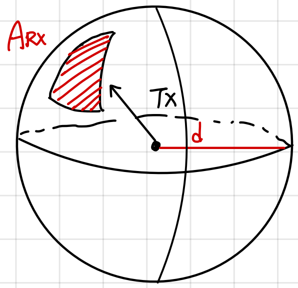
Wireless Communication Ch4

2024 Fall

Free space attenuation

- Suppose we are in free space
- Energy spreaded into a sphere surface when the antenna is isotropical



- Suppose we receive the signal with an effective area A_{RX} antenna on the surface we will have

$$\underline{P_{RX}(d) = P_{TX}\frac{1}{4\pi d^2}\cdot A_{RX}}$$

- If the antenna is NOT isotropical, we add the antenna gain G_{TX} to indicate energy concentration effect.

$$\underline{P_{RX}(d) = P_{TX}\cdot G_{TX}\frac{1}{4\pi d^2}\cdot A_{RX}}$$

- By definition, we have the relationship

$$\underline{G_{RX} = \frac{4\pi}{\lambda_c^2}A_{RX}} \quad \text{since} \quad P_{RX}(d) = P_{TX}G_{TX}G_{RX}\left(\frac{\lambda_c}{4\pi d}\right)^2$$

[For constant antenna gain, pathloss ↑ if f_c ↑
For constant A_{RX}, pathloss does NOT change if f_c change

⇒ we usually fixed G_{TX}, G_{RX} instead of A_{RX} A_{TX}.
because A_{RX} change according to λ_c

- $\left(\frac{\lambda_c}{4\pi d}\right)^2$ is called "free space loss factor"

Validation of assumption

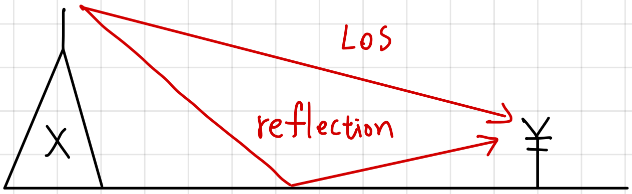
- Distance between Tx and Rx need to be at least Rayleigh distance
- Rayleigh distance $\boxed{d_R = \frac{2L_a^2}{\lambda_c}}$ Far-Field
- L_a is the largest dimension of antenna
任何方向上，取最長的那端

The d^{-4} power law

- one of the "falk laws" in wireless communication

→ received signal power is inversely proportional to d^4

- This law is justified by
  - (1) one LoS path (line of sight)
  - (2) one reflected path



→ They have almost deterministic effect

- Representative e.g.

$$P_{RX}(d) = P_{TX} G_{TX} G_{RX} \left(\frac{h_{TX} h_{RX}}{d^2}\right)^2$$

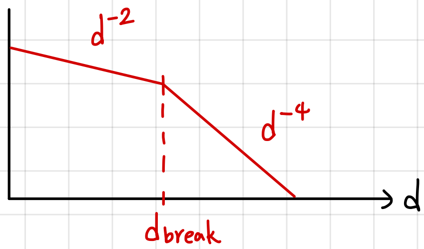
⇒ feasible range $d \geq \frac{4 h_{TX} h_{RX}}{d^2}$

- Final extension of d^{-4} law

$$\boxed{P_{RX}(d) = P_{RX}(1) - 20\log_{10} d_{break} - n \cdot 10\log_{10}\left(\frac{d}{d_{break}}\right)}$$

We combine d^{-2} and d^{-4} law to create pathloss model

$$\begin{cases} PL(d) \sim d^2 \; ; \; d < d_{break} \\ PL(d) \sim d^4 \; ; \; d \geq d_{break} \end{cases}$$



Final extension of d^{-4} law

$$\boxed{P_{RX}(d) = P_{RX}(1) - 20\log(d_{break}) - n \cdot 10\log_{10}\left(\frac{d}{d_{break}}\right)}$$

- exactly used in link-budget
- $1.5 < n < 5.5$

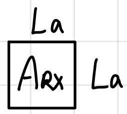
Two methodologies

Mainstream : modeling and measurement.

Sub-area : Ray-tracing → computational-intense approach

Ex 4.1

Q: Suppose $G_{Rx} = 100 = 20dB$, on a square antenna

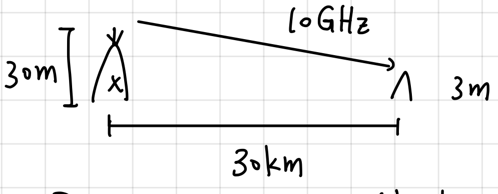


What is our Rayleigh distance

A: $A_{Rx} = L_a^2 = \frac{\lambda_c^2}{4\pi} G_{Rx} = \frac{\lambda_c^2}{4\pi} \cdot 100 \approx 8\lambda_c^2$

$d_R = \frac{2L_a^2}{\lambda_c} = \frac{2A_{Rx}}{\lambda_c} = 16\lambda_c$ #

Ex. Fixed wireless Access



$P_{Rx}(d) = P_{Tx} G_{Tx} G_{Rx} \left(\frac{h_{Tx} h_{Rx}}{d^2}\right)^2$

$P_{Tx} = 46\,dBm$, $F = 5dB$, $N_0 = -174\,dBm/Hz$

$B = 1\,GHz$, require SNR : $10dB$

What is the minimum $G_{Tx} = G_{Rx} = G_{out}$?

(i) $d_{break} = \frac{4h_{Tx}h_{Rx}}{\lambda_c} = \frac{4 \cdot 30 \cdot 3}{3\cdot 10^8/10\cdot 10^9} = 12\,km$ 有超過 dbreak. 可使用公式

(ii) $P_{Rx}(d) = P_{Tx} G_{Tx} G_{Rx} \left(\frac{h_{Tx} h_{Rx}}{d^2}\right)$

$= P_{Tx} G_{ant}^2 \left(\frac{30 \cdot 3}{(3\cdot 10^4)^2}\right)$

$= P_{Tx} G_{ant}^2 \cdot 10^{-14}$

$= 46 + 2G_{ant} - 140 \ (dB)$

(iii) Require SNR = 10dB. $P_n = -174 + 10\log_{10} \underbrace{10^9}_{B} + \underbrace{5}_{F=5dB}$ $\quad \frac{\text{SNR at Rx input}}{\text{SNR at Rx output}}$

Require $P_{Rx}(d) = P_n + \underbrace{10}_{\text{required SNR}} = -69\,dBm$

$\Rightarrow 46 - 2G_{ant} - 140 \geq -69$

$G_{ant} \geq 12.5\,dB$

(iv) check <u>Rayleigh distance</u> if we know La