Propagation Models

Contents

1 Propagation models in NetSim

Propagation models are used to model signal attenuation for all wireless links. These include WLAN – 802.11, Legacy Networks, ZigBee / IOT / WSN – 802.15.4, LTE, Cognitive radio – 802.22 and VANET.

1.1 Propagation Loss

Three different and mutually independent propagation phenomena influence the power of the received signal: path loss, shadowing and multipath fading.

The different models available in NetSim are

1. **Path loss Models**
   - Friis Free Space Propagation (Default option in GUI)
   - Log Distance
   - HATA Suburban
   - HATA Urban
   - COST 231 HATA Suburban
   - COST 231 HATA Urban
   - Indoor Office
   - Indoor Factory
   - Indoor Home
   - No Path Loss
2. **Shadowing Models**
   - None
   - Constant
   - Lognormal
3. **Fading Models**
   - None
   - Rayleigh
   - Nakagami

2 Path loss

Path loss is the reduction in power density of an electromagnetic wave as it propagates through space. Path loss may be due to many effects, such as free reflection, aperture-medium coupling loss, and absorption. The general formula by which path loss is calculated is

$$RXpower = TX_{power} + Gain_{TX} + Gain_{RX} - PL_{1meter} - 10 \log D^{n}$$

Where n is the path loss exponent, whose value is normally in the range of 2 to 5. In NetSim, the default value for path loss exponent is 2 and D is the distance between transmitter and the receiver, usually measured in meters.

And PL_{1meter} is the path loss at reference distance (here taken as 1m). This value varies depending on the radio and is a user input available in the PHY layer of the radios. For 802.11b this value is 40dB

And the Gain represents the transmit and receive antenna gains

Example:

Calculating the received power at 2 due to node 1 transmission. The transmitter power of node1 is 100mW (20dBm), frequency is 2412MHz

Rx_Power (dbm) = 20dBm + 0 + 0 – 40dB – 40dB = -60dBm

The default value for reference distance d0 and path loss at reference distance PL_d0 are

1. 802.11 a / b / g / n / ac / p
    a. 2.4 GHz : Default d0 = 1m and PL_D0 = 40dB
    b. 5 GHz: Default d0 = 1 m and PL_D0 = 47 dB
2. 802.15.4 - Default d0 = 8m and PL_D0 = 58.5 dB
3. In LTE the calculation is done for each carrier for uplink and download. Default d0 = 1m and PL_D0 = 32 dB

2.1 Path loss models

2.1.1 Friis Free space propagation model

The free space propagation model is used to predict received signal strength when the transmitter and receiver have a clear, unobstructed line-of-sight path between them. Satellite communication systems and microwave line-of-sight radio links typically undergo free space propagation. The free space power received by a receiver antenna which is separated from a radiating transmitter antenna by distance d, is given by the Friis free space equation

$$P_r = P_t + G_t + G_r + 20\log_{10}[\frac{\lambda}{(4 * \pi * do)}] + (10 * 2 * \log_{10}(\frac{do}{d}))$$

where P_t is the transmitted power

P_r is the received power

G_t is the transmitter antenna gain

G_r is the receiver antenna gain

d is the T-R separation distance in meters

λ is the wavelength in meters

2.1.2 Log distance

The average received power logarithmically decreases with distance, whether in outdoor or indoor radio channels. The average large-scale path loss for an arbitrary T-R separation is expressed as a function of distance by using path loss exponent n.

$$P_r = P_t + G_t + G_r + 20\log_{10}[\frac{\lambda}{(4 * \pi * do)}] + (10 * \eta * \log_{10}(\frac{d_0}{d}))$$

Where η is path loss exponent. Netsim allows users to set $2.0 \leq \eta \leq 5.0$

d_0 is the reference distance

d is the Transmitter Receiver separation distance

2.1.3 Hata Urban

The hata model is an empirical formulation of the graphical path loss data provided by Okumura. Hata presented the urban area propagation loss as a standard formula and supplied correction equations for applications to other situations. The standard formula for median path loss in urban areas is given by

$$Pr = [Pt] - L50\,(dB)$$

$$L50(dB) = 69.55 + 26.16\log(fc) - 13.82\log(hte) - a(hre) + (44.9 - 6.55\log(hte))\log(d) \quad ------------ eq(1)$$

Where

L_{50} (dB) = 50th percentile (median) value of path loss

f_c = Frequency in MHz

hte = Transmitter antenna height (Range 30m to 200m, default 30m)

hre = Receiver antenna height (Range 1m to 10m, default 1m)

d = Separation distance in km. Since the input is in meters, it is divided by 1000 to convert to km in the code

a (hre) = correction factor for effective mobile antenna height which is a function of the size of coverage area.

$$a\ (hre)\ =\ 8.29\ (log\ 1.54\ h\ \ re\ )2 - 1.1\ db \quad \text{for } f_c < 300 \text{ MHz}$$

$$a\ (hre)\ =\ 3.2\ (log\ 11.74\ h\ \ re\ )2 - 4.97\ db \quad \text{for } f_c >= 300 \text{ MHz}$$

