Wireless Channel Modeling: Basics

Amitangshu Pal

Free space propagation

Isotropic transmission ➔ at distance *d*, the power is distributed over the surface of a sphere of distance *d*

$$P_r(d) = \frac{P_t}{4\pi d^2}$$

Receiver antenna provides an aperture with an effective area for catching a fraction of this power

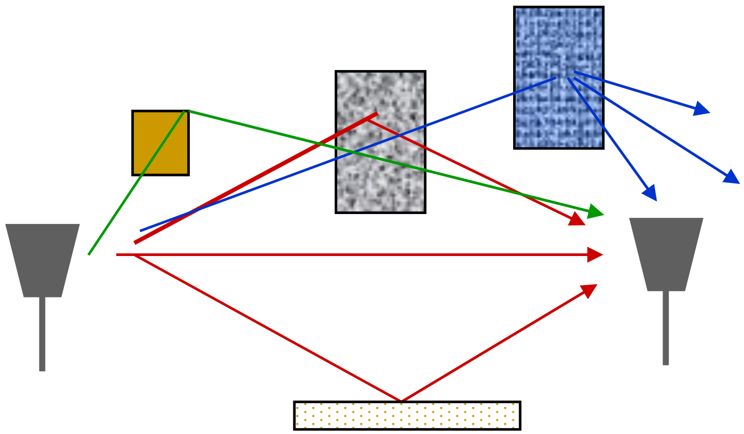
If the transmitter uses a directional antenna:

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

$$P_L(d) = \frac{P_t}{P_r} \qquad \therefore P_L(d) \propto d^2$$

Source of Inaccuracies

- Signal components goes through
  - Reflections
  - Scattering
  - Diffraction



- Signal attenuation from obstructions
  - Random due to random # and type of obstructions

Simplified Path Loss Model

- Used when path loss dominated by reflections
- Most important parameter is the path loss exponent n, determined empirically

$$P_L(d) \propto d^n \qquad 2 \le n \le 8$$

$\boldsymbol{n}$ → **Path loss exponent**

Combined Path Loss and Shadowing

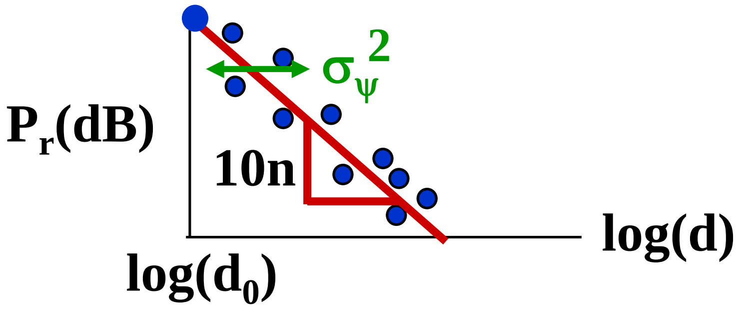
$$P_L(d) \propto d^n \qquad \therefore \frac{P_L(d)}{P_L(d_0)} = \frac{d^n}{d_0^n}$$

