Department of Electrical Engineering
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ELEG 5693 Wireless Communications
Propagation and Noise Part I

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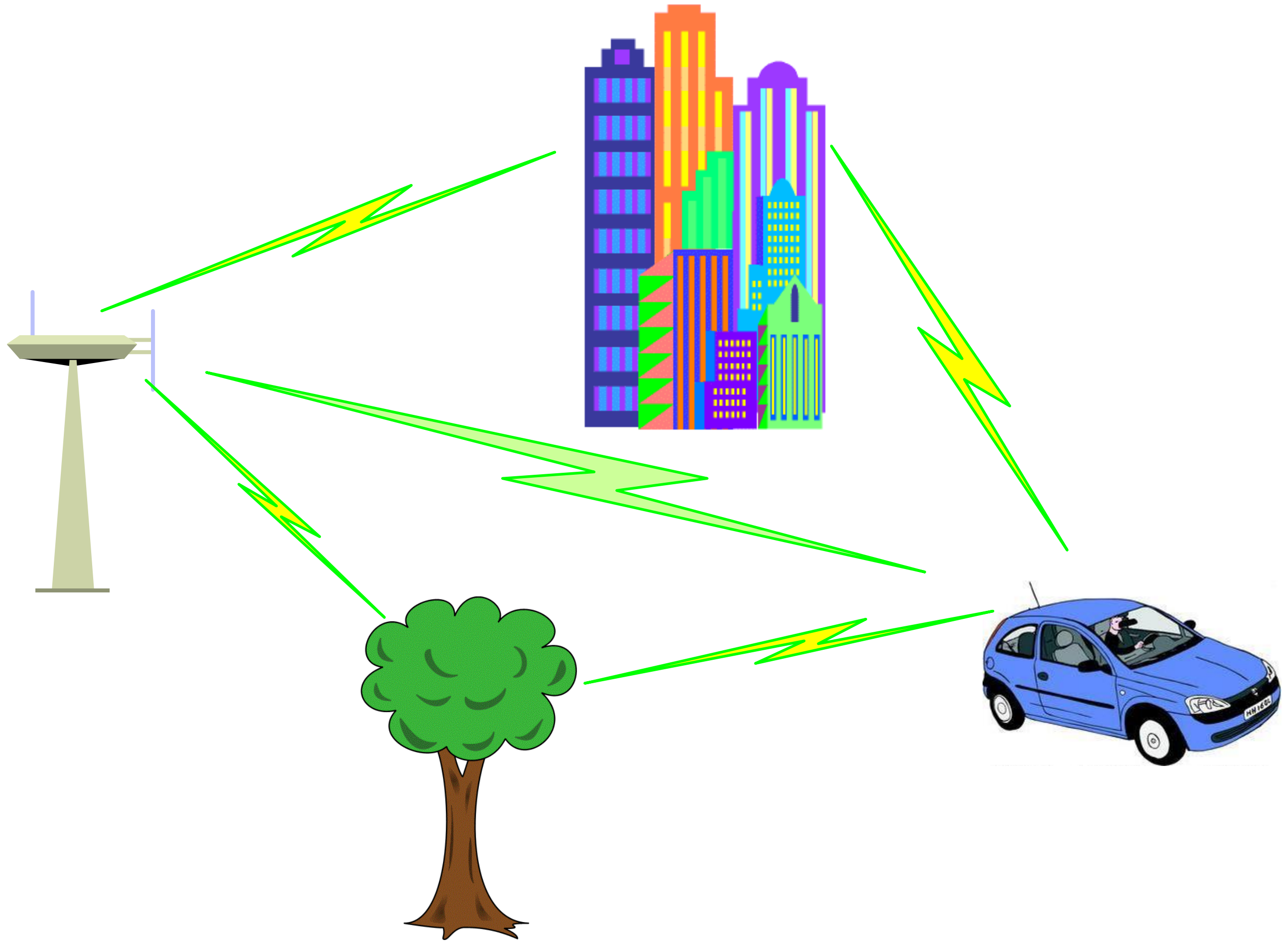
OUTLINE

- Wireless channel
- Path loss
- Shadowing
- Small scale fading
- Channel classifications
- Noise and interference
- Simulation model

