MIMO-OFDM Wireless Communications

The Wireless Channel: Propagation and Fading

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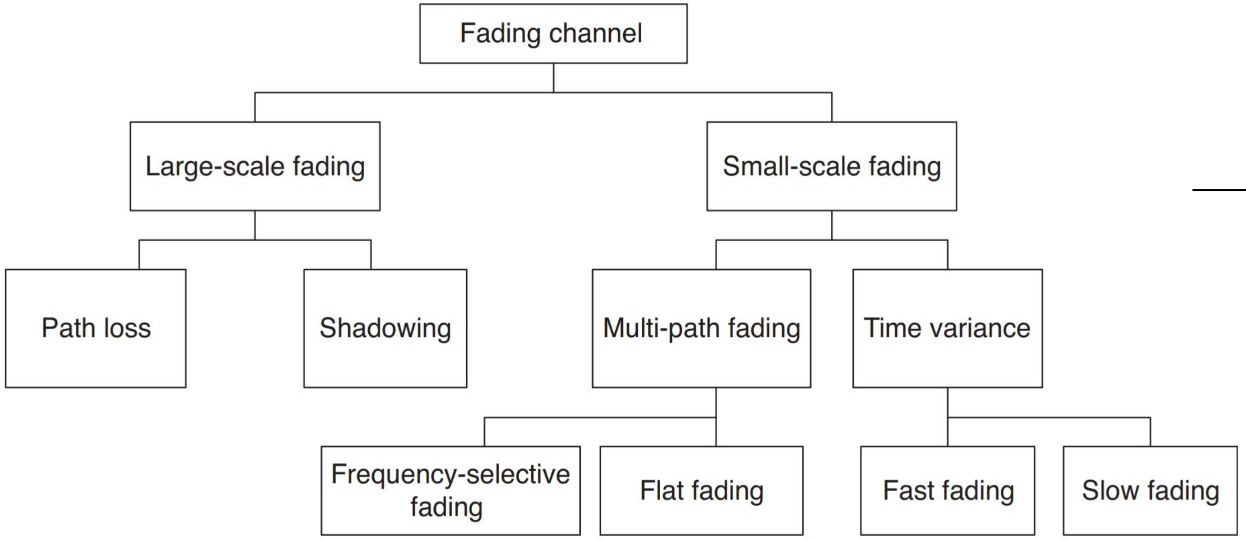
Contents

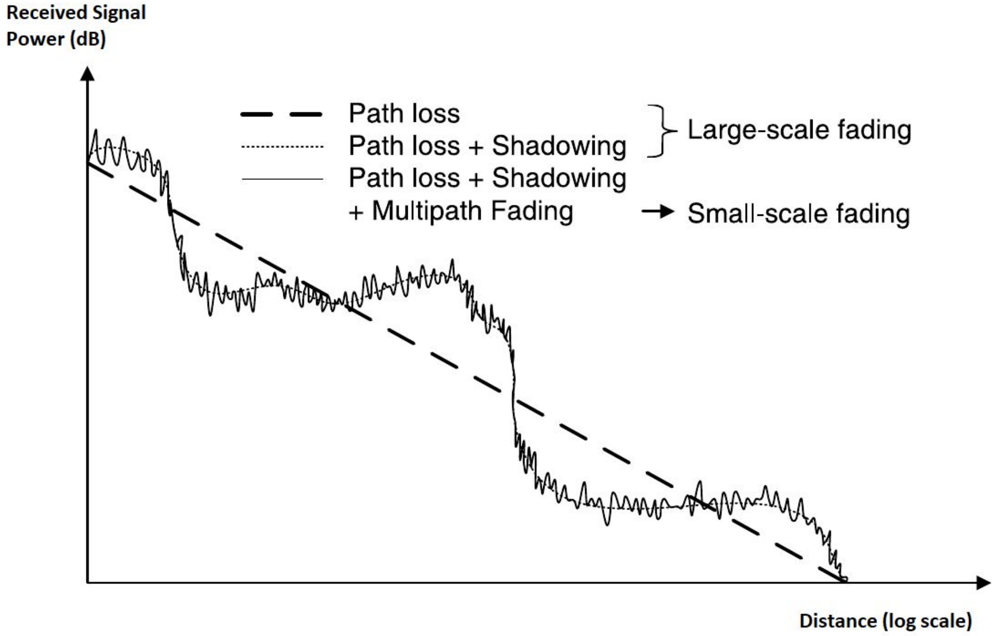
- ❑ Classification of Fading Channels
  - ❑ Large Scale fading – General Path Loss Models
    - General Path Loss Models MATLAB simulations
    - Okumura/Hata Model
    - Hata Model Simulation: Urban, Suburban & Open Area
    - Small Scale Fading
- ❑ SISO Channels
  - Indoor Models