$$[P_L(d)]dB = [P_L(d_0)]dB + 10n\log_{10}\left(\frac{d}{d_0}\right)$$

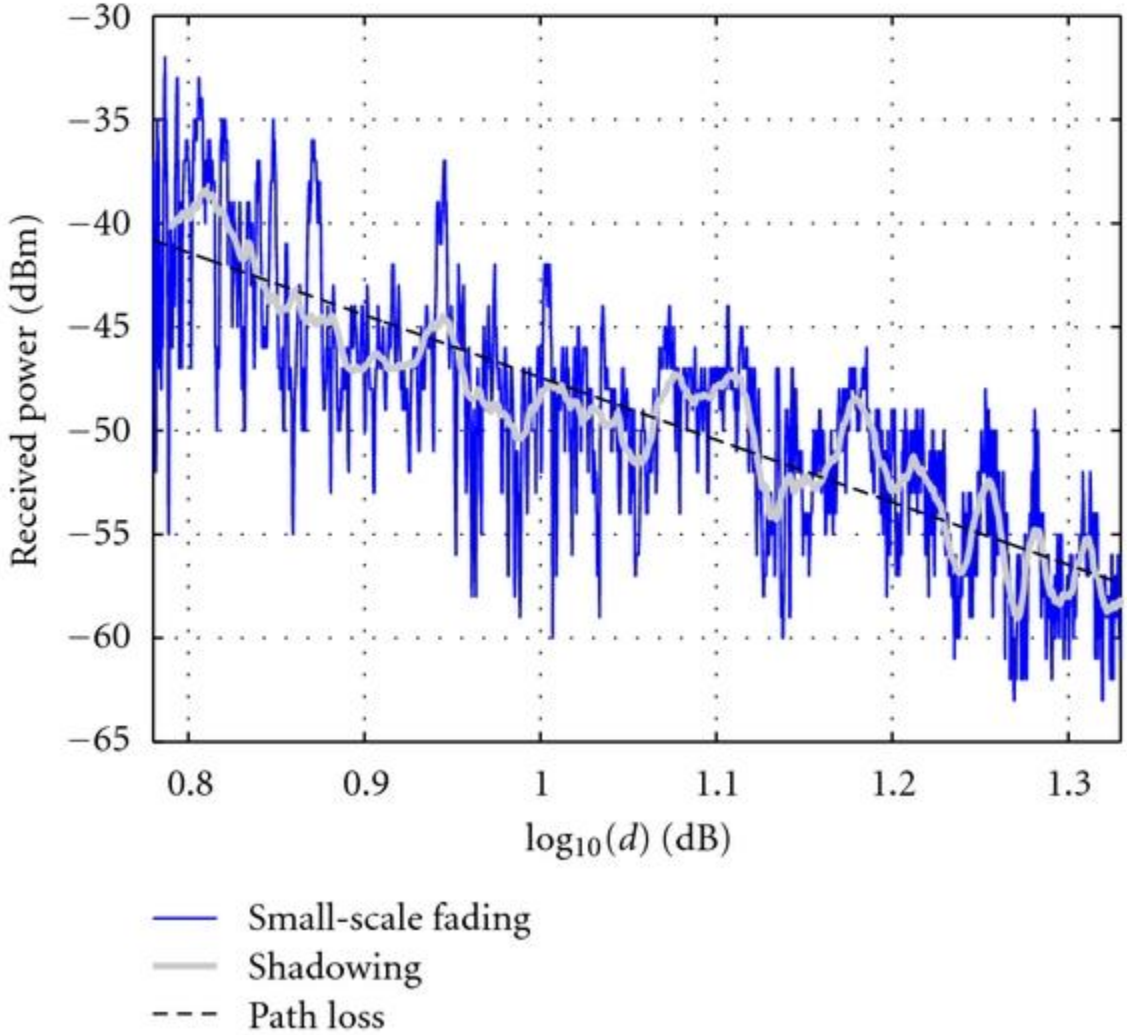
$$[P_L(d)]dB = [P_L(d_0)]dB + 10n\log_{10}\left(\frac{d}{d_0}\right) + \chi; \qquad \chi = \mathbb{N}(0, \sigma^2)$$

$$\begin{aligned} P_r(d)[dBm] &= P_t(d)[dBm] - P_L(d)[dB] \\ &= P_t(d)[dBm] - [P_L(d_0)]dB - 10n\log_{10}\left(\frac{d}{d_0}\right) + \chi \end{aligned}$$