CHANNEL: PROPAGATION ENVIRONMENT



CHANNEL: PROPAGATION MODES

- **Free-space (line-of-sight)**
  - There is a clear transmission path between transmitter (Tx) and receiver (Rx).
  - E.g. satellite
- **Reflection**
  - The bouncing of electromagnetic waves from surrounding objects
  - Size of reflecting objects must be large compared to the wavelength of signal
  - Reflecting surface must be smooth compared to the wavelength of signal
  - E.g. ground, building, walls, windows, lakes

CHANNEL: PROPAGATION MODES (CONT'D)

- **Diffraction**
  - The bending of electromagnetic waves around objects (such as buildings), or through objects (such as trees).
  - Due to diffraction, signals can propagate
    - Around curved surface of Earth
    - Beyond LOS horizon
    - Behind obstructions
- **Scattering**
  - Electromagnetic waveforms incident upon rough or complex surfaces are scattered in many directions
    - Relfection: smooth surface, one direction
- **Refraction (not common in terrestrial wireless communication).**
  - Electromagnetic waves bend as they move from one medium to another.

CHANNEL

Channel: a collection of propagation effects and other signal impairments caused by the environments

- **Wireless channel: propagation, noise and interference**
  - Propagation effects: line-of-sight, reflection, diffraction, scattering
    - Induced by the transmission of desired signals itself
    - Impairments: large scale fading (path loss, shadowing), small scale fading
    - Unique to wireless communication
  - Noise and interference: unwanted electrical signals interfering with desired signal.
    - Thermal noise (movements of electrons)
    - Automobile ignition, electrical machinery, etc.
    - Interferences from other users operating on the same frequency.

Present in all communication systems

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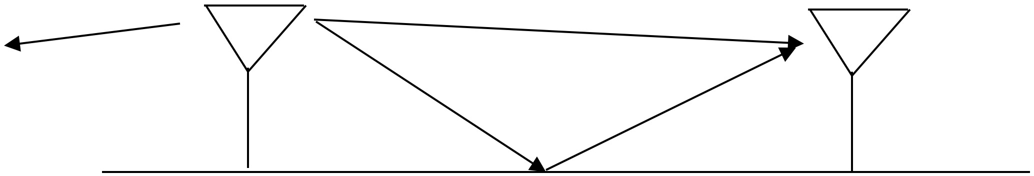
PATH LOSS

- **Path loss: the power loss during signal propagation from Tx to Rx**
  - Only a portion of the power from Tx will be captured by the receiver.



- **Path loss is defined as the ratio between the signal power at transmitter (P_T) and signal power at receiver (P_R).**

$$L_p = \frac{P_T}{P_R}$$

$$L_p(dB) = 10\log_{10}\frac{P_T}{P_R} = 10\log_{10}P_T - 10\log_{10}P_R$$

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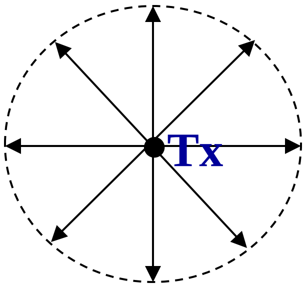
PATHLOSS: MODELS

- **Free-space path loss model**
  - Clear, unobstructed LOS.
  - Doesn’t consider surrounding objects.
  - Highly simplified model
  - E.g. satellite
- **Ray-tracing models**
  - Consider the effects of reflection, diffraction from surrounding environment
  - More complex, depends on site geometry
- **General model**
  - Simple flexible mathematical model
  - Captures the essence of path loss under various conditions
  - Good for high level analysis

PATHLOSS: FREE-SPACE

- **Isotropic radiation**
  - Signal strength are equal in all directions
  - Isotropic antenna: an antenna transmits equally in all directions.



- **At distance R from Tx antenna, the power per unit area**

$$\Phi_R = \frac{P_T}{4\pi R^2}$$

P_T : Tx power

The surface area of a sphere with radius R

- **Power at Rx**

$$P_R = \frac{P_T}{4\pi R^2} A_e$$

Effective area of Rx antenna

PATHLOSS: FREE-SPACE

- **Friis equation: path-loss equation for general antennas**

$$P_R = P_T G_T G_R \left(\frac{\lambda}{4\pi R} \right)^2$$

R: Distance between Tx and Rx.

$\lambda = c/f$: wavelength.