Classification of fading channels



Limitation on:

- Signal Coverage
- Data Rates



Large Scale Fading – General Path Loss Models

- The Friis' equation for received power is given as:

$$P_r(d) = \frac{P_t G_t G_r \lambda^2}{(4\pi)^2 d^2 L} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Where

P_t = transmit power
G_t = Gain of transmit antenna
G_r = Gain of receive antenna
$\lambda = Wave\ length\ of\ the\ signal$
d = transmitter-receiver separation
L = System loss factor

- Given system loss = 1,

- The Path Loss in dB is:

$$PL_F(d) = 10 log\left(\frac{P_t}{P_r}\right) = 10\log(G_t) + 10\log(G_r) + 20\log(\lambda) - 20\log(4\pi d) \ldots\ldots (2)$$

- This is called Free-space Path Loss Model

- By modifying the free-space path loss with the path loss exponent n, that varies with the environments, a more generalized path loss model called log-distance path loss model is constructed:

$$PL_{LD}(d)[dB] = PL_F(d_o) + 10nlog\left(\frac{d}{d_o}\right) \ldots\ldots\ldots\ldots\ldots..(3)$$

Where d_o is the reference distance at which the log-distance path loss inherits the characteristics of (2).

n accommodates all lossy environments

Environment	Path-Loss Exponent n
Free-Space	2
Urban area cellular radio	2.7 to 3.5
Shadowed urban cellular radio	3 to 5
In building line-of-sight	1.6 to 1.8
Obstructed in building	4 to 6
Obstructed in factories	2 to 3

- Distance between two points alone cannot fully explain the signal strength level at th e receiver.
- Shadowing is introduced in the log-distance model to account for variation of signal propagation behavior between two different signal paths assuming the same propag ation distance.

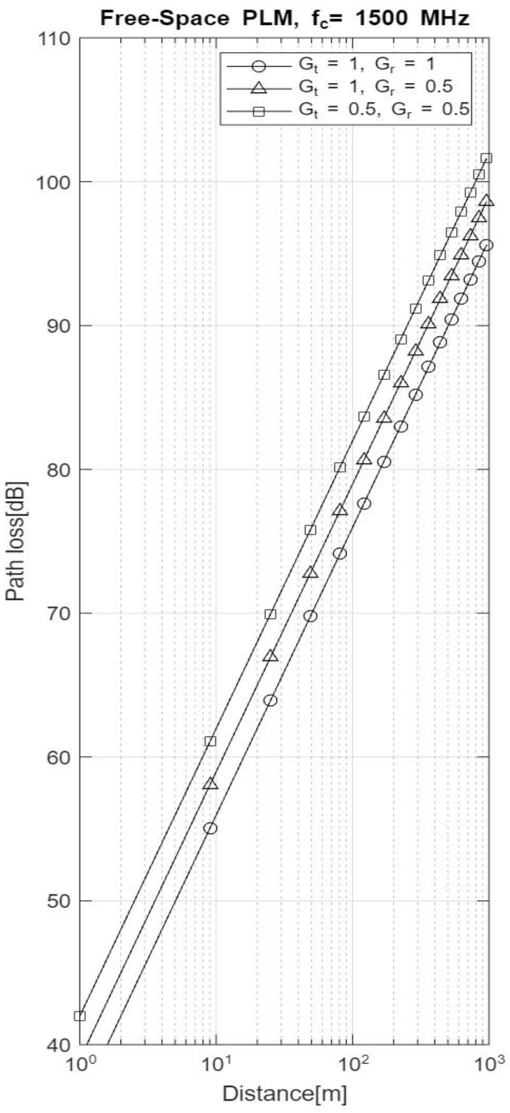
$$\Rightarrow PL_{LN}(d)[dB] = PL_{LD}(d)[dB] + X_\sigma$$