Log Normal Shadowing Model

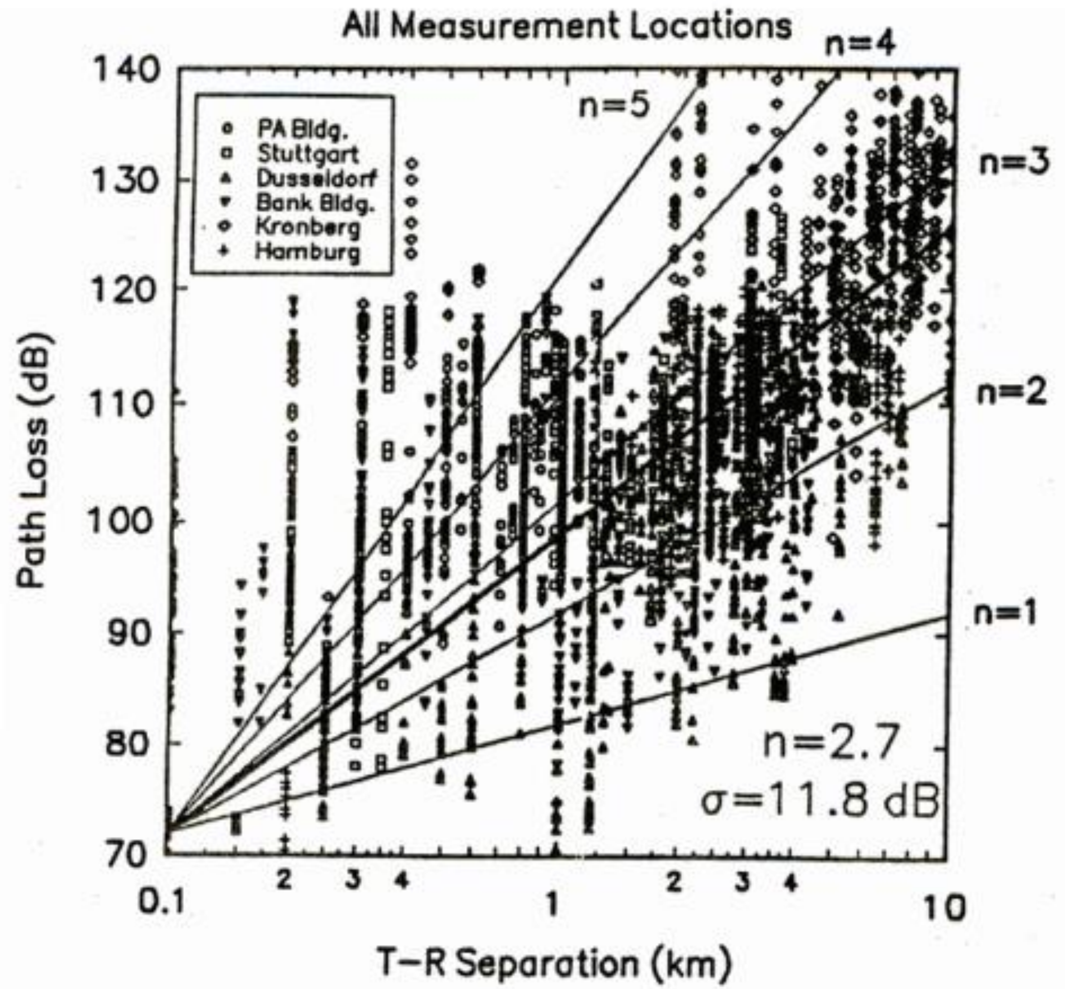


Combined Path Loss and Shadowing



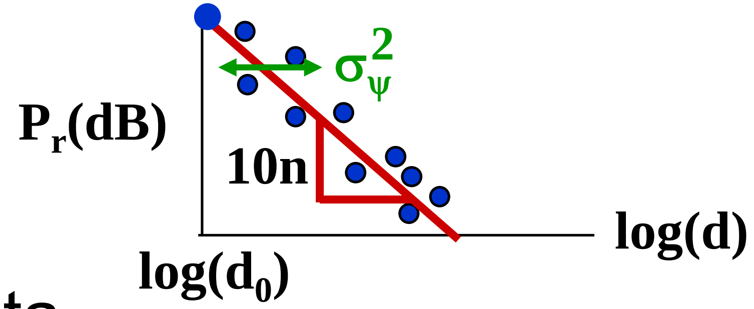
https://www.hindawi.com/journals/jr/2011/340372/fig6/