G_T: Transmit antenna gain

G_R: Receive antenna gain

- **For system with fixed P_T, G_T and G_R**
  - $R \uparrow \Rightarrow P_R \downarrow$
  - $f \uparrow \Rightarrow \lambda \downarrow \Rightarrow P_R \downarrow$

PATHLOSS: FREE-SPACE

- **Example**
  - In order to operate properly, a receiver must capture the signal power of at least -90dBm. Assuming a 100-miliwatt transmitter and free-space path loss. The antenna gain at Tx and Rx are 3dB. What is the service area radius of the Tx for a signal frequency of 800MHz?

Sol:

$$P_T = 100mW$$

$$P_R(dBm) = 10\log_{10}\frac{P_R(mW)}{1(mW)} \Rightarrow P_R(mW) = 10^{P_R(dBm)/10} = 10^{-9}(mW)$$

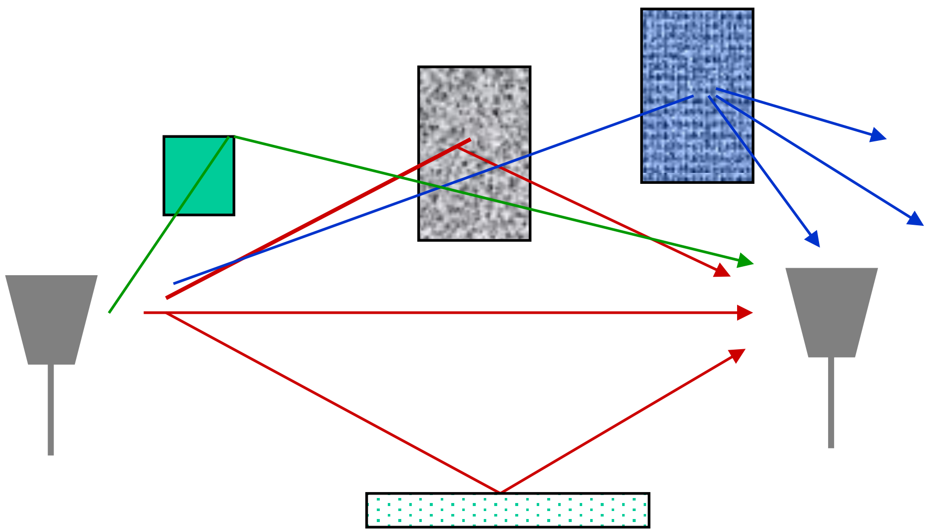
$$G_T(dB) = G_R(dB) = 3dB \Rightarrow G_T = G_R = 10^{3/10} = 2$$

$$P_R = P_T G_T G_R \left(\frac{\lambda}{4\pi R}\right)^2 \Rightarrow R = \frac{\lambda}{4\pi}\sqrt{\frac{P_T G_T G_R}{P_R}}$$

$$R = \frac{c}{4\pi f}\sqrt{\frac{P_T G_T G_R}{P_R}} = 18.9km$$

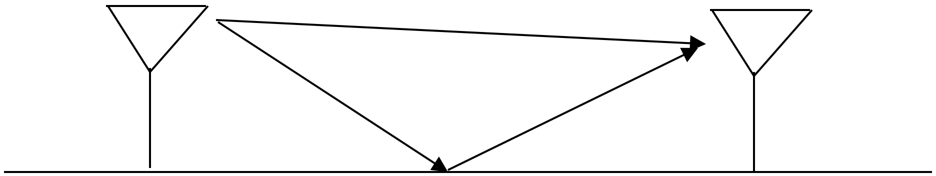
PATHLOSS: RAY-TRACING MODELS

- **Ray-tracing model**
  - Besides LOS, also considers the effects of reflection, diffraction and scattering ➔ considers the effects from each ray



PATH LOSS: RAY TRACING MODEL

- **Example: plane-earth reflection**



Δd :Distance between two paths

Rx signal from LOS: $E_0(t) = A_0 \cos(2\pi f t + \theta)$

Rx signal from reflection: $E_r(t) = \rho A_0 \cos[2\pi f (t + \Delta d / c) + \theta]$

$= \rho A_0 \cos[2\pi f t + \psi + \theta]$

$\psi = 2\pi f \Delta d / c = 2\pi \Delta d / \lambda$: phase difference caused by distance difference

