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SEOUL, KOREA
Information and Intelligent
Systems Laboratory

Wireless Communications Seminar

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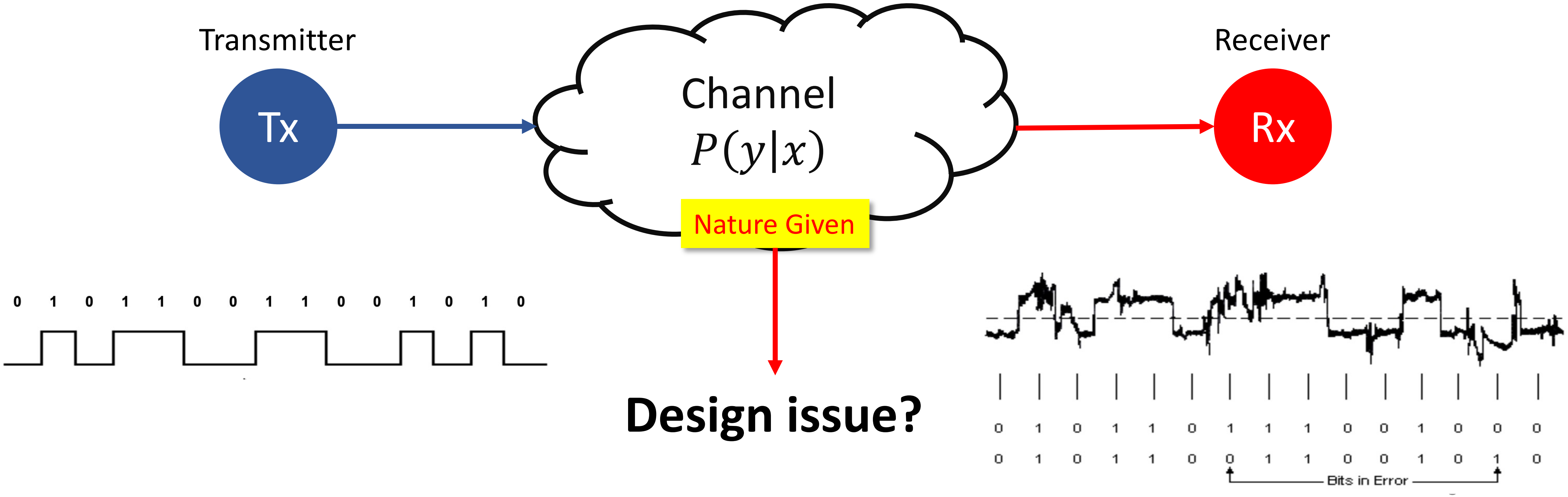
CONTENTS

- Communication System models
- Propagation Characteristics
- Channel / Path Loss Models
- Outage Probability & Cell-Coverage

Communications

- Wireless Channel
  - Probabilistic modeling (