On the Validation of Radio Propagation Models

Analytical validation of Network Simulator used Propagation and Bit Error Rates Models

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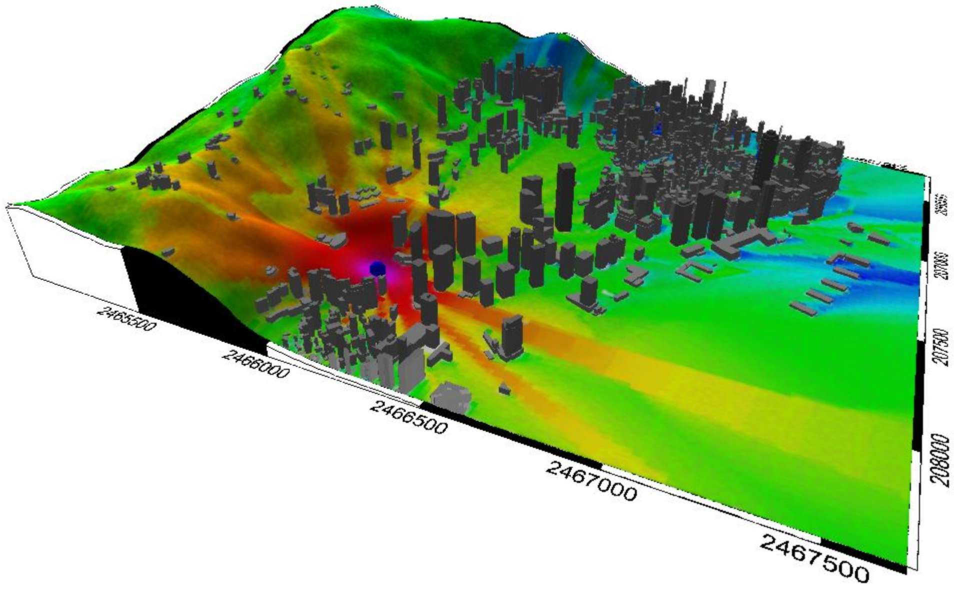
Disclaimer

- The initial purpose of this work was to verify and check the implementation of the *Nakagami Fading Model* in ns-3. At the half of the work I realized that the generated material is a good starting point for path loss in general. Especially to develop intuition how path loss influence the Wireless simulation at the whole. How model knobs influences the characteristic of the channel, etc.
- The complete work is public available and can be used for further investigation: `git clone http://git.jauu.net/wireless-propagation.git`
- Suggestion, enhancement or critic is highly welcome!

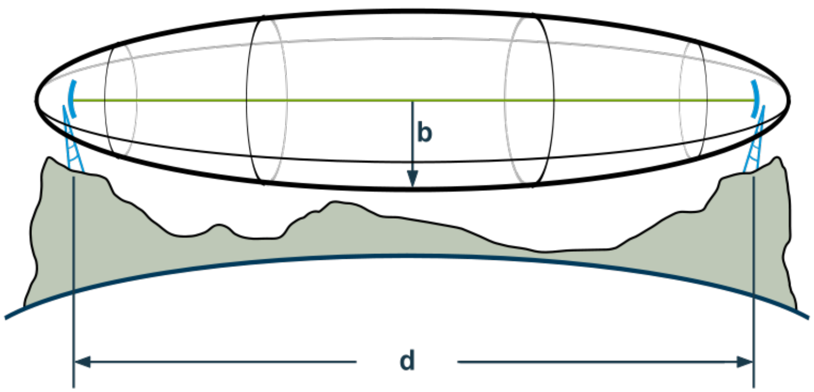
Introduction

- A Wireless channel is unsteady and lossy
- Wireless network simulators requires a model of this characteristic
- Most relevant parameters for wave propagation:
  1. Attenuation
  2. Slow Fading (shadowing)
  3. Fast Fading (multipath scattering)
- For the Symbol/Bit Error Rate (BER) the modulation scheme is crucial



Fresnel Zone

- The 1st Fresnel (pronounced Fray-nell) zone is a spheroid with its center along the shortest distance between antennas.
- If there are no obstacles in the space forming 60% of this distance, propagation characteristics are said to be the same as in free space
- Ensure line of sight between the transceivers
- If a Fresnel zone is not established, multipath interference will occur
- The Fresnelzone depends on the frequency: $> F \rightarrow \ < b$
- $F_n = \sqrt{\frac{n\lambda d_1 d_2}{d_1+d_2}}, \lambda = \frac{v}{f}$



Attenuation

- So how to calculate the attenuation of a channel?
- How to map slow- and fast fading conditions?

Friis

- Friis is a transmission equation gives the power received by one antenna under idealized conditions.
- Formula:

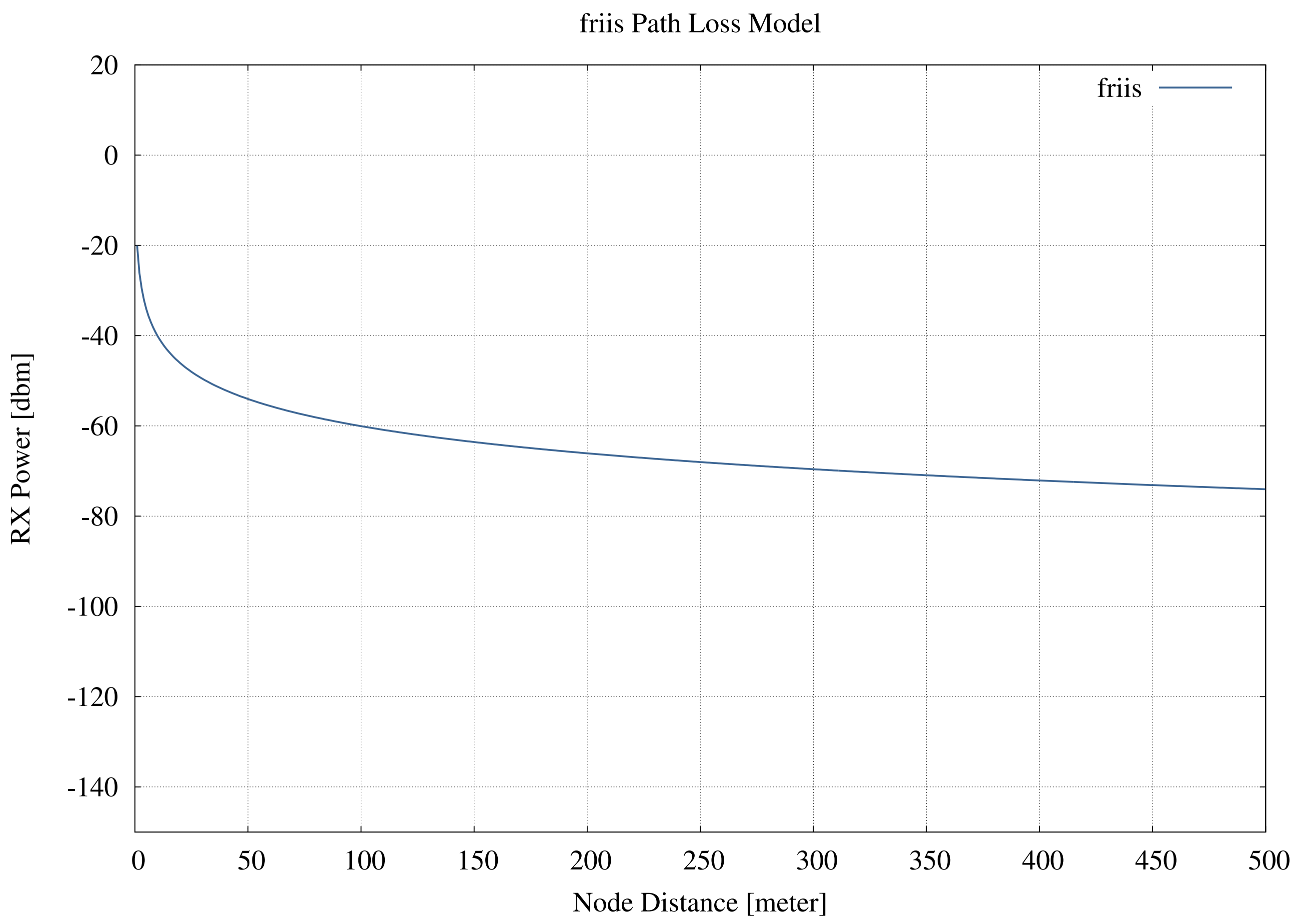
$$\frac{P_r}{P_t} = G_t G_r (\frac{\lambda}{4\pi R})^2$$

P_r Receiving power (dBm)
P_t Transmitter power (dBm)
G_t Antenna Gain Transmitter (dBi/dBd)
G_r Antenna Gain Receiver (dBi/dBd)
λ Wavelength (meter, ...)
R Distance between the nodes (meter, ...)

