} &= 10 * \log_{10}(L) && (1.2)\\ &= 10 * \log_{10}\frac{P_r}{P_t} && (1.3)\\ &= 10 * \log_{10} P_r - 10 * \log_{10} P_t && (1.4)\\ &= P_r(dB) - P_t(dB) && (1.5) \end{aligned}$$

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

$$\begin{aligned} L &= \left(\frac{4\pi d}{\lambda}\right)^2 && (1.6)\\ L_{dB} &= 20 * \log_{10}\frac{4\pi}{\lambda} + 20 * \log_{10} d && (1.7)\\ &= \alpha + \beta * \log_{10} f_c + \gamma * \log_{10} d && (1.8) \end{aligned}$$

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

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

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

where $\mathrm{d_0}$ 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 $\mathrm{L_{dB}(d_0)}$. The path-loss measurements at many such reference points help in computing the path-loss model parameters (α_0, β_0, γ_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].

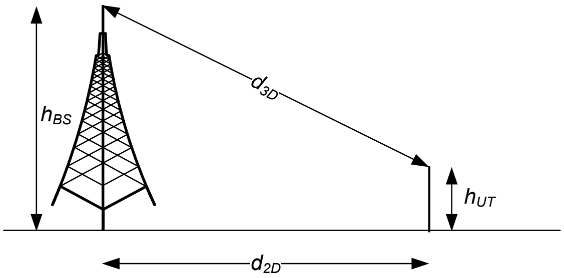


Figure 1-1: Definition of d_{2D} and d_{3D} for outdoor UTs

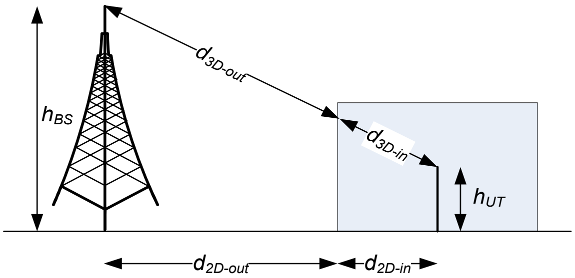


Figure 1-2: Definition of $d_{2D\text{-}out}$, $d_{2D\text{-}in}$ and $d_{3D\text{-}out}$, $d_{3D\text{-}in}$ for indoor UTs.

Note that

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

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

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	$PL_{\text{UMi-LOS}} = \begin{cases} PL_1 & 10\text{m} \le d_{\text{2D}} \le d'_{\text{BP}} \\ PL_2 & d'_{\text{BP}} \le d_{\text{2D}} \le 5\text{km} \end{cases}$, see note 1 $PL_1 = 32.4 + 21\log_{10}(d_{\text{3D}}) + 20\log_{10}(f_c)$ $PL_2 = 32.4 + 40\log_{10}(d_{\text{3D}}) + 20\log_{10}(f_c) - 9.5\log_{10}((d'_{\text{BP}})^2 + (h_{\text{BS}} - h_{\text{UT}})^2)$	$\sigma_{\text{SF}} = 4$	$1.5\text{m} \le h_{\text{UT}} \le 22.5\text{m}$ $h_{\text{BS}} = 10\text{m}$
	NLOS	$PL_{\text{UMi-NLOS}} = \max(PL_{\text{UMi-LOS}}, PL'_{\text{UMi-NLOS}})$ for $10\text{m} \le d_{\text{2D}} \le 5\text{km}$ $PL'_{\text{UMi-NLOS}} = 35.3\log_{10}(d_{\text{3D}}) + 22.4 + 21.3\log_{10}(f_c) - 0.3(h_{\text{UT}} - 1.5)$	$\sigma_{\text{SF}} = 7.82$	$1.5\text{m} \le h_{\text{UT}} \le 22.5\text{m}$ $h_{\text{BS}} = 10\text{m}$ Explanations: see note 4
		Optional $\text{PL} = 32.4 + 20\log_{10}(f_c) + 31.9\log_{10}(d_{\text{3D}})$	$\sigma_{\text{SF}} = 8.2$	
InH - Office	LOS	$PL_{\text{InH-LOS}} = 32.4 + 17.3\log_{10}(d_{\text{3D}}) + 20\log_{10}(f_c)$	$\sigma_{\text{SF}} = 3$	$1\text{m} \le d_{\text{3D}} \le 150\text{m}$
	NLOS	$PL_{\text{InH-NLOS}} = \max(PL_{\text{InH-LOS}}, PL'_{\text{InH-NLOS}})$ $PL'_{\text{InH-NLOS}} = 38.3\log_{10}(d_{\text{3D}}) + 17.30 + 24.9\log_{10}(f_c)$	$\sigma_{\text{SF}} = 8.03$	$1\text{m} \le d_{\text{3D}} \le 150\text{m}$
		Optional $PL'_{\text{InH-NLOS}} = 32.4 + 20\log_{10}(f_c) + 31.9\log_{10}(d_{\text{3D}})$	$\sigma_{\text{SF}} = 8.29$	$1\text{m} \le d_{\text{3D}} \le 150\text{m}$
InF	LOS	$\text{PL}_{\text{LOS}} = 31.84 + 21.50\log_{10}(d_{3D}) + 19.00\log_{10}(f_c)$	$\sigma_{\text{SF}} = 4.3$	$1 \le d_{3D} \le 600$ m
	NLOS	InF-SL: $\text{PL} = 33 + 25.5\log_{10}(d_{3D}) + 20\log_{10}(f_c)$ $\text{PL}_{\text{NLOS}} = \max(\text{PL}, \text{PL}_{\text{LOS}})$	$\sigma_{\text{SF}} = 5.7$	
		InF-DL: $\text{PL} = 18.6 + 35.7\log_{10}(d_{3D}) + 20\log_{10}(f_c)$ $\text{PL}_{\text{NLOS}} = \max(\text{PL}, \text{PL}_{\text{LOS}}, \text{PL}_{\text{InF-SL}})$	$\sigma_{\text{SF}} = 7.2$	
		InF-SH: $\text{PL} = 32.4 + 23.0\log_{10}(d_{3D}) + 20\log_{10}(f_c)$ $\text{PL}_{\text{NLOS}} = \max(\text{PL}, \text{PL}_{\text{LOS}})$	$\sigma_{\text{SF}} = 5.9$	
		InF-DH: $\text{PL} = 33.63 + 21.9\log_{10}(d_{3D}) + 20\log_{10}(f_c)$ $\text{PL}_{\text{NLOS}} = \max(\text{PL}, \text{PL}_{\text{LOS}})$	$\sigma_{\text{SF}} = 4.0$	