2.1.4 Hata Suburban

To obtain path loss in suburban area, the standard Hata formula in equation 1 is modified as

$$Pr\ =\ [Pt]\ -\ L50\ (dB)$$

$$L50\ (dB) = L50(urban)(dB) - 2\left[\frac{logfc}{28}\right]^2 - 5.4 \qquad ------- eq(2)$$

2.1.5 COST231 Hata Urban and COST231 Hata Suburban

The European Co-operative for Scientific and Technical Research (EURO-COST formed COST231 working committee to develop an extended version of the Hata model COST231 proposed the following formula to extend Hata's model. The proposed model for path loss is

$$Pr\ =\ [Pt]\ -\ L50\ (dB)$$

$$L50(dB) = 46.3 + 33.9\log(fc) - 13.82\log(hte) - a(hre) + (44.9 - 6.55\log(hte))\log(d) + CM$$

Where C_M =
- 3 dB for urban
- 0 dB for suburban

2.1.6 Indoor office and Indoor factory

$$Pr = [Pt] + [Gt] + [Gr] + 20log10\left[\frac{\lambda}{(4 * \pi * do)}\right] + \left(10 * \eta * log10\left(\frac{do}{d}\right)\right)$$

Where η =
- 2.6 for Indoor_office
- 2.1 for Indoor_factory

2.1.7 Indoor home:

$$Pr = [Pt] + [Gt] + [Gr] + 20log10\left[\frac{\lambda}{(4 * \pi * do)}\right] + \left(10 * \eta * log10\left(\frac{do}{d}\right)\right)$$

Where η = 3

The default values of path loss exponent for all path loss models in NetSim are as shown below:

Path loss model	Path loss exponent (default)
Friis free space	2
Log distance	2
COST231 Urban	-
COST231 Hata Suburban	-
Hata Urban	-
Hata Suburban	-
Indoor Office	2.6
Indoor Factory	2.1
Indoor Home	3

3 Shadowing models

3.1 Log normal shadowing

The mode in the Friis free space propagation equation does not consider the fact that the surrounding environmental clutter may be vastly different at two different locations having the same T-R separation. This leads to measured signals which are vastly different than the average value predicted by the above equation. Measurements have shown that at any value of d, the path loss PL (d) at a particular location is random and distributed log-normally about the mean distance-dependent value i.e.

$$PL(d)[dB] = PL(d) + X\sigma = PL_{d_0} + 10nlog\left(\frac{d}{d_0}\right) + X\sigma$$

Where Xσ is a zero-mean Gaussian distributed random variable (in dB) with standard deviation σ (in dB)

The log normal distribution describes random shadowing effects which occur over a large number of measurement locations which have the same T-R separation, but have different levels on the clutter propagation path. This phenomenon is referred to as log-normal shadowing

The default values of standard deviation (dB) for all shadowing models in NetSim are as shown below:

Shadowing Model	Standard Deviation
Log Normal	5
Constant	5

4 Fading models

Fading is caused by interference between two or more versions of transmitted signal which arrive at the receiver at slightly different times. These waves, called multipath waves, combine at the receiver antenna to give a resultant signal which can vary widely in amplitude and phase, depending on the distribution of the intensity and relative propagation time of the waves and the bandwidth of the transmitted signal.

In built-up urban areas, fading occurs because the height of the mobile antennas are well below the height of surrounding structures, so there is no single line-of-sight path to the base station. The code for calculating fading power is present in fn_NetSim_IEEE802_11_Phy_In() function in IEEE_802_11.c file inside IEEE802_11 project.

The default values of Fading parameters in NetSim are as shown below:

Fading Model	**Parameter**	**Value**
Rayleigh	Scale Parameter	5
Nakagami	Fading Figure	5
	Shape parameter	1
	Scale Parameter	2

4.1 Nakagami Fading

The Nakagami distribution is related to the gamma distribution. In particular, given a random variable

$$Y \sim \gamma(K, \Theta)$$

it is possible to obtain a random variable

$$X \sim Nakagami\ (m, \Omega)$$

by setting k = m, ϴ= Ω/m and taking the square root of Y

$$X = \sqrt{y}$$

4.2 Rayleigh Fading

In mobile radio channels, the Rayleigh distribution is commonly used to describe the statistical time varying nature of the received envelope of a flat fading signal, or the envelope of an individual multipath component. It is well known that the envelope of the sum of two quadrature Gaussian noise signals obeys a Rayleigh distribution. The Rayleigh distribution has a probability density function (pdf) is given by

$$P(r) = \frac{r}{\sigma^2} exp\left(-\frac{r^2}{2\sigma^2}\right) \quad 0 <= r <= \infty$$

$$P(r) = 0 \qquad r < 0$$

Where σ = rms value of the received voltage signal before envelope detection

σ^2 = time-average power of the received signal before envelope detection

The probability that the envelope of the received signal does not exceed a specified value R is given y corresponding cumulative distribution function (CDF) is given by

$$P(R) \ = \Pr(r \leq R) = \int_0^R p(r)dr = 1 - \ exp \ (-\frac{R^2}{2\sigma^2})$$