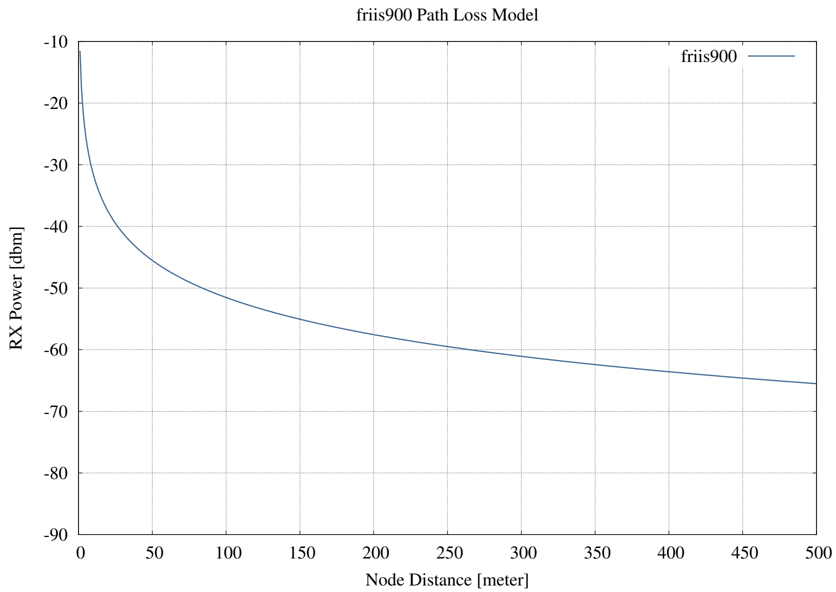
- But: ideal conditions are never achieved[1]

[1] one exception is satellite communications when there is negligible atmospheric absorption

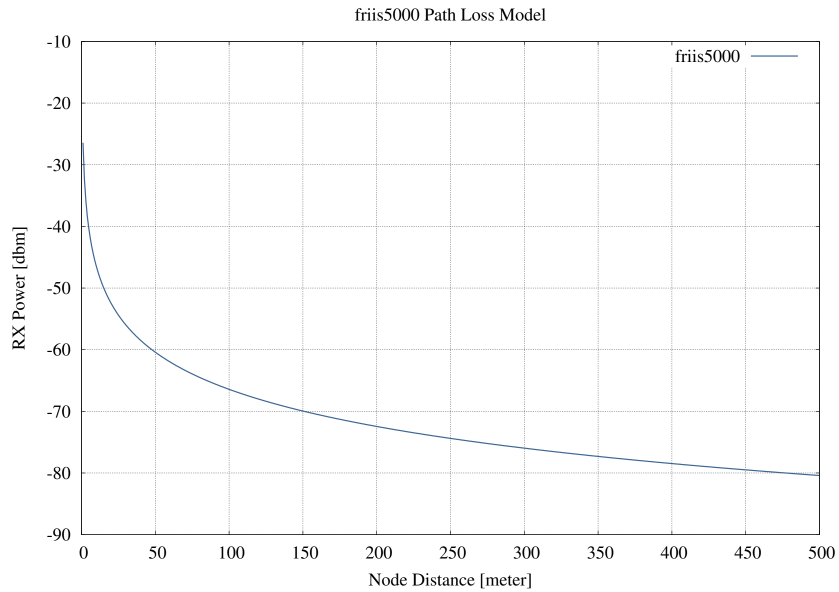
Friis


friis Path Loss Model
friis
RX Power [dbm]
20
0
-20
-40
-60
-80
-100
-120
-140
0
50
100
150
200
250
300
350
400
450
500
Node Distance [meter]

Friis Wavelength Influences



(a) Frequency: 900 Mhz (GSM)

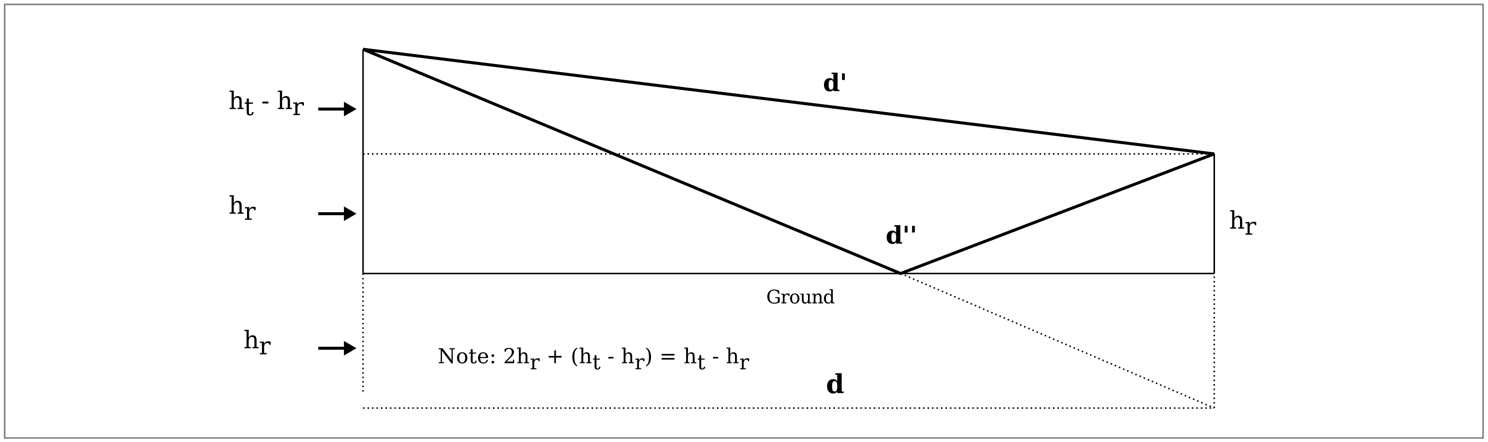


(b) Frequency: 5.0 GHz (802.11)

