Wireless Channel Modeling

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Antennas

- Electrical conductors used to radiate or collect electromagnetic energy

- Transmission antenna: Electrical energy → converted to electromagnetic energy → radiated into the surrounding

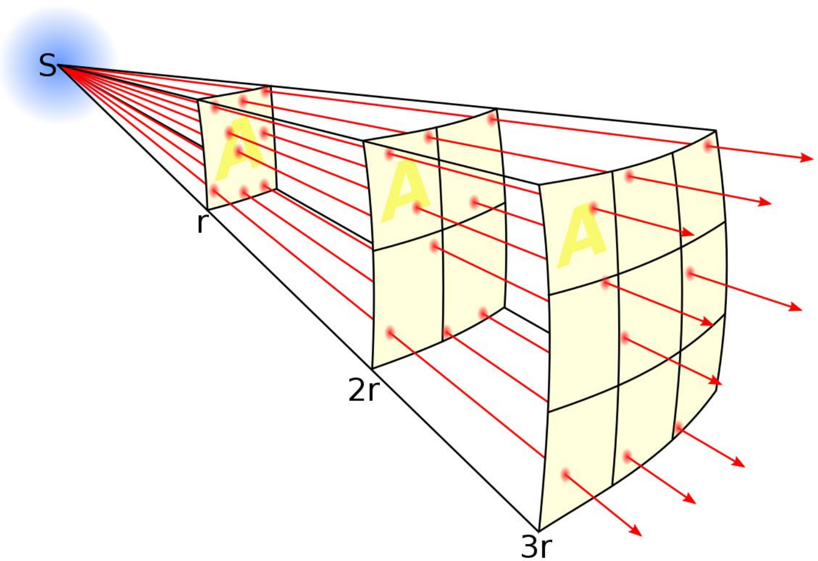
- Reception antenna: Electromagnetic energy → converted to electrical energy → fed to the receiver

Isotropic Antennas

❑ Isotropic antenna:

- A point in space that radiates power in all directions equally with a spherical radiation pattern

$$\frac{P_t}{P_r} = \left(\frac{4\pi d}{\lambda}\right)^2 = \left(\frac{4\pi f d}{c}\right)^2$$



Src: https://en.wikipedia.org/wiki/Free-space_path_loss

Isotropic Antennas

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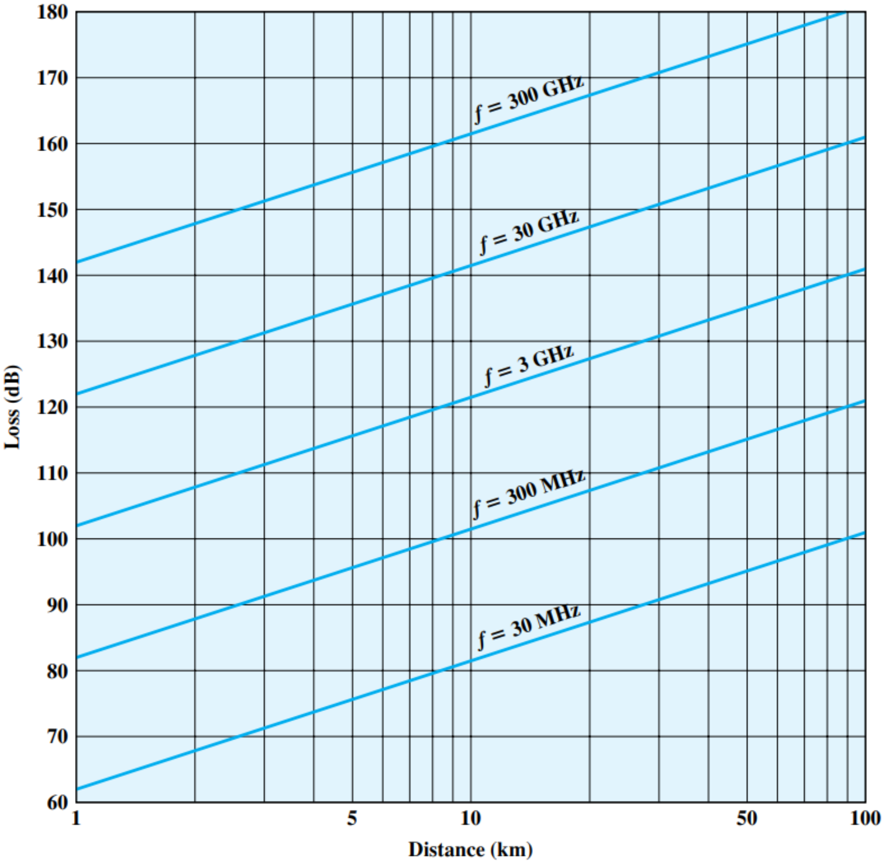
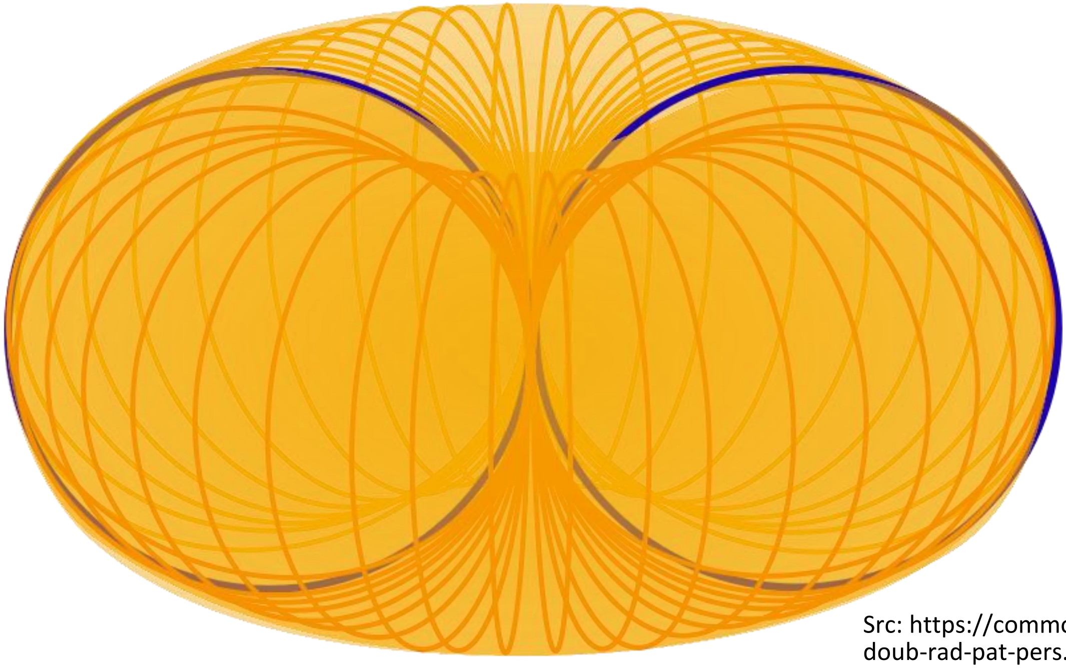


Omni-directional Antennas

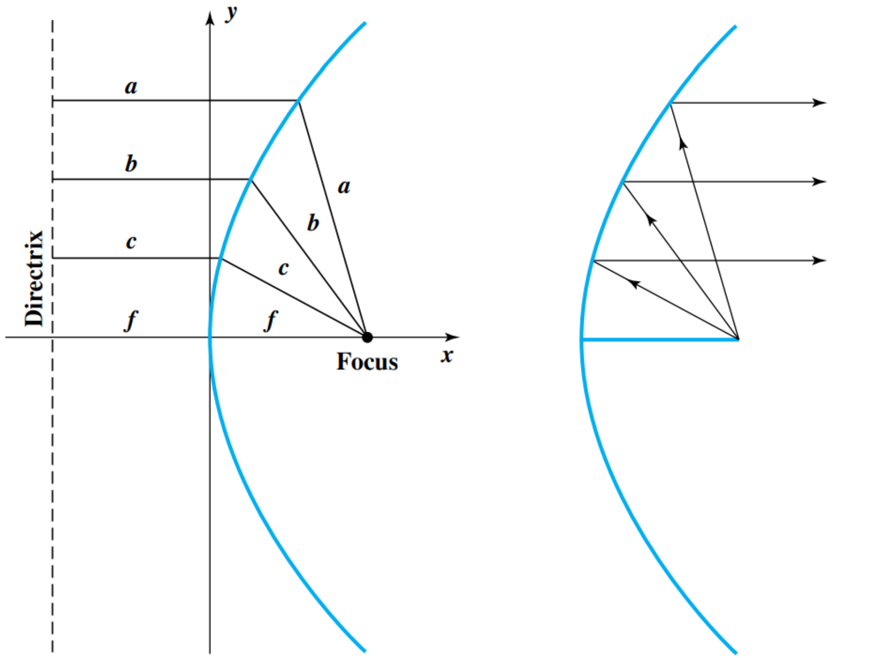
- Omni-directional antenna: power propagates uniformly in all directions in a plane
  - Cell phones, FM radios, walkie-talkies etc.



Src: https://commons.wikimedia.org/wiki/File:Elem-doub-rad-pat-pers.svg

Directional Antennas

❑Directional antenna: Parabolic reflective antenna



(a) Parabola

(b) Cross section of parabolic antenna showing reflective property

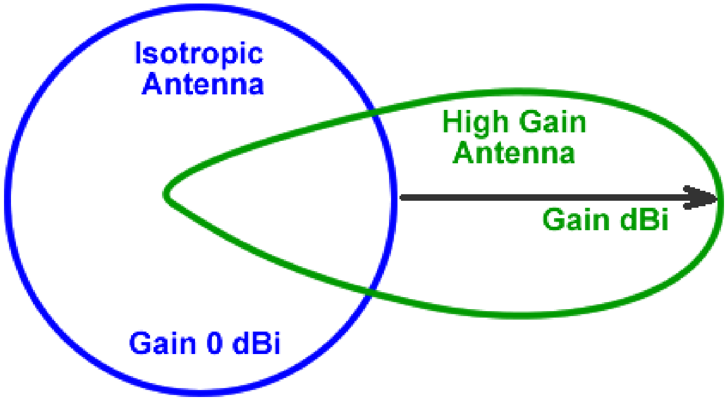
Antennas

- Directional antenna: Parabolic reflective antenna
  - Satellite communications, radio telescopes etc.

Src:https://commons.wikimedia.org/wiki/File:Antenna_03.JPG

Antenna Gain

- Antenna gain:
  - Measure of directionality
  - Defined as the power output in a particular direction, compared to that produced in any direction by a perfect isotropic antenna (dBi)
  - http://www.cisco.com/en/US/prod/collateral/wireless/ps7183/ps469/product_data_sheet09186a008008883b.html



Src: https://www.ahsystems.com/articles/Understanding-antenna-gain-beamwidth-directivity.php

Radiated power of isotropic antenna

$$G_{dB} = 10\log_{10}\frac{P_i}{P_d}$$

Radiated power of directional antenna

Free Space Path Loss

❑ Free space path loss:

$$\frac{P_t}{P_r} = \frac{1}{G_t G_r}\left(\frac{4\pi d}{\lambda}\right)^2 = \frac{1}{G_t G_r}\left(\frac{4\pi f d}{c}\right)^2$$

- G_t: Transmit antenna gain
- G_r: Receiver antenna gain
  - Receiver antenna provides an aperture with an effective area for receiving a fraction of the transmitted power

Path Loss

- Free space path loss:

$$P_L(d) = \frac{P_t}{P_r} = \frac{1}{G_t G_r}\left(\frac{4\pi d}{\lambda}\right)^2 = \frac{1}{G_t G_r}\left(\frac{4\pi f d}{c}\right)^2 \qquad \therefore P_L(d) \propto d^2$$

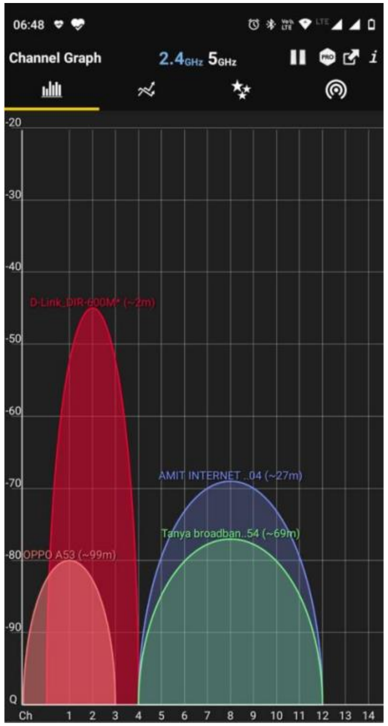
- Signal goes through
  - Reflections
  - Scattering
  - Diffractions
  - Attenuation due to obstructions

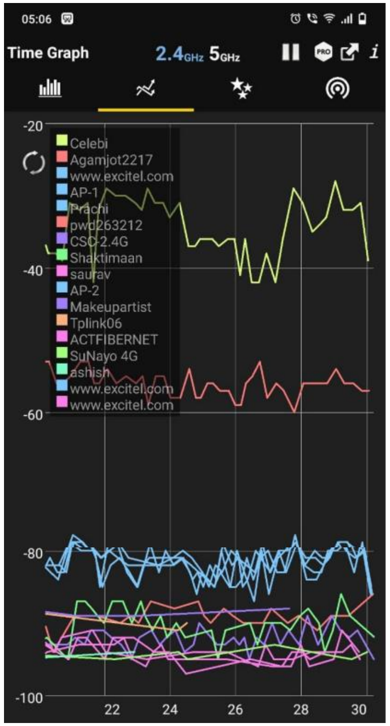
- In general: $P_L(d) \propto d^n \quad 2 \leq n \leq 8$

$n \rightarrow$ Path loss exponent

Path Loss

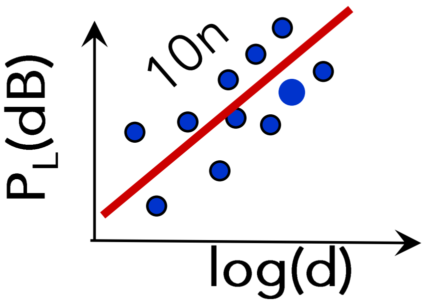
- Data from Wifi Analyzer: https://play.google.com/store/apps/details?id=com.farproc.wifi.analyzer&hl=en_IN&gl=US





Combined Path Loss and Shadowing

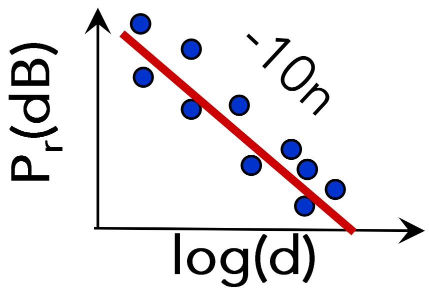
$P_L(d) \propto d^n$ $\quad\quad \therefore \dfrac{P_L(d)}{P_L(d_0)} = \dfrac{d^n}{d_0^n}$



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

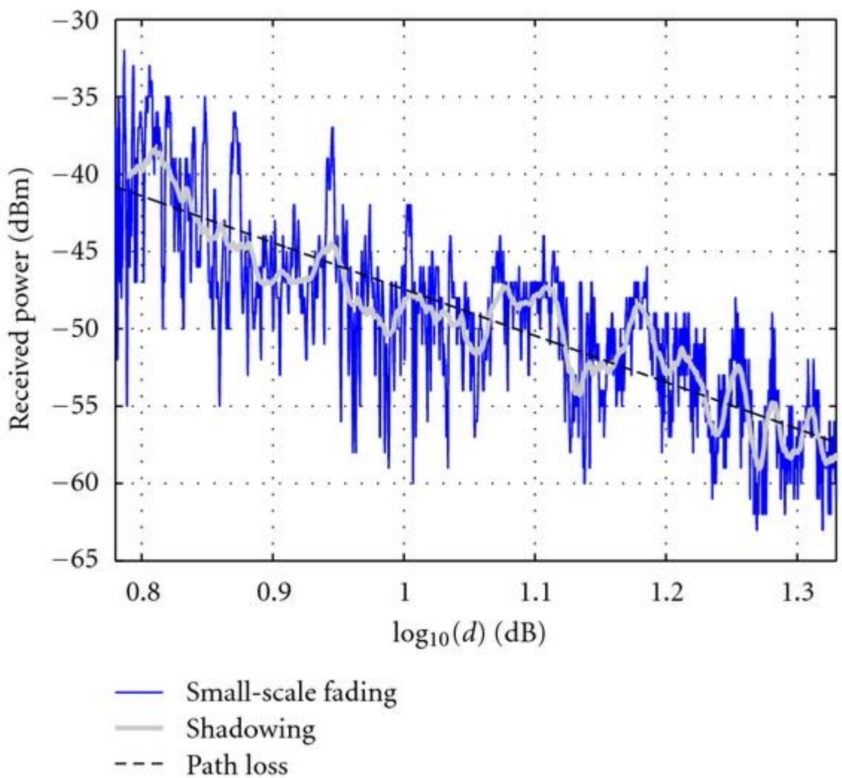
$$[P_L(d)]dB = [P_L(d_0)]dB + 10n \log_{10}\left(\frac{d}{d_0}\right) + \chi; \qquad \chi = \mathbb{N}(0, \sigma^2)$$

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

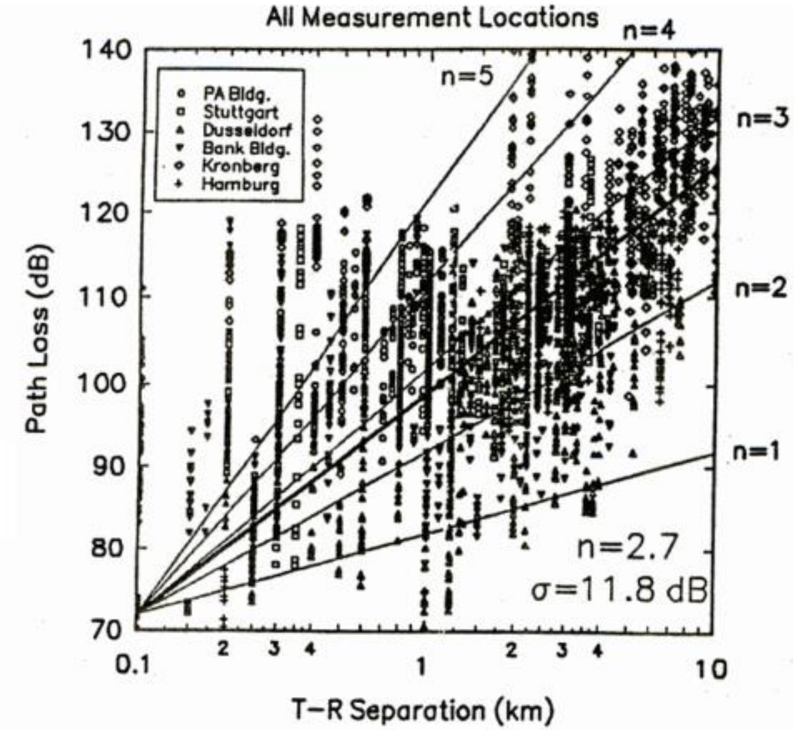


Log Normal Shadowing Model

Some Real Data



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



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

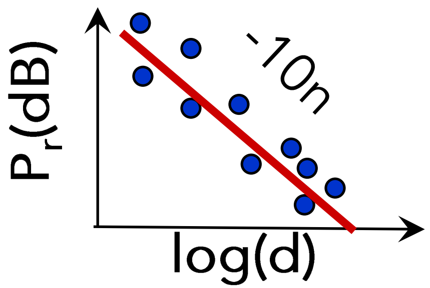
Src: Wireless Communications by Theodore S. Rappaport

How to Measure n?

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

$$= P_r(d_0)[dBm] - 10n\log_{10}\left(\frac{d}{d_0}\right) + \chi$$

- Measuring n:
    - Draw the "Best fit" line through dB data
    - Find the slope → divide by 10



- Shadowing variance:
    - Variance of data relative to the best fit straight line

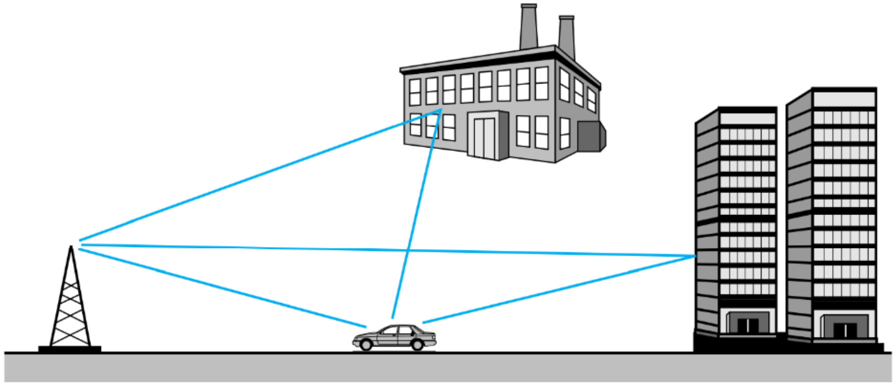
Typical Values for Path loss exponent

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

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

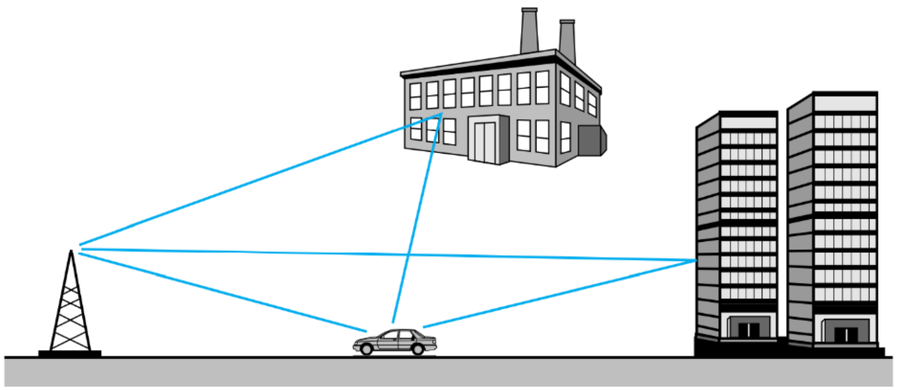
Multipath Propagation

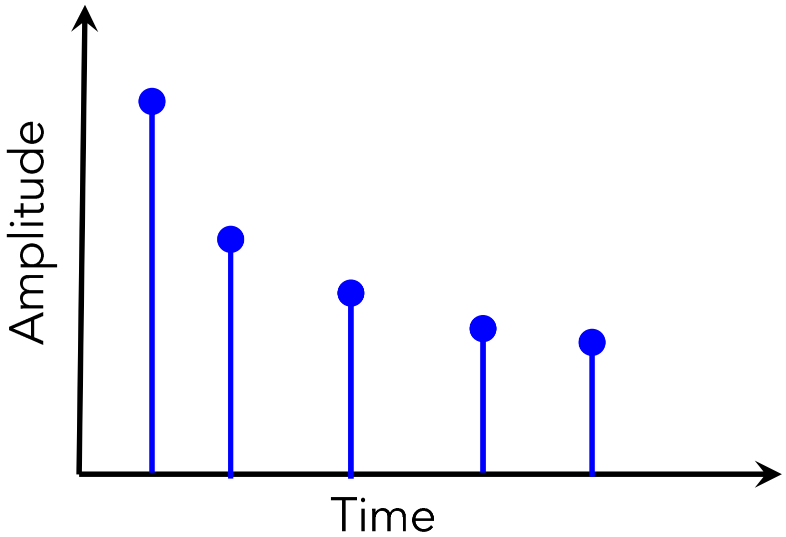
Multipath Propagation



- Multiple signal components reach at the receiver
- Each component experiences different levels of attenuation and delay
  - Leads to time-varying channel impulse response

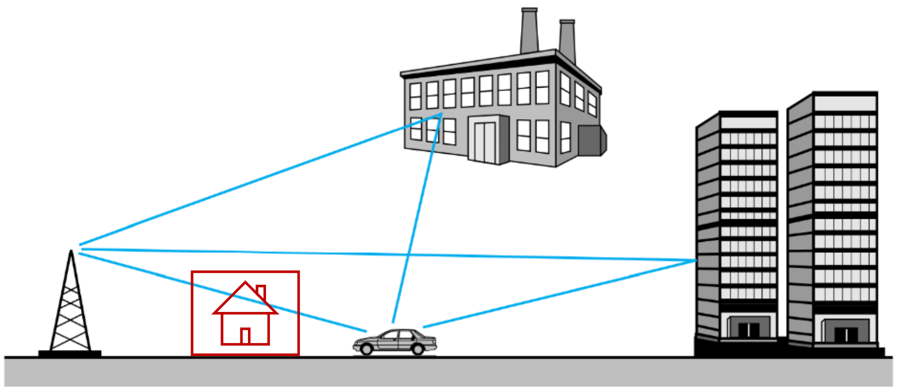
Multipath Propagation

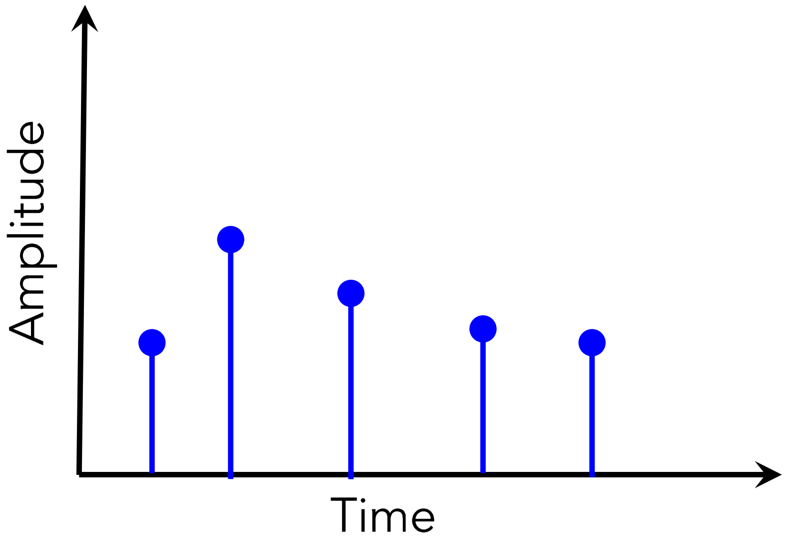




Channel Impulse Response

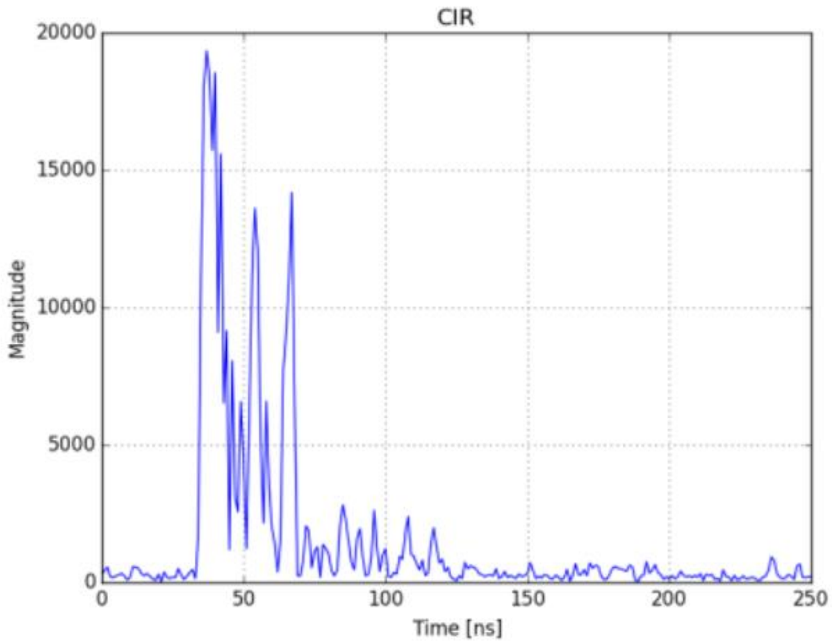
Multipath Propagation

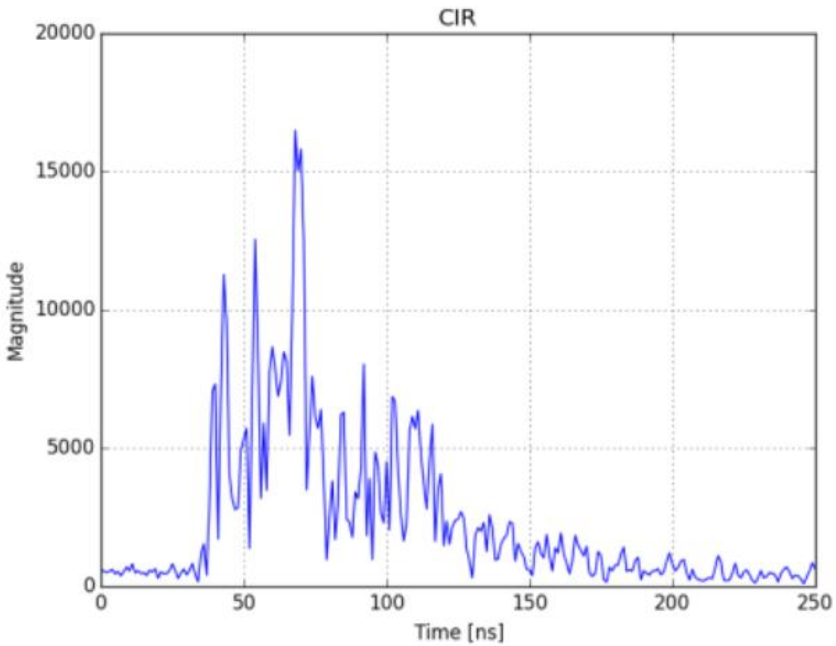




Channel Impulse Response

Multipath Propagation





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