ρ : due to reflection and distance difference

At the receiver: $E_{total}(t) = E_0(t) + E_r(t)$

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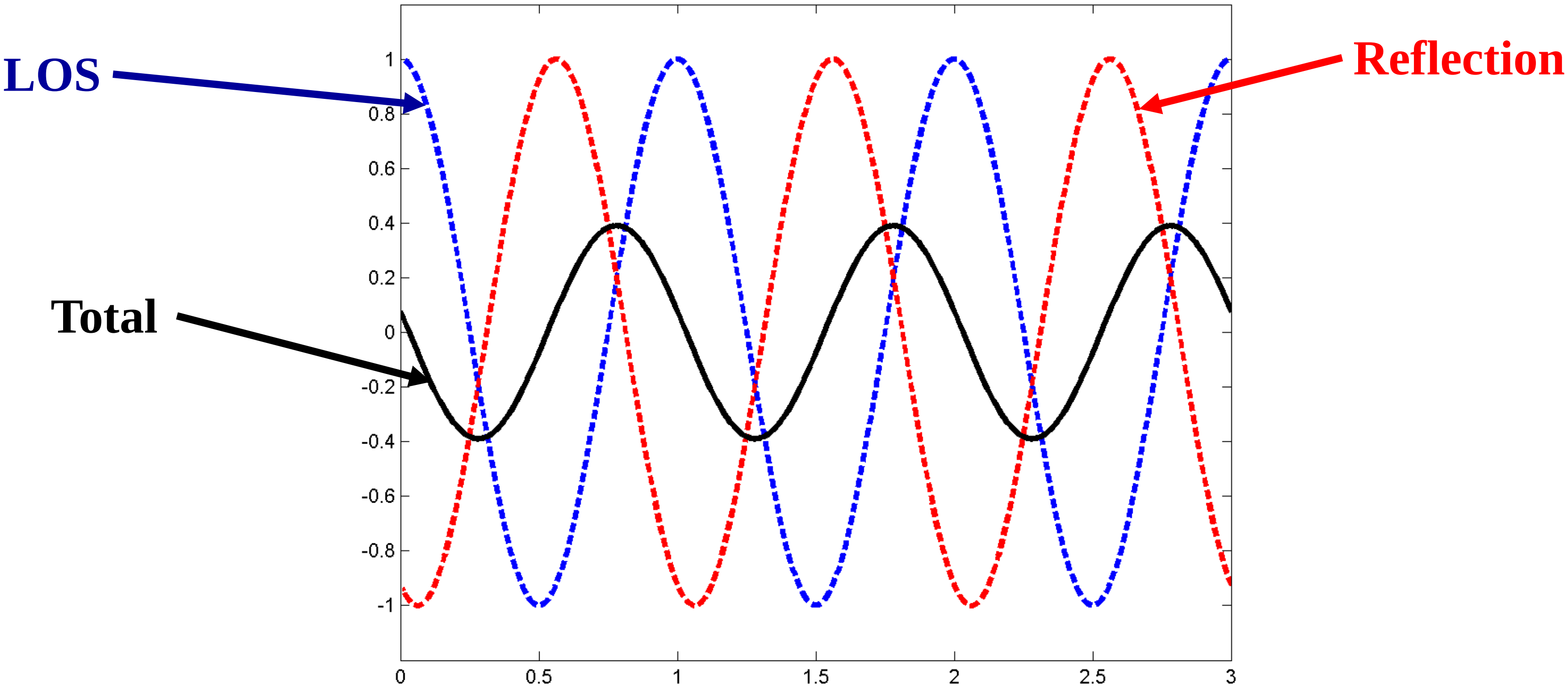
PATH LOSS: RAY TRACING MODEL

- **The phase difference between the two rays will result in construction or destruction effects of the Rx signal**



PATH LOSS: GENERAL MODEL

- **A general model capturing the essence of path loss in various environment**

$$P_R = P_T \frac{1}{\beta_0}\left(\frac{r_0}{r}\right)^n$$

r_0 : reference distance (typically 1 meter)

β_0 : measured path loss at reference distance

n : path loss exponent (can be obtained through measurement)