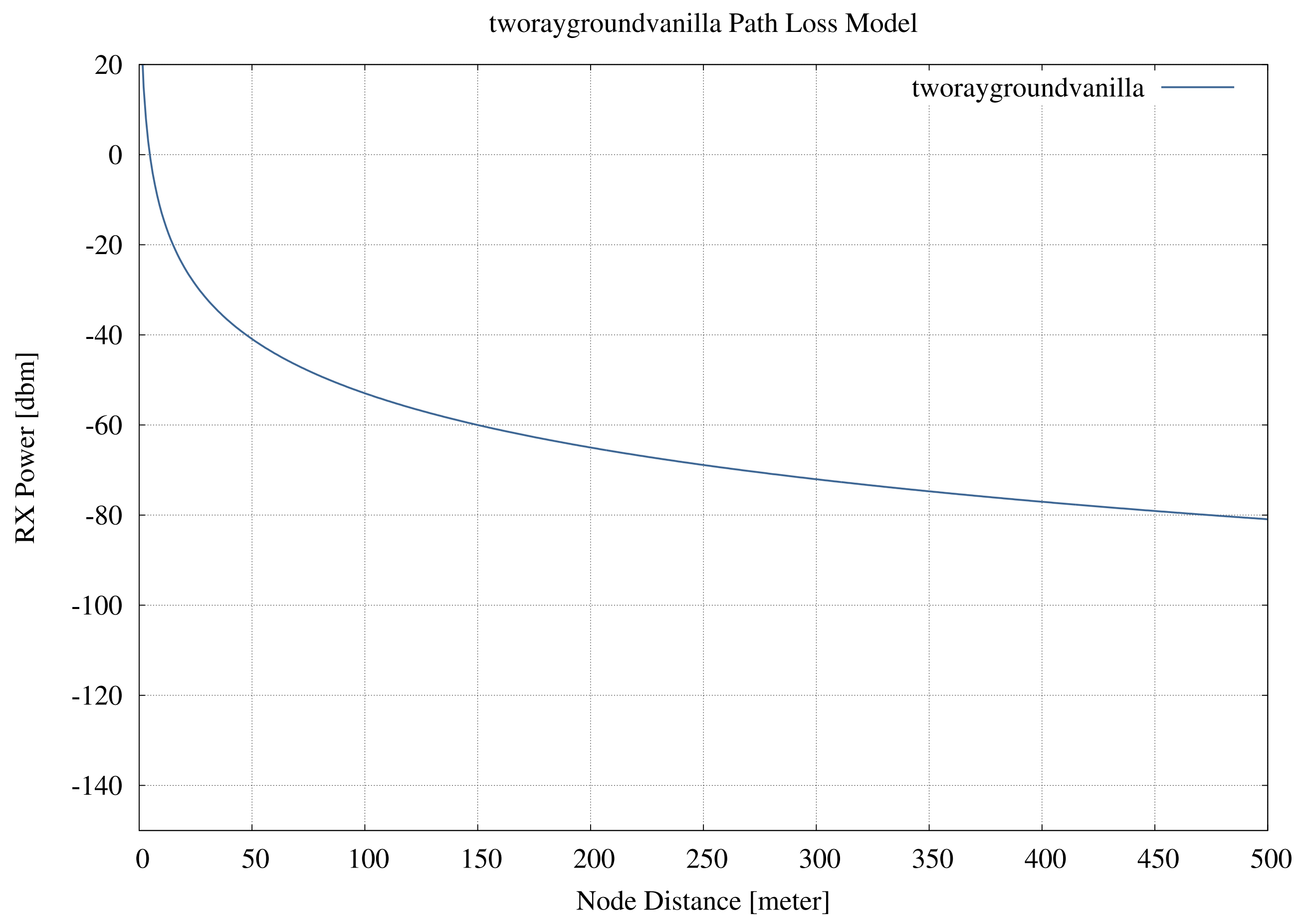
- The higher the frequency, the higher the loss.

Two Ray Ground

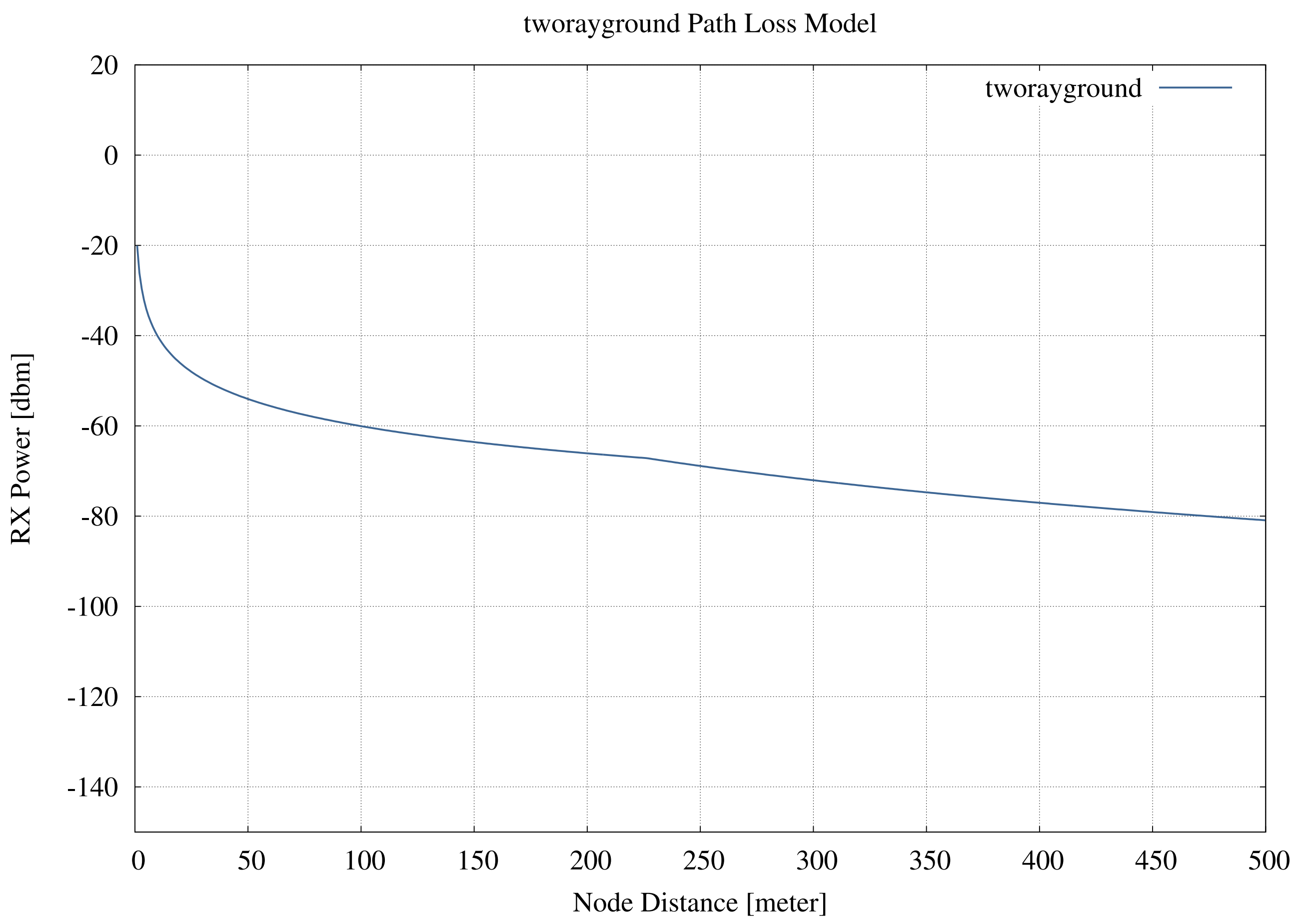
- Friis at long distance tends to accurate prediction
- The single line-of-sight path is seldom the only means of propagation
- The two-ray ground reflection model considers both the direct path and a ground reflection path
- $P_r(d) = \frac{P_t G_t G_r h_t^2 h_r^2}{d^4 L}$
  - L: 1
- Increased power loss compared to Free Space Model
- No good results for small distance $\longrightarrow$ use Free Space Model for near distances