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: Breakpoint distance $d'_{BP} = 4\, h'_{BS}\, h'_{UT}\, f_c/c$, where f_c is the centre frequency in Hz, $c = 3.0\times10^8$ 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=1m with a probability equal to $1/(1+C(d_{2D}, h_{UT}))$ and chosen from a discrete uniform distribution uniform(12,15,…,(h_{UT}-1.5)) otherwise. With $C(d_{2D}, h_{UT})$ given by

$$C(d_{2D}, h_{UT}) = \begin{cases} 0 & , h_{UT} < 13\text{m} \\ \left(\dfrac{h_{UT} - 13}{10}\right)^{1.5} g(d_{2D}) & ,13\text{m} \le h_{UT} \le 23\text{m} \end{cases},$$

where

$$g(d_{2D}) = \begin{cases} 0 & , d_{2D} \le 18\text{m} \\ \dfrac{5}{4}\left(\dfrac{d_{2D}}{100}\right)^3 \exp\left(\dfrac{-d_{2D}}{150}\right) & ,18\text{m} < d_{2D} \end{cases}.$$

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.

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 $PL_{UMa\text{-}LOS}$ = Pathloss of UMa LOS outdoor scenario.

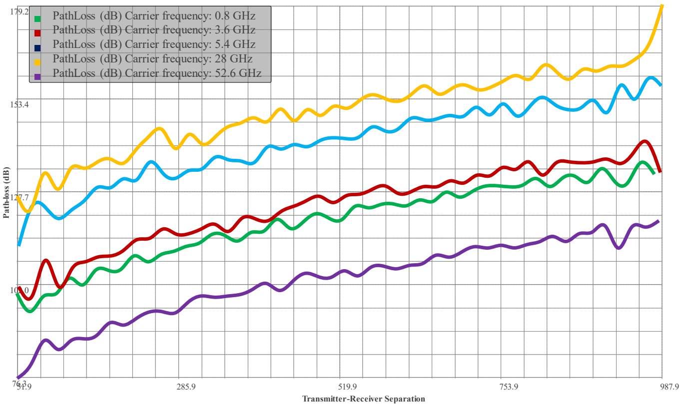
Note 4: $PL_{UMi\text{-}LOS}$ = Pathloss of UMi-Street Canyon LOS outdoor scenario.

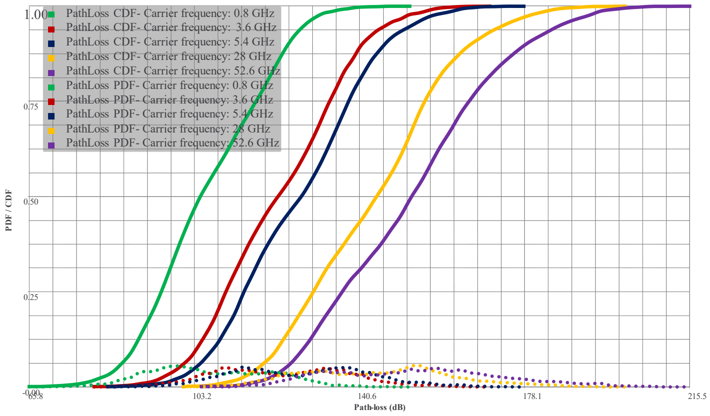
Note 5: Break point distance $d_{BP} = 2\pi\, h_{BS}\, h_{UT}\, f_c/c$, where f_c is the centre frequency in Hz, $c = 3.0 \times 10^8$ m/s is the propagation velocity in free space, and h_{BS} and h_{UT} are the antenna heights at the BS and the UT, respectively.

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

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





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