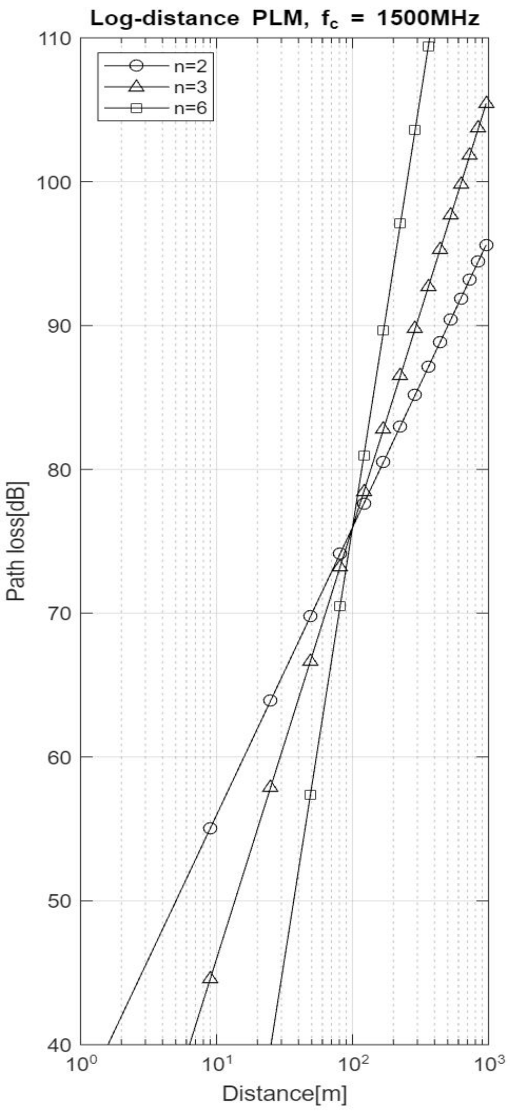
$$\therefore PL_{LN}(d)[dB] = PL_F(d_o) + 10nlog\left(\frac{d}{d_o}\right) + X_\sigma \qquad (4)$$