Combined Path Loss and Shadowing



Scatter plot of measured data and corresponding MMSE path loss model cities in Germany. For this data, $n = 2.7$ and $\sigma = 11.8$ dB

Model Parameters from Empirical Measurements



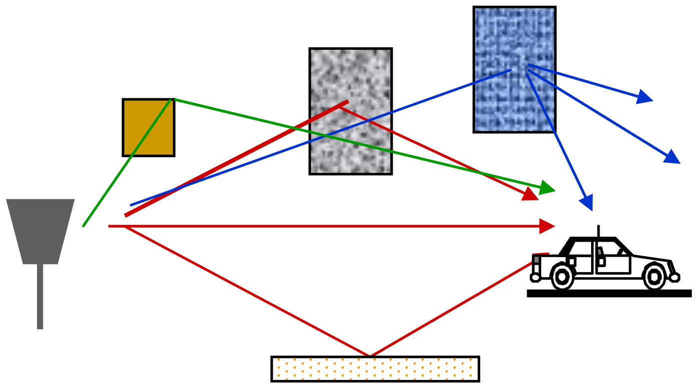
- Finding n
- Path loss at d_0 known:
  - "Best fit" line through dB data
  - Exponent is MMSE estimate based on data
  - Captures mean due to shadowing
- Shadowing variance
  - Variance of data relative to path loss model (straight line) with MMSE estimate for n

Model Parameters from Empirical Measurements

Environment	Path Loss Exponent (n)
Free space	2
Urban area cellular radio	2.7 to 3.5
Shadowed urban cellular radio	3 to 5
Inside a building - line-of-sight	1.6 to 1.8
Obstructed in building	4 to 6
Obstructed in factory	2 to 3

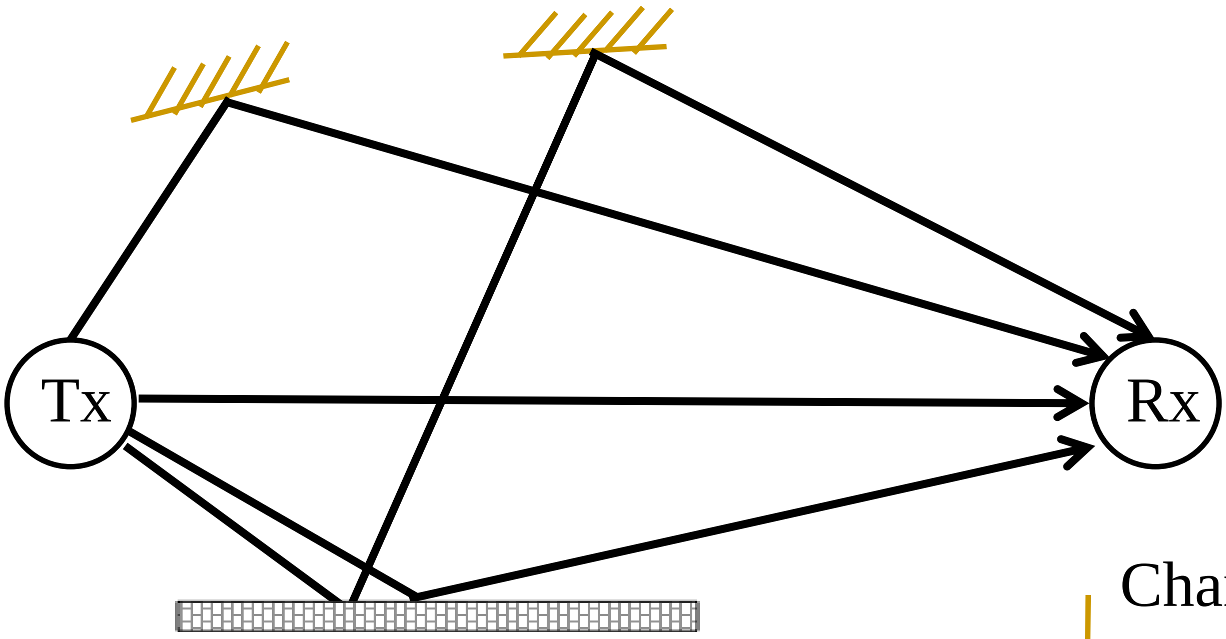
https://www.gaussianwaves.com/2013/09/log-distance-path-loss-or-log-normal-shadowing-model/