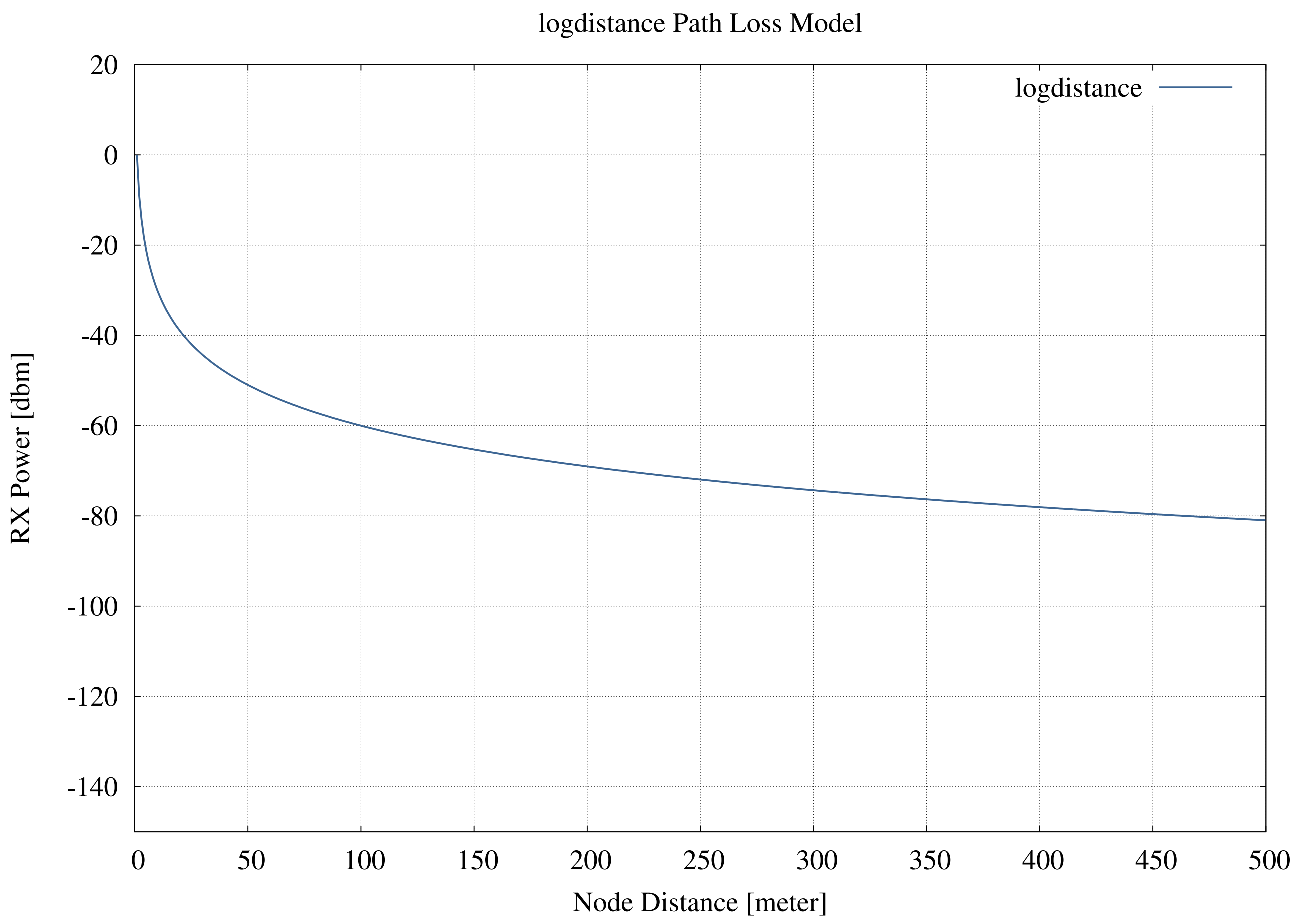
Two Ray Ground (vanilla)