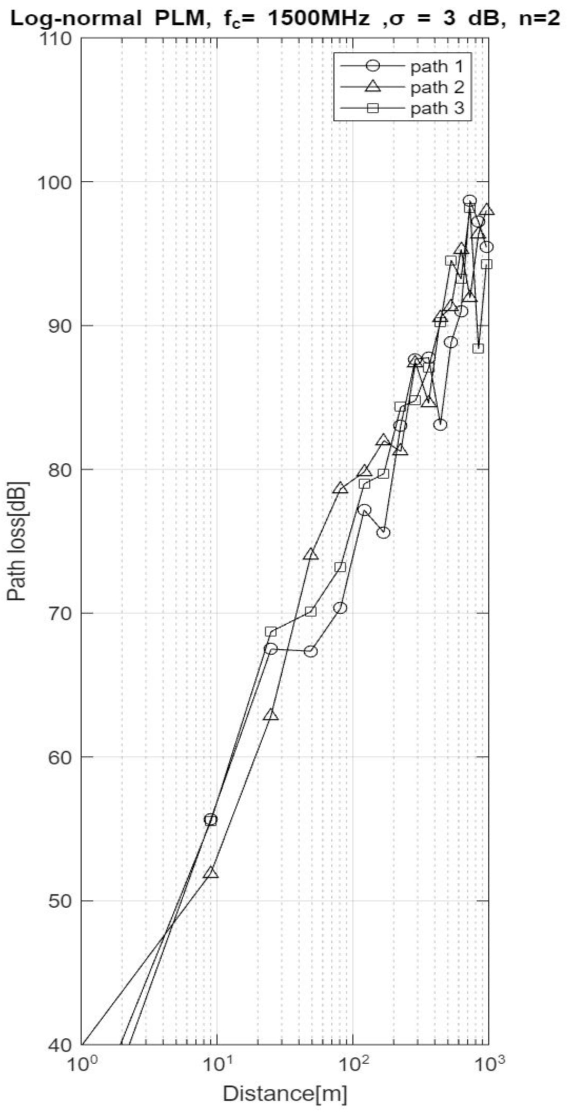
- (4) is called log-normal shadowing model

X_σ = shadowing parameter (zero mean Gaussian distributed random variable in dB with standard deviation σ, also in dB)

Free-space, Log-distance & Log-normal shadowing path loss MATLAB simulations







Okumura/Hata Model

- Mobile Communication System Characteristics:

  - frequency band: 500-1500 MHz
  - Cell radius: 1-100 Km
  - Antenna height: 30-1000m

$$PL_{Ok}(d)[dB] = PL_F + A_{MU}(f,d) - G_{Rx} - G_{Tx} + G_{AREA} \quad \text{.........................(1)}$$

$Where,\ A_{MU}(f,d) = median\ attenuation\ factor\ at\ frequency, f$
$G_{Rx} = Receive\ antenna\ gain, \qquad G_{Tx} = Transmit\ antenna\ gain$
$G_{AREA} = Gain\ due\ to\ type\ of\ environment$

- Hata Model extends Okumura model for urban, suburban and open area environments.

$$PL_{Hata,U}(d)[dB] = 69.55 + 26.16 \log f_c - 13.82 \log h_{TX} - C_{RX} + (44.9 - 6.55 \log h_{TX}) \log d \quad \text{.......................(2)}$$