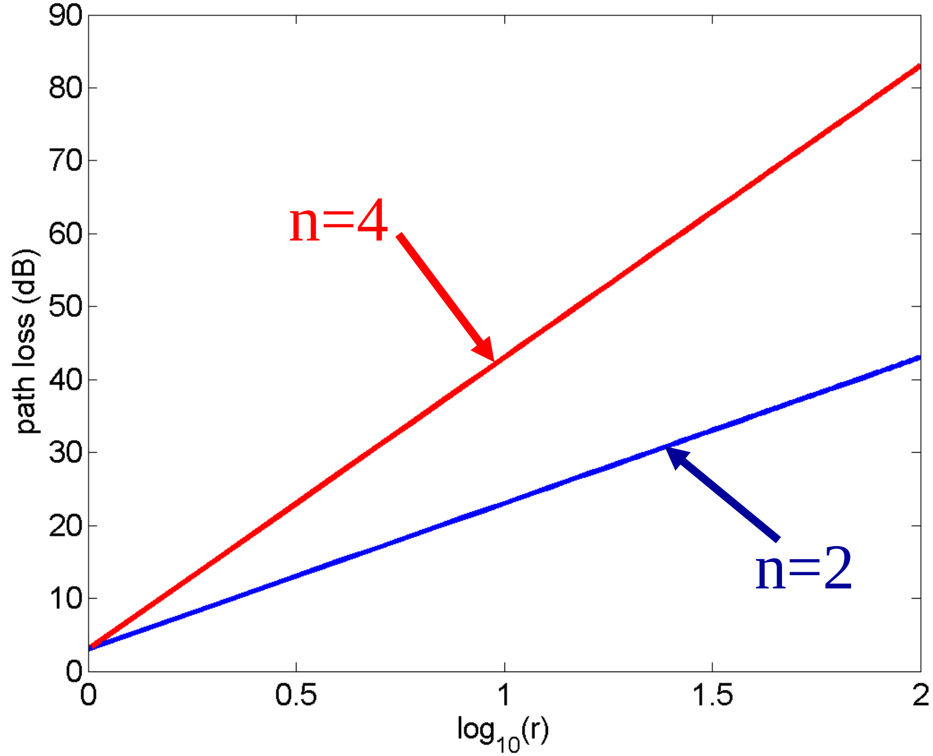
r : distance between transmitter and receiver

- ***n*: path loss exponent**
  - r ↑➔ P_R ↓
  - The larger the value of *n*, the faster the Rx power falls off with the increase of distance.
  - Free space: n = 2; rolling rural: n = 3.5; suburban: 4; dense urban: 4.5

PATH LOSS: GENERAL MODEL

- **Usually represented in the unit of dB**

$$L_p = \frac{P_T}{P_R} = \beta_0 \left(\frac{r}{r_0}\right)^n \Rightarrow L_p(dB) = 10\log_{10}\beta_0 + n \times 10\log_{10}\left(\frac{r}{r_0}\right)$$



Fix P_T

$L_p \uparrow \Rightarrow P_R \downarrow$

PATH LOSS: GENERAL MODEL

- **Example:**
  - At a distance $r_0 = 10$ meter from Tx, the measured power is $P_T / \beta_0 = 2mW$. The path loss exponent is n = 2.9. The appropriate operation of the receiver requires the signal power at receiver must be at lease -90mW. What is the service radius? (using the general path loss model)

Sol.

$$P_R(dBm) = 10\log_{10}\frac{P_R(mW)}{1(mW)} => P_R(mW) = 10^{P_R(dBm)/10} = 10^{-9}(mW)$$

$$r = r_0 \sqrt[n]{\frac{(P_T / \beta_0)}{P_R}} = 10\sqrt[2.9]{\frac{2mW}{10^{-9}mW}} = 16.1km$$

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SHADOWING

- **Shadowing:**
  - Caused by large obstructions that are distant from MS
  - Analogy: the shadow of light due to mountain.
  - Effects of shadowing is random due to random # and type of obstructions.
  - The existence of shadowing is verified through field measurement.
- **Consider the effects of path loss and shadowing**

$$P_R = P_T \times \underbrace{\frac{1}{\beta_0}\left(\frac{r_0}{r}\right)^n}_{\text{path loss}} \times \underbrace{S}_{\text{shadowing}}$$

S : models the effects of shadowing. Random variable.