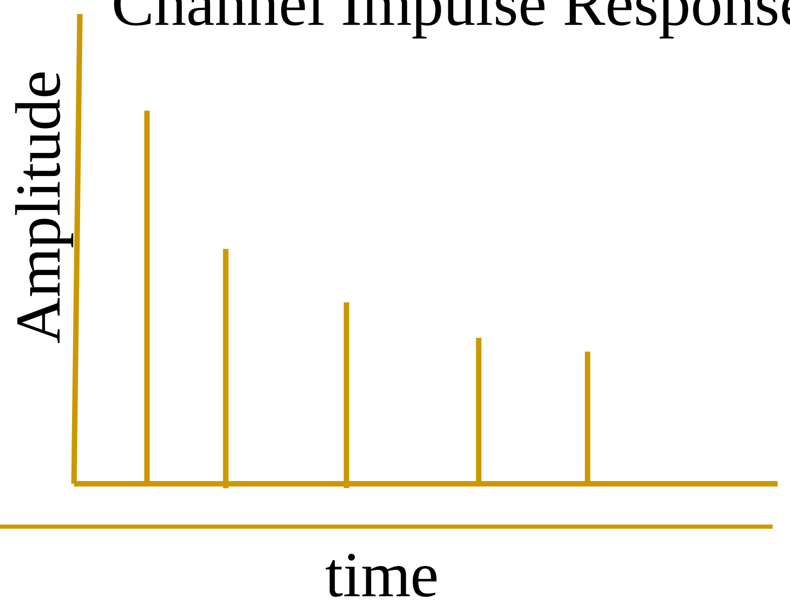
Statistical Multipath Model



- Multiple signal components reach at the receiver, each with
  - Different amplitude
  - Different phase
  - Different delay
- Random components change with time
- Leads to time-varying channel impulse response