$Where, C_{Rx} = correlation\ coefficient\ of\ receive\ antenna$

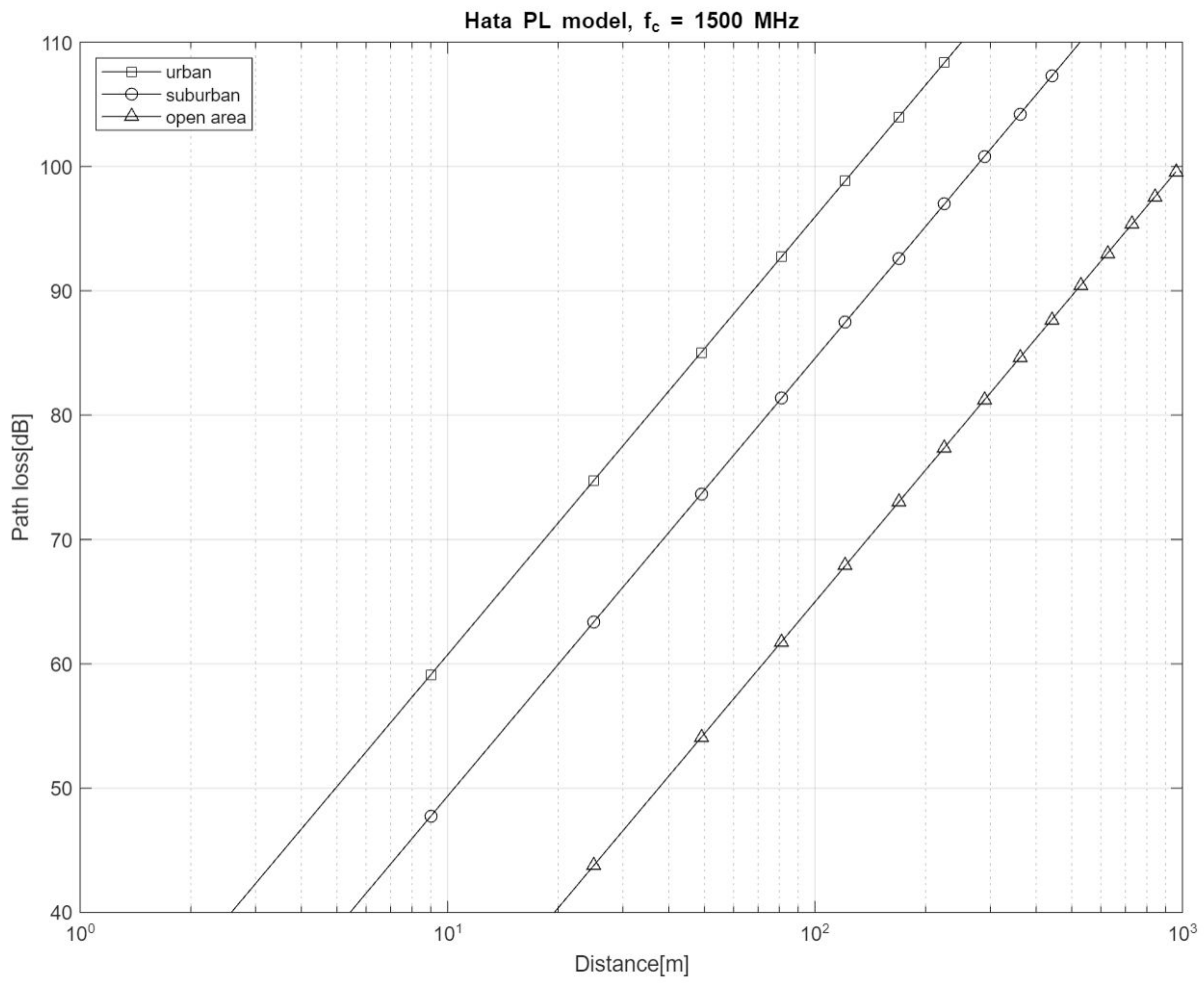
$$C_{Rx} = 0.8 + (1.1 \log f_c - 0.7) h_{Rx} - 1.56 \log f_c$$

$$C_{RX} = \begin{cases} 8.29(\log(1.54 h_{RX}))^2 - 1.1 & \text{if } 150\,\text{MHz} \le f_c \le 200\,\text{MHz} \\ 3.2(\log(11.75 h_{RX}))^2 - 4.97 & \text{if } 200\,\text{MHz} \le f_c \le 1500\,\text{MHz} \end{cases}$$

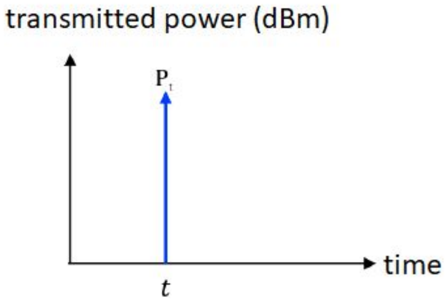
$$PL_{Hata,SU}(d)[dB] = PL_{Hata,U}(d) - 2\left(\log \frac{f_c}{28}\right)^2 - 5.4 \qquad \text{.............................(3)}$$