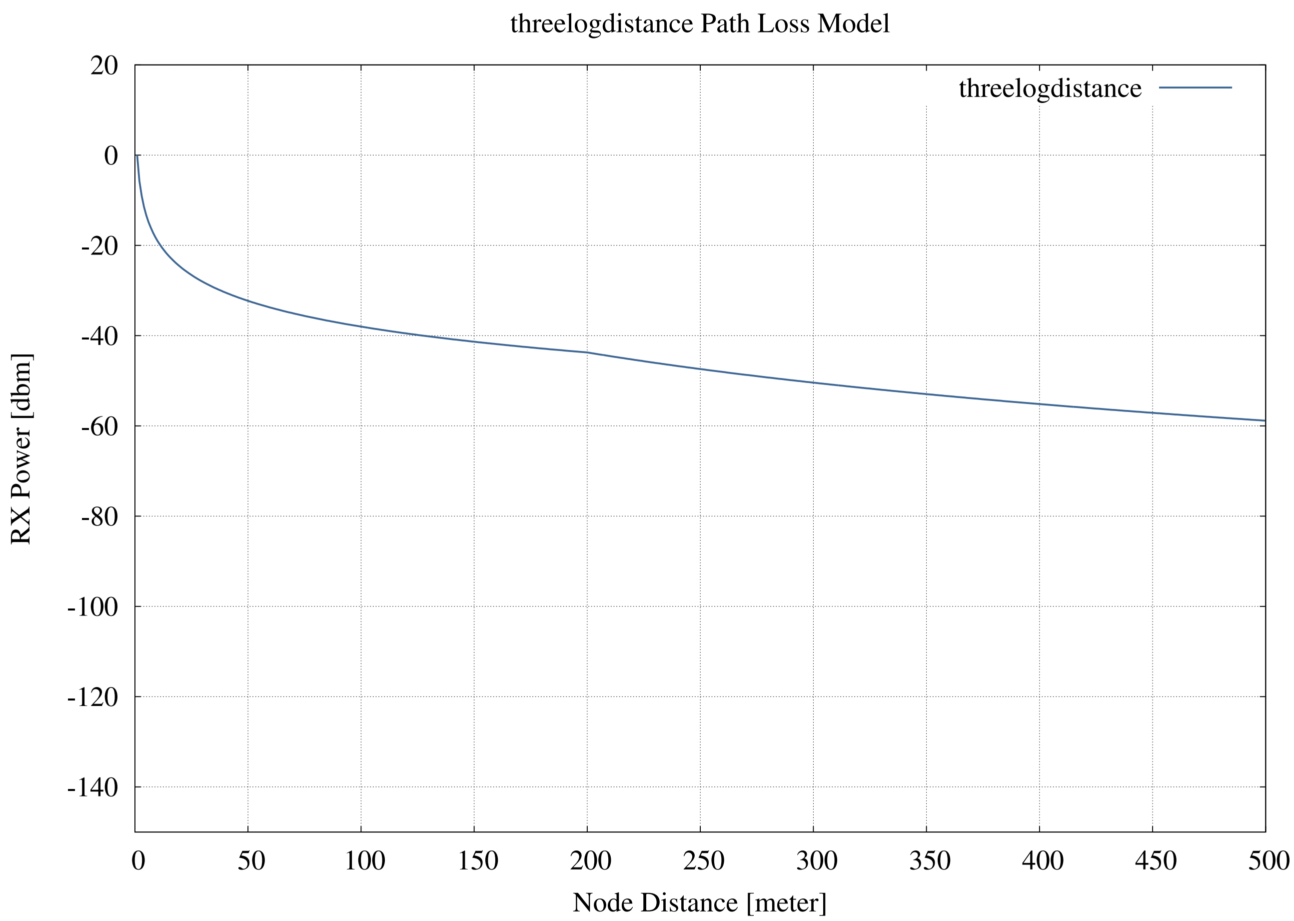
Two Ray Ground



Log Distance Model

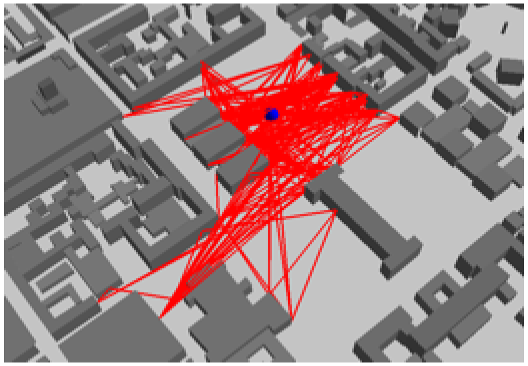


Three Log Distance Model



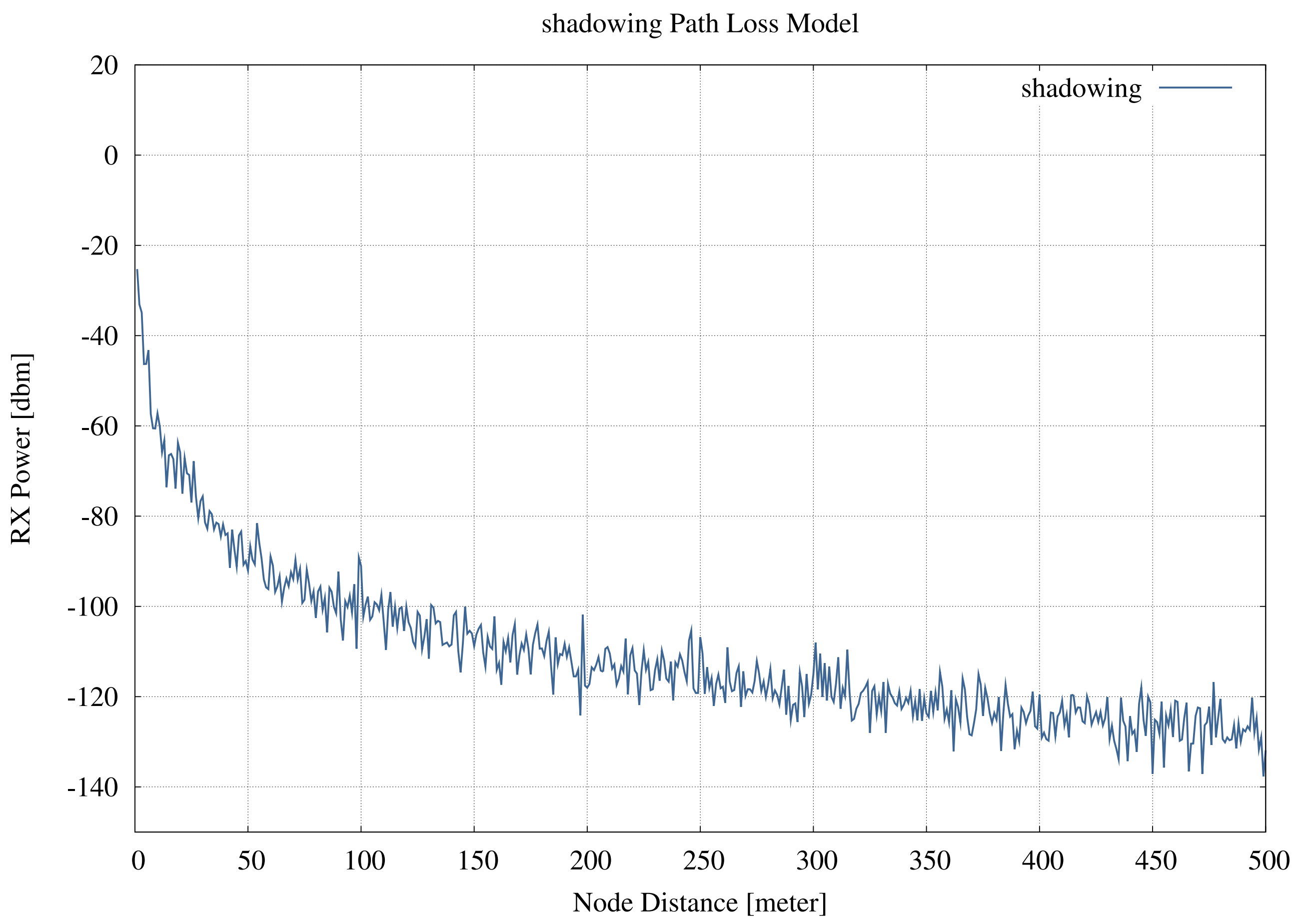
Fading

- Fading is deviation of the attenuation
- Reasons:
  - Shadowing from obstacles
  - Multipath propagation

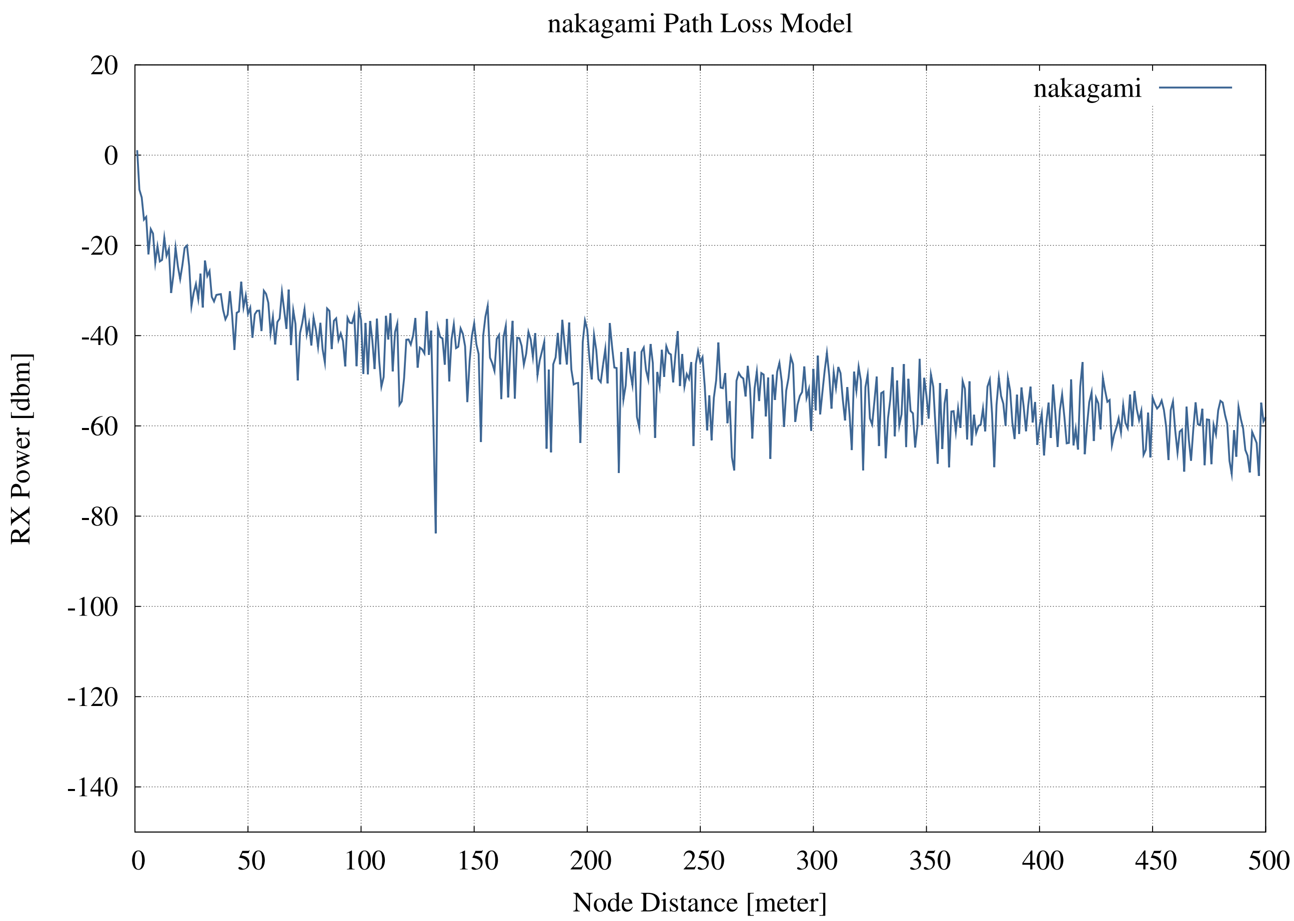


- Slow Fading
  - Roughly constant amplitude and phase change over time
  - Hills, buildings, ...
  - Often modeled using a log-normal distribution
- Fast fading
  - Amplitude and phase change varies considerably
  - Multiple reflections
- Modeled as a random process