The mean value r_{mean} of the Rayleigh distribution is given by

$$rmean \ = \ E[R] = \int_0^\infty rp(r)dr = \ \sigma\sqrt{\frac{\pi}{2}} = 1.2533\sigma$$

And the variance of the Rayleigh distribution is given by σ_r^2 which represents the ac power in the signal envelope

$$\sigma r^2 \ = \ E[r^2]\text{–} \ E^2[r] = \int_0^\infty r^2 p(r)dr - \frac{\sigma^2\pi}{2} = \ \sigma^2(2 - \frac{\pi}{2})$$

5 SINR Calculation

Analogous to the SNR used often in wired communications systems, the SINR is defined as the power of a certain signal of interest divided by the sum of the interference power (from all the other interfering signals) and the power of some background noise. The interference power is the difference between the total power received by the receiver and the power received from one particular transmitter.

The background thermal noise in dBm at room temperature is given by:

$$P \ (in \ dBm) = -174 + 10 \times log_{10}(\Delta f)$$

Where Δf is the Bandwidth in Hertz. For 802.15.4, Δf = 2 MHz. For 802.11a, b, g, Δf = 20 MHz, and for 802.11n, Δf = 20 MHz or 40 MHz

$$P \ (in \ mW) = 10^{\left(\frac{P \ (indBm)}{10}\right)}$$

Therefore, SINR in dBm is calculated as:

$$SINR \ (in \ dBm) = log_{10}\left(\frac{Received \ power \ (in \ mW)}{Interference \ Noise \ (in \ mW) \ + \ Thermal \ Noise \ (in \ mW)}\right)$$

Note: Floating numbers may lose precision when converting from dbm to mw or vice (Ref: https://msdn.microsoft.com/en-us/library/c151dt3s.aspx). Hence

- If the received power (in mw) is less than 0.0001 then it’s assumed to be zero.

- If the received power (in mw) is 0 then dbm value for same is -10000.0 not -∞
- While adding two powers, decimal points after fifth digit is ignored. Ex 2.0000005+3.0000012 = 5.0

6 Bit Error Rate (BER) Calculation

Note that the BER source codes are not open for user modification. If a user wishes to change the BER then they can comment NetSim's BER function call and write their own function. This can be written in C or it can be written in MATLAB (and a call made to MATLAB from NetSim).

$$SNR_{dB} = RxPower_{dB} - NoisePower_{dB}$$

$$Noise = kTB$$

$$SNR_{linear} = 10^{\frac{SNR_{dB}}{10}}$$

$$\frac{Eb}{N0} = SNR \times \frac{Bandwidth_{Hz}}{DataRate_{bitspersecond}}$$

6.1 BER Calculation for QAM

Computation of the exact bit error rate (BER) for square M-ary QAM (8, 16, 32, 64, 128 and 256 QAM)

$$P_b = \frac{1}{\log_2 \sqrt{M}} \sum_{k=1}^{\log_2 \sqrt{M}} P_b(k)$$

where

$$P_b = \frac{1}{\sqrt{M}} \sum_{j=0}^{(1-2^{-k}).\sqrt{M}-1} \left[(-1)^{\left\lfloor \frac{j.2^{k-1}}{\sqrt{M}} \right\rfloor} . \left(2^{k-1} - \left\lfloor \frac{j.2^{k-1}}{\sqrt{M}} - \frac{1}{2} \right\rfloor \right) . erfc \left((2.j+1) \sqrt{\frac{3(\log_2 M).r}{2(M-1)}} \right) \right]$$

and

$$r = \frac{E_b}{N_0}$$

6.2 BER Calculation for DQPSK, O-QPSK and QPSK

$$BER = 0.5 * ERFC \left(0.5 \times \frac{Eb}{N0} \right)^{\frac{1}{2}}$$

Note: The 802.15.4 2003 and 802.15.4 2006 standards used the formula BER = $\frac{8}{15} \times \frac{1}{16} \times \sum_k -1^k \binom{16}{k} e^{-20 \times SINR \times (\frac{1}{k}-1)})$ for O-QPSK which has since been changed

6.3 BER Calculation for DBPSK and BPSK

$$BER = 0.5 * ERFC \left(\frac{Eb}{N0}\right)^{\frac{1}{2}}$$

6.4 BER Calculation for LTE

In the case of LTE an SNR-BER table is looked up for each MCS.

7 References

- Ronell B. Sicat, "Bit Error Probability Computations for M-ary Quadrature Amplitude Modulation", EE 242 Digital Communications and Codings, 2009