SHADOWING

- **dB representation**

$$10\log_{10} P_R = 10\log_{10}\frac{P_T}{\beta_0} + n\times 10\log_{10}\left(\frac{r_0}{r}\right) + 10\log_{10} S$$

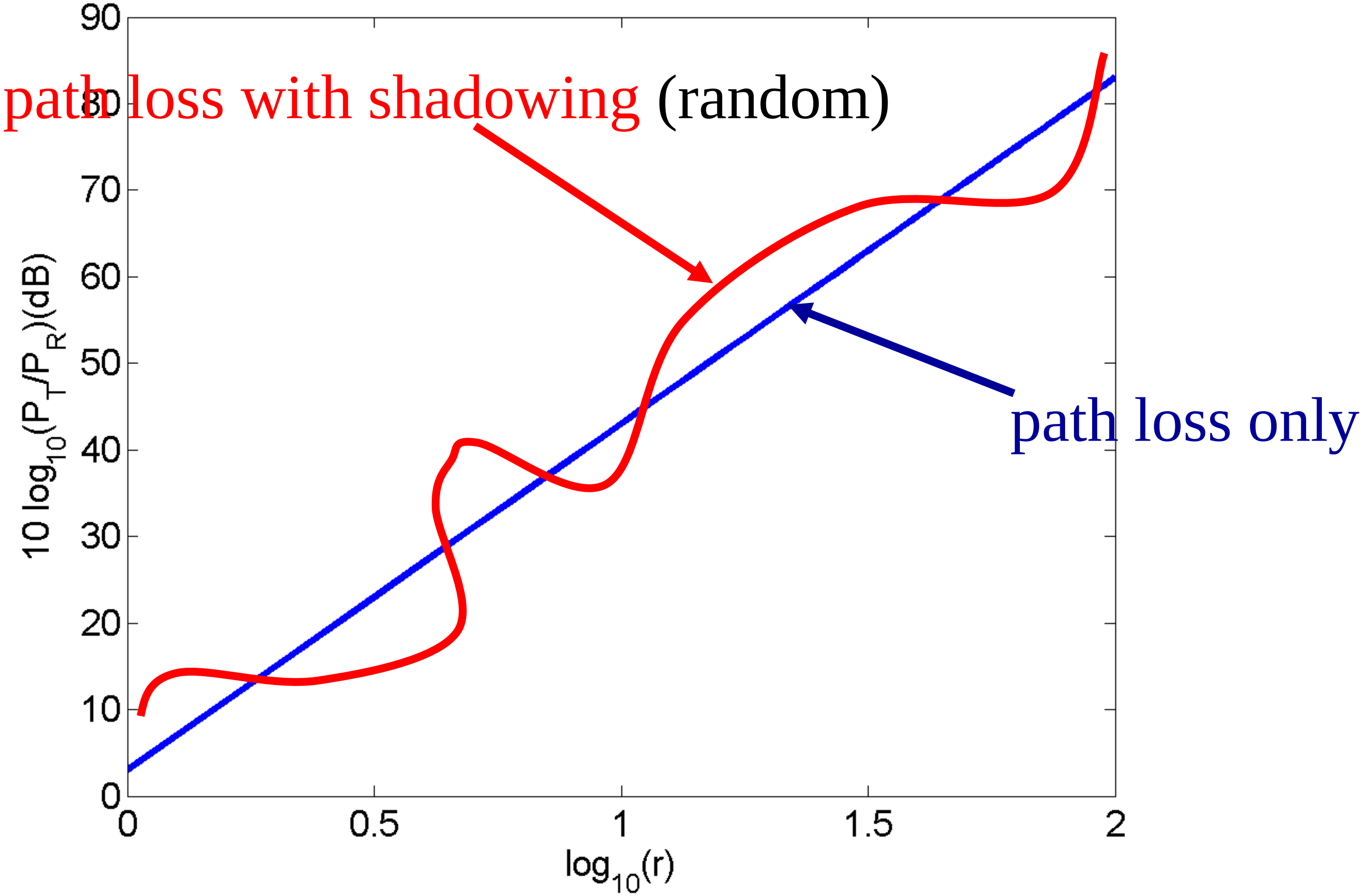
- $S(dB) = 10\log_{10} S$ **: follows Gaussian distribution (normal distribution)**

$$f_{S(dB)}(x) = \frac{1}{\sqrt{2\pi}\sigma_{dB}}\exp\left(-\frac{(x-m_{dB})^2}{2\sigma_{dB}^2}\right)$$

S(dB) follows normal distribution➔ the log of *S* follows normal distribution
➔ The distribution of *S* is called lognormal distribution

Shadowing is called lognormal shadowing

SHADOWING



combined effects of path loss and shadowing (red curve)

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