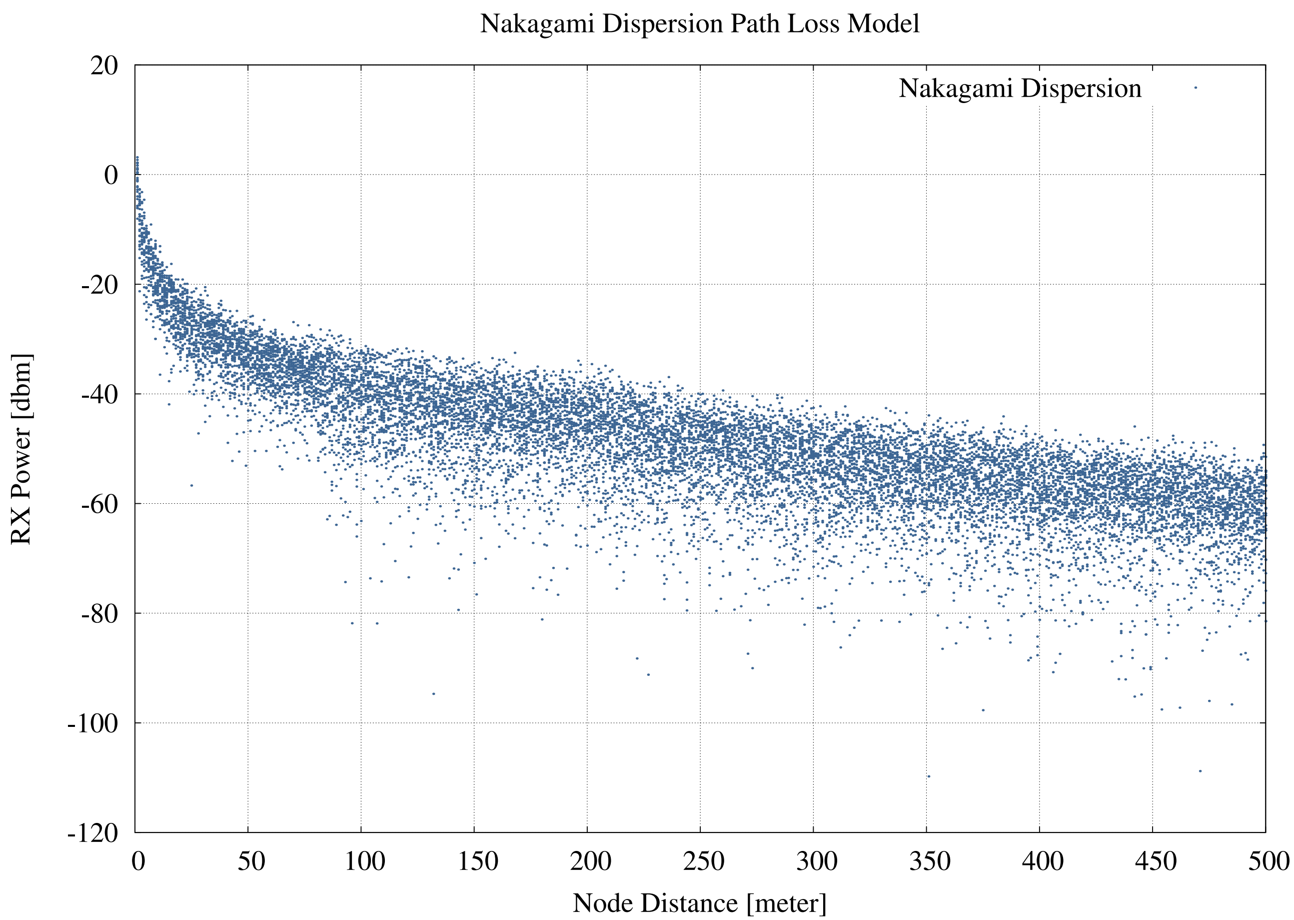
Shadowing Model



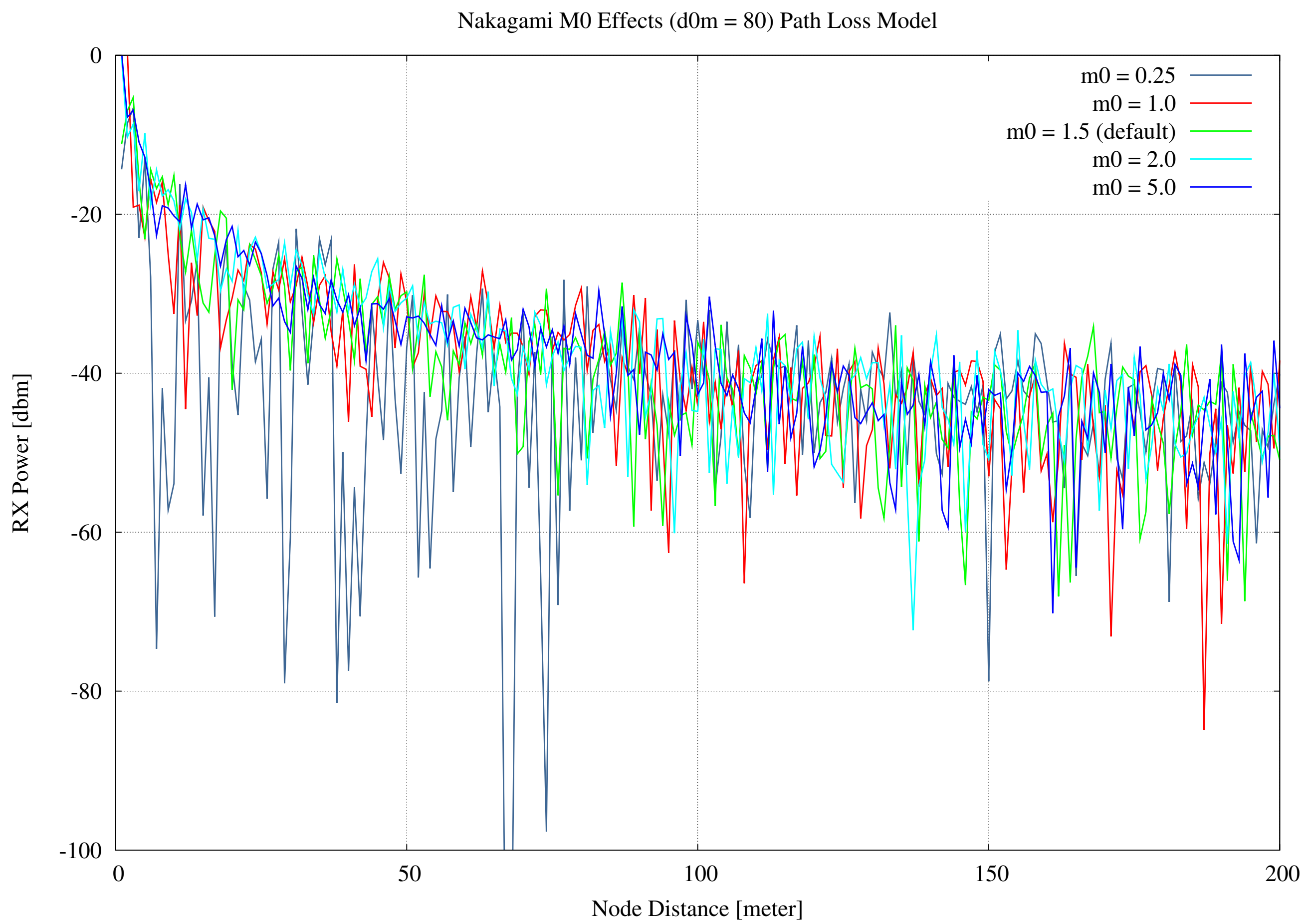
Nakagami Model



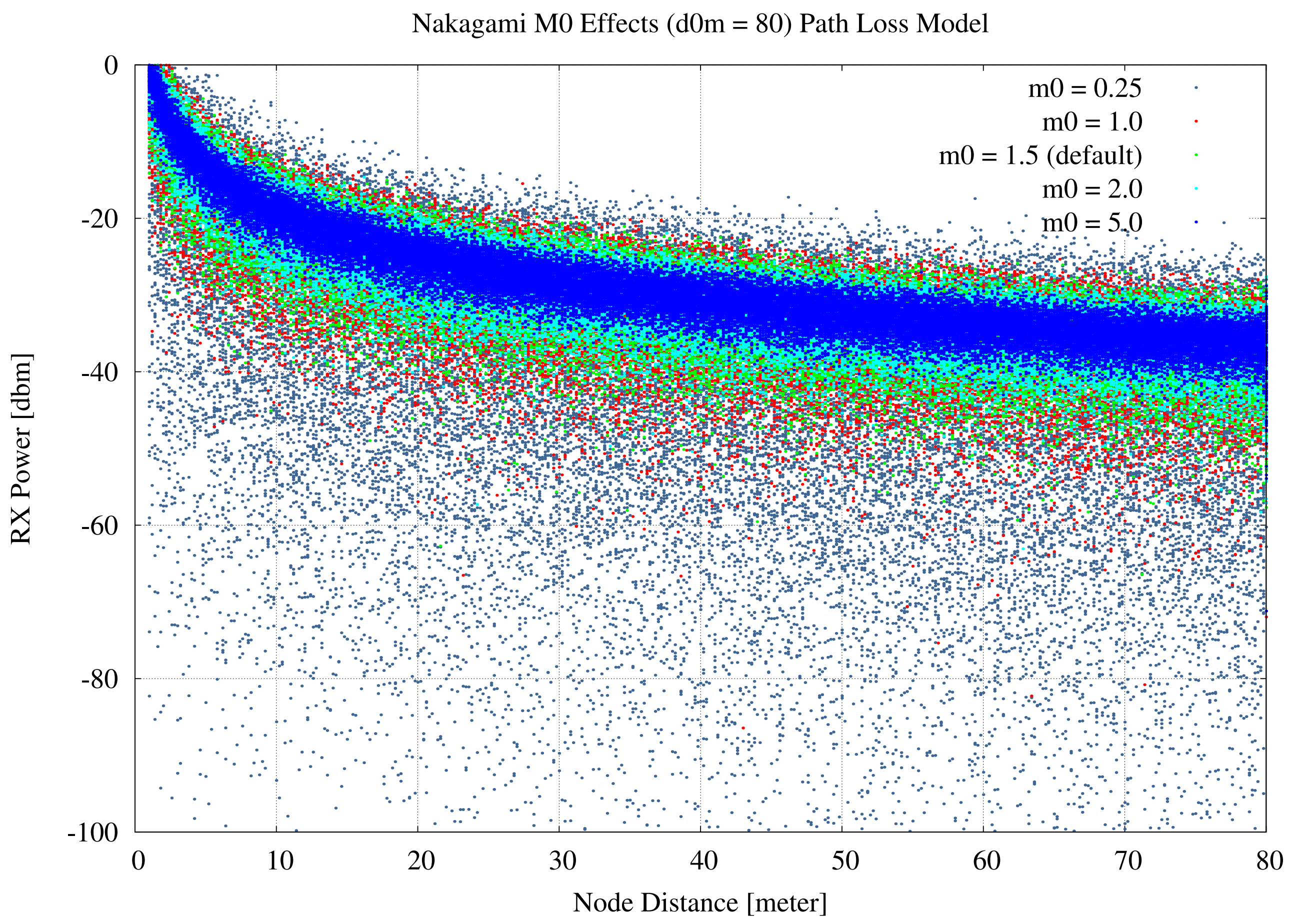
Nakagami Model Distribution



Nakagami Model m0 Effect



Nakagami Model m0 Effect



RX Power to SNR (1/2)

- Signal-to-Noise Ratio (SNR or S/N)
- Ratio of a signal power to the noise power corrupting the signal
- $SNR = \frac{P_{signal}}{P_{noise}}$
- Noise:
  - Boltzmann constant * Bandwidth * Receiver Noise * Implementation Loss
  - Boltzmann constant (k_B): 3.91^{-21} (B * Temp in Kelvin)
  - Bandwidth: 20^6 Hz
  - Receiver Noise: 15.8 W (12 dB)
  - Implementation Loss: 1.58 W (2 dB)

RX Power to SNR (2/2)

- Noise: 1.99^{-12} Watt $= -87dBm$
- Example:
  - Signal: -60 dBm
  - Noise: -87 dBm
  - SNR: -27 dB

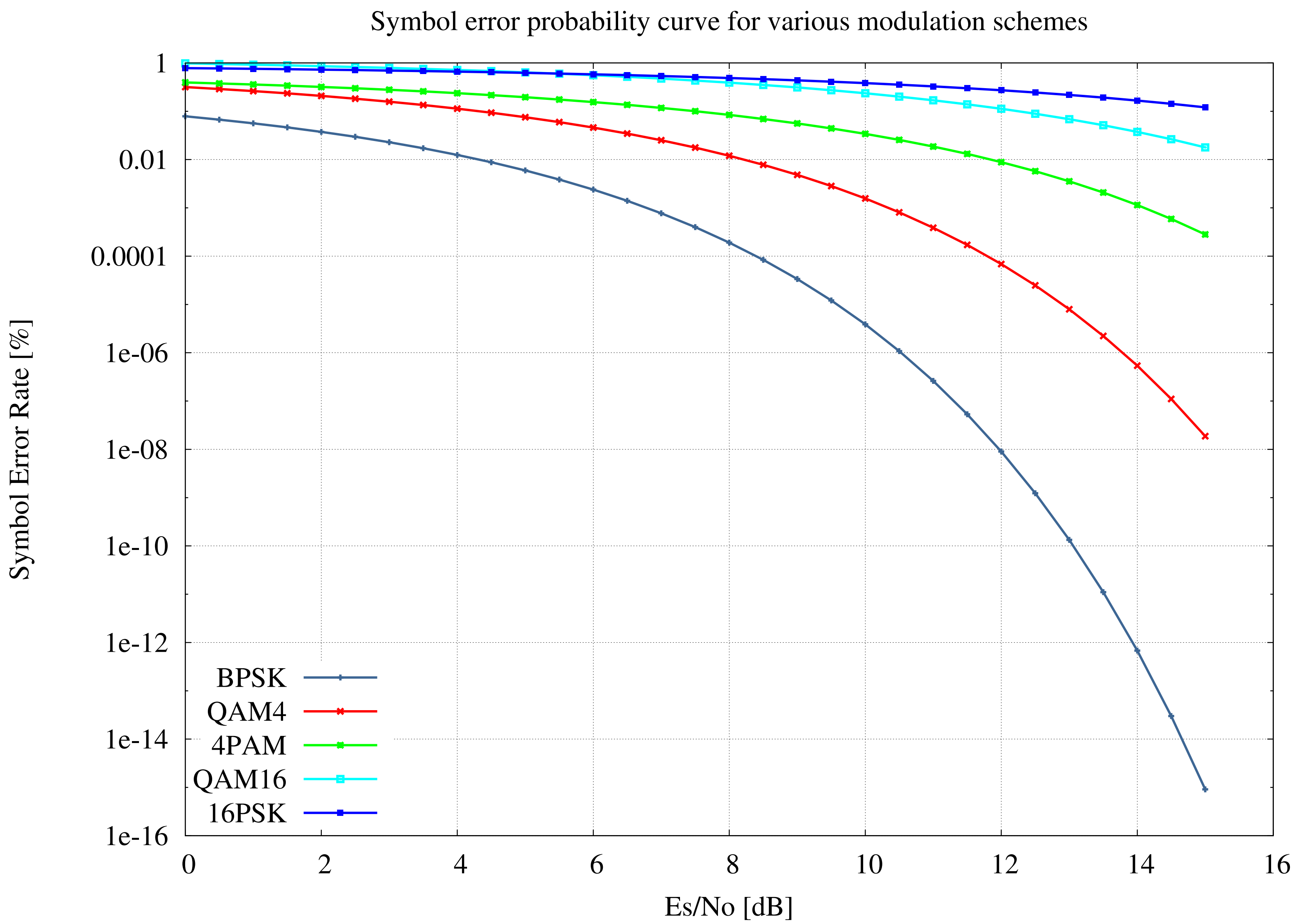
Symbol/Bit Error Rate (1/3)