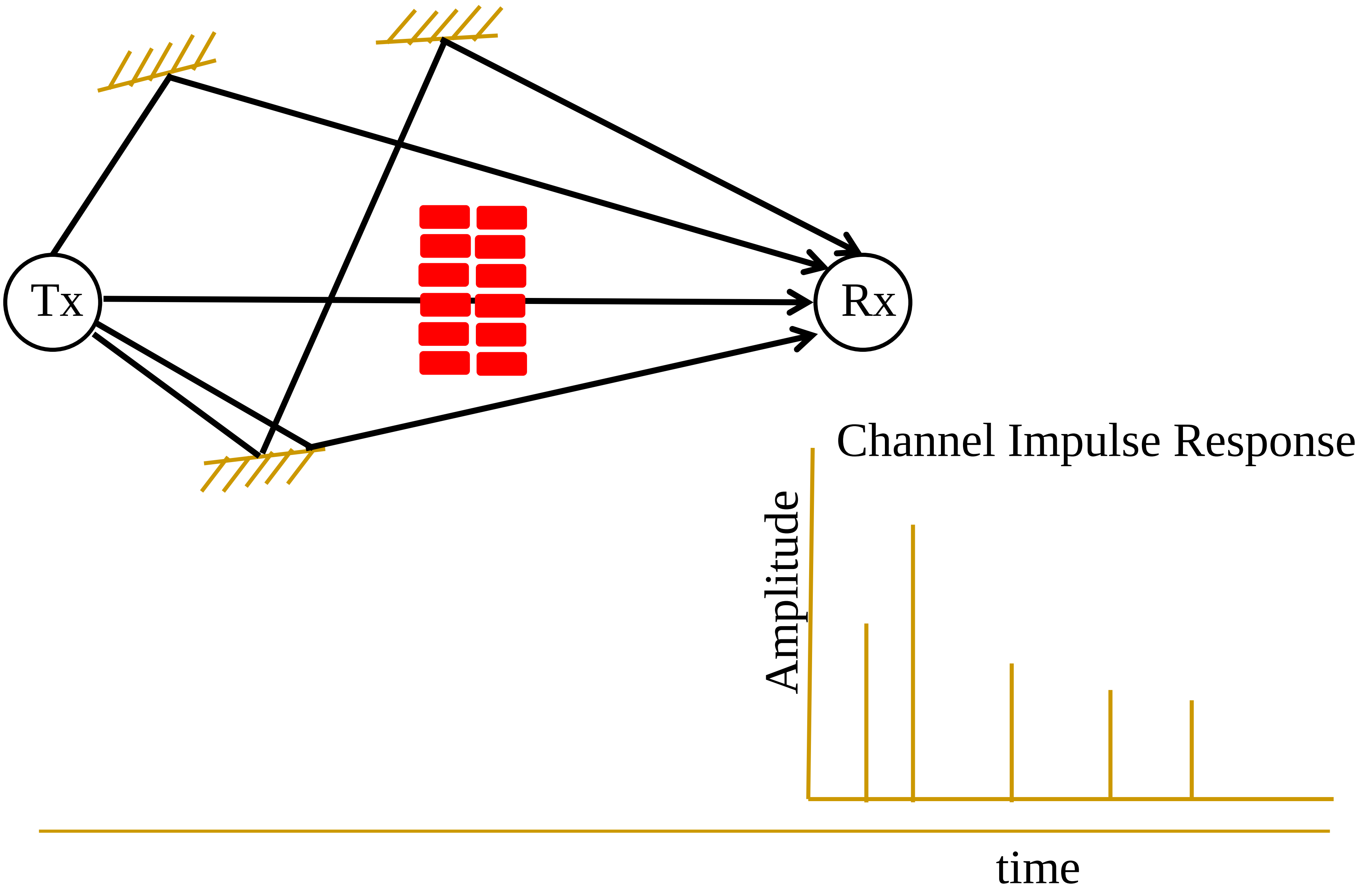
Statistical Multipath Model





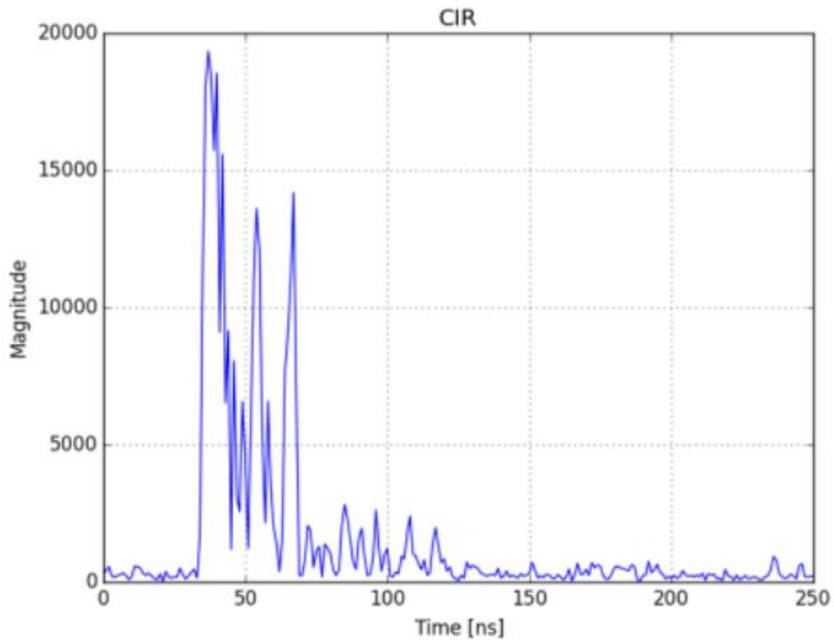
https://www.slideserve.com/holly/indoor-localization-using-fingerprinting