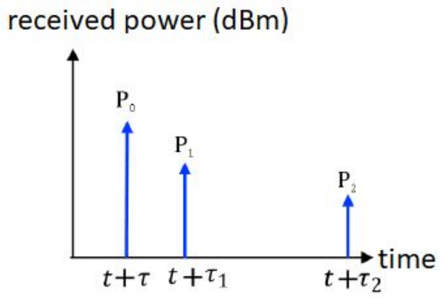
$$PL_{Hata,O}(d)[dB] = PL_{Hata,U}(d) - 4.78(\log f_c)^2 + 18.33 \log f_c - 40.97 \qquad \text{...................(4)}$$

Hata Model Simulation for Urban, Suburban and Open Area Environment



Small Scale Fading





Parameters derived from the Power Delay Profile:

- RMS Delay Spread, σ_τ
- Mean Excess Delay, $\bar{\tau}$

- $\sigma_\tau = \sqrt{\overline{\tau^2} - (\bar{\tau})^2}$ ....(5) *where*
- $\bar{\tau} = \dfrac{\sum_k \tau_k P(\tau_k)}{\sum_k P(\tau_k)}$ ....(6) and $\overline{\tau^2} = \dfrac{\sum_k \tau_k^2 P(\tau_k)}{\sum_k P(\tau_k)}$ ....(7)

- The bandwidth within which the multipath channel is considered to be flat, ***Coherence Bandwidth*** is given as: $B_c \approx \dfrac{1}{\sigma_\tau}$

Flat Fading requirement: $B_s \ll B_c$ and $T_s \gg \sigma_\tau$ & Frequency selective fading: $B_s \gg B_c$ and $T_s \gg \sigma_\tau$

- Depending on the relative motion between the transmitter and the receiver, the multipath channel is either coherent in time or not.
- The **Coherent time**, $T_c \approx \frac{1}{f_m}$ *where* f_m *= Doppler Spread*
- The bandwidth of the Doppler Spectrum, $B_d = 2f_m$

Fast Fading condition: $T_s > T_c$ and $B_s < B_d$ & Slow Fading requirement: $T_s \ll T_c$ and $B_s \gg B_d$

SISO Channels

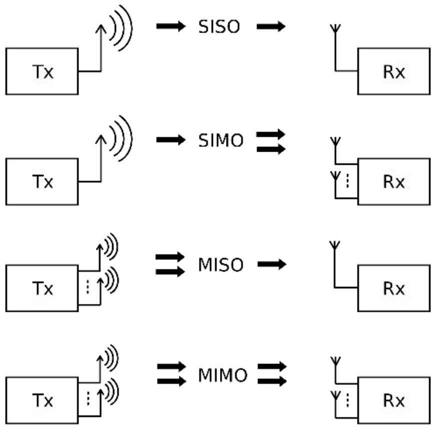
- In order to create an accurate channel model in a specific environment, we must have ***full*** knowledge on the:

• Characteristics of reflectors (orientation and movement).

• Power of the reflected signal at any specified time.