- Symbol Error Rate
- Common digital modulation schemes:
  - Binary phase-shift keying (BPSK, 2 Symbols)
  - Quadrature phase-shift keying (QPSK, 4 Symbols)
  - 8 Phase-shift keying (8PSK, 8 Symbols)
  - n-Quadrature amplitude modulation (QAM, 16, 32, 64 Symbols)
  - ...

Symbol/Bit Error Rate (2/3)

- Symbol Error Rate vs. Es/No
- $P_{S,MQAM} = 2(1 - \frac{1}{\sqrt{M}})erfc(\sqrt{\frac{3}{2(M-1)}\frac{E_s}{E_0}}) - (1 - \frac{2}{\sqrt{M}} + \frac{1}{M})erfc^2(\sqrt{\frac{3}{2-(M-1)}\frac{E_s}{E_0}})$
- Inverse Error Function (also known as Gauss error function):
  - $erfc(x) = \frac{2}{\sqrt{\pi}}\int_x^\infty e^{-t^2}dt$
- Symbol Error Rate $\longrightarrow$ Bit Error Rate: $\frac{P_{S,MQAM}}{BitsperSymbol}$

Symbol/Bit Error Rate (3/3)



The End

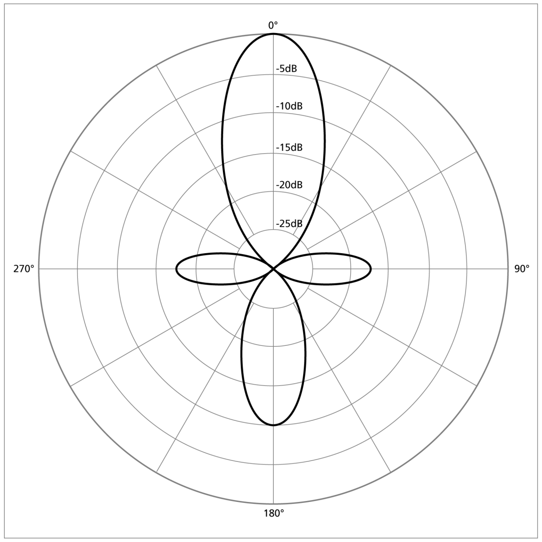
- Questions?

SINR and IPW2200

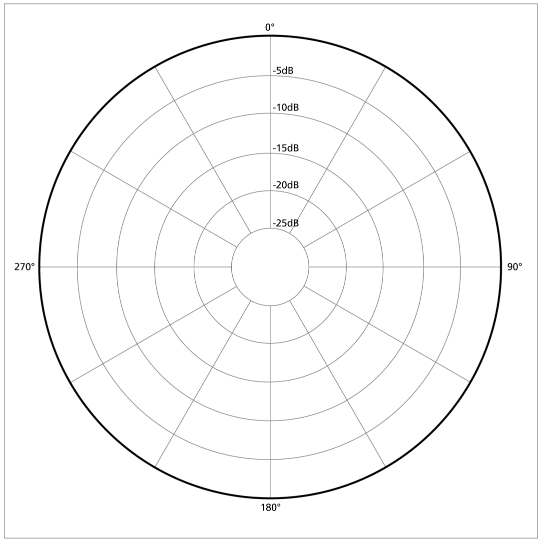
- Signal-To-Noise Ratio (aka SNR and S/R)
- snr(dB) = signal level(dBm) - average noise level(dBm)
- Ratio of a signal power to the noise power corrupting the signal
- To receive a useful information the signal must clearly be higher then the noise
- Sidenote IPW2200 driver and `/proc/net/wireless`
  - `iwconfig eth1` → Link Quality=69/100 Signal level=-55 dBm Noise level=-82 dBm
  - Noise: initial set to -85 dBm
  - Every new packet updates the noise level (and average it with the previous one)
  - `priv->exp_avg_noise`
  - RSSI: received signal strength indication
  - RSSI: a measurement of the power present in a received radio signal

- 0 to 255
- RSSI is acquired during the preamble stage of receiving an 802.11 frame
- RSSI is stored on the RX descriptor (stats.rssi) and is measured by baseband and PHY for each individual packet
- see `drivers/net/wireless/ipw2x00/ipw2200.c:ipw_rx()`

Some Background on Antennas



- Basic types
  - Omnidirectional
  - Semi-directional
  - Directional
- Omnidirectional
  - Omnidirectional antennas radiate energy equally in all directions around the antenna's vertical axis
  - Most common for WLAN: dipole antenna



- Semi-Directional
  - Patch
  - Panel
  - Yagi
  - Common examples: TV antennas or Cellular repeaters antennas

- Highly Directional
  - Parabolic dish
  - Grid antenna

Common dbM/Watt Values[2]

- 80 dBm 100 kW Typical transmission power of FM radio station with 50 km range
- 60 dBm 1 kW = 1000 W Typical combined radiated RF power of microwave oven elements
- 33 dBm 2 W Maximum output from a UMTS/3G mobile phone (Power class 1 mobiles)
- 30 dBm 1 W = 1000 mW Typical RF leakage from a microwave oven
- 20 dBm 100 mW Bluetooth Class 1 radio, 100 m range
- 15 dBm 32 mW Typical WiFi transmission power in laptops
- 4 dBm 2.5 mW Bluetooth Class 2 radio, 10 m range
- 0 dBm 1.0 mW = 1000 muW Bluetooth standard (Class 3) radio, 1 m range
- -10 dBm 100 muW Typical maximum received signal power (-10 to -30 dBm) of wireless network

[2] Source: WP

- -70 dBm 100 pW Typical range (-60 to -80 dBm) of wireless (802.11x) received signal power over a network
- -127.5 dBm 0.178 fW = 178 aW Typical received signal power from a GPS satellite
- -174 dBm 0.004 aW = 4 zW Thermal noise floor for 1 Hz bandwidth at room temperature (20 C)