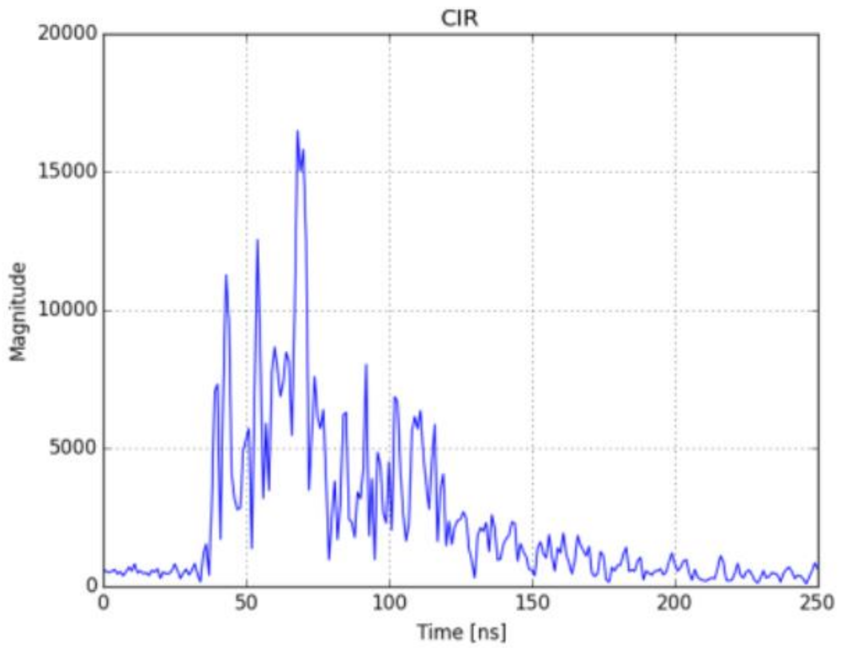
Statistical Multipath Model



https://www.slideserve.com/holly/indoor-localization-using-fingerprinting

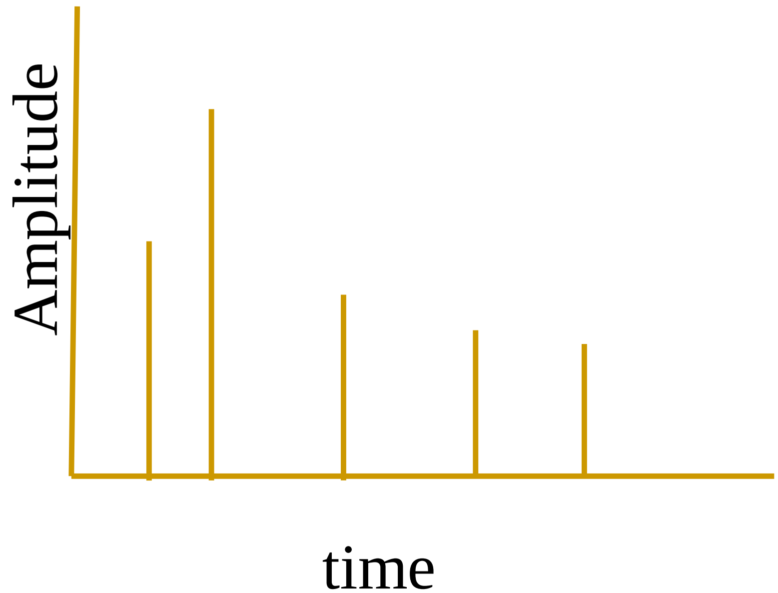
Statistical Multipath Model





Bregar, Klemen & Hrovat, Andrej & Mohorcic, Mihael. (2016). NLOS Channel Detection with Multilayer Perceptron in Low-Rate Personal Area Networks for Indoor Localization Accuracy Improvement.

Channel Impulse Response



$$h(t) = \overbrace{a_0\delta(t-\tau_0)}^{\text{Multipath Component}} + a_1\delta(t-\tau_1) + \ldots + a_{L-1}\delta(t-\tau_{L-1}) =$$

impulse Response of Wireless Channel

$$\boxed{= \sum_{i=0}^{L-1} a_i\delta(t-\tau_i)}$$

https://www.slideserve.com/holly/indoor-localization-using-fingerprinting