Not possible in reality

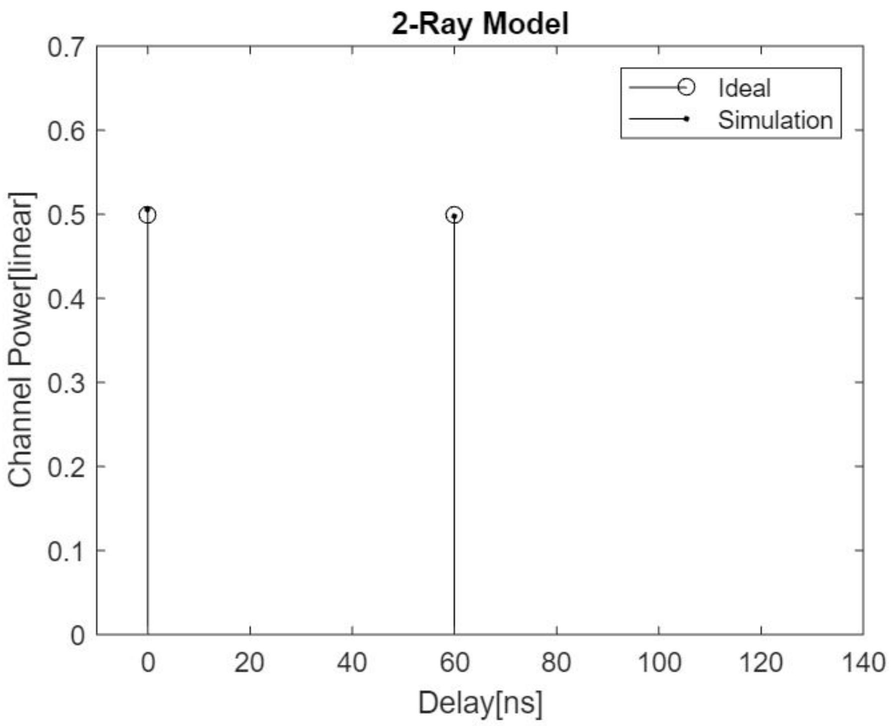
- We resort to the ***specific channel model*** which can represent an average channel condition in the given environment.
- The channel model can vary with the antenna configuration in the transmitter and receiver.



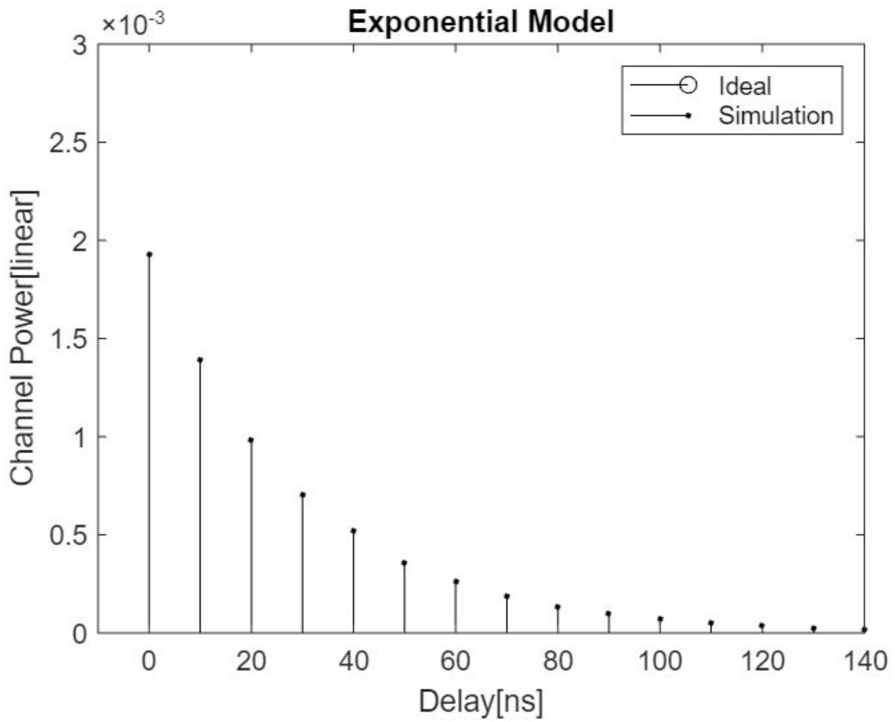
Indoor Channel Models

- The two most popular indoor channel models:

  (i) 2-ray model (ii) exponential model



- Two rays, one for a direct path with a zero delay ($\tau_0 = 0$) and the other for a path which is a reflection with delay, $\tau_1 > 0$
- Not accurate: Magnitude of the second path is less than the first path in practice.
- Acceptable only when there is significant loss in the first path.



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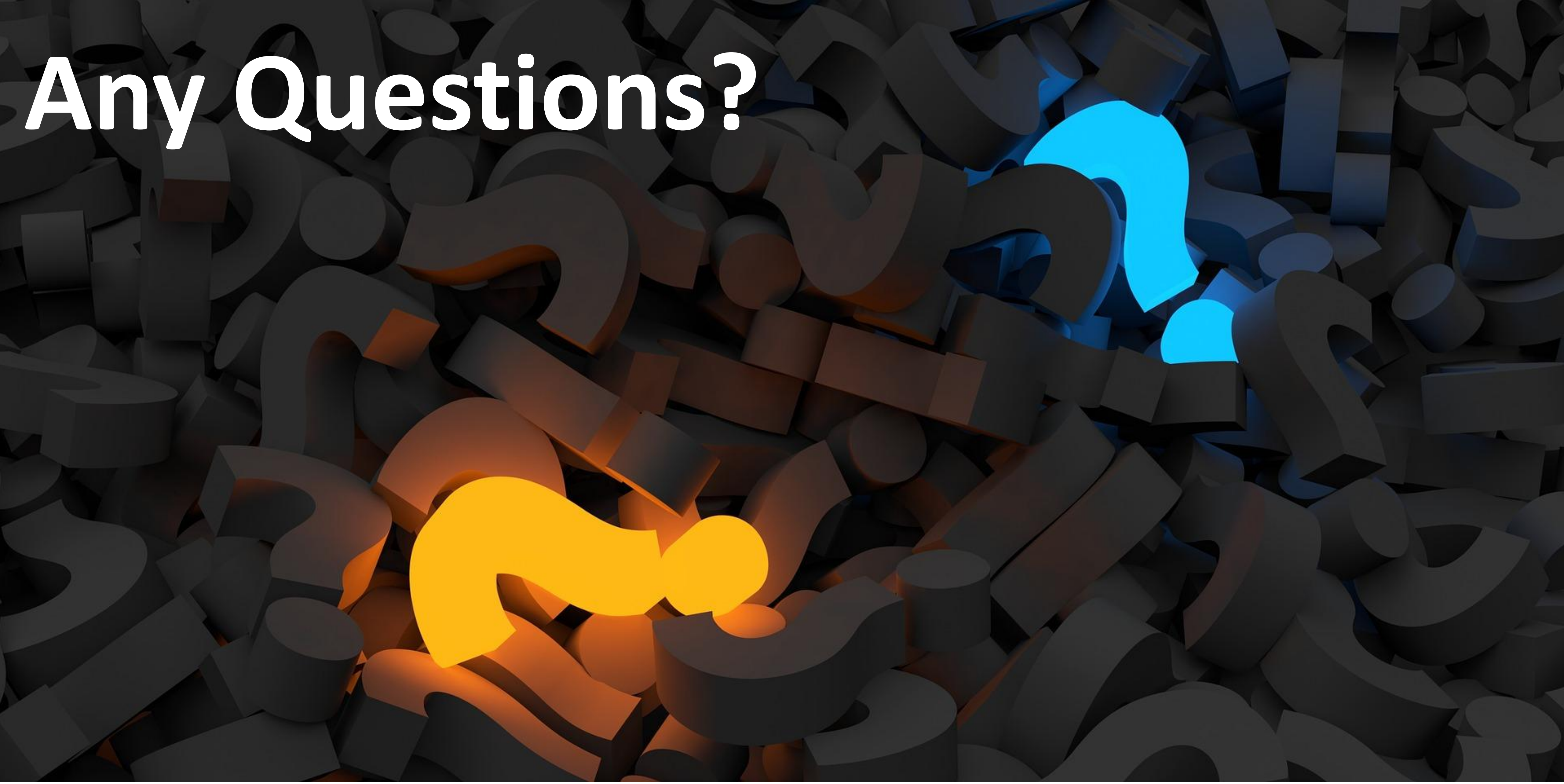
- Average channel power decreases exponentially with channel delay.

$$P(\tau) = \frac{1}{\tau_d} e^{-\frac{\tau}{\tau_d}}$$

- More appropriate for an indoor channel environment

Any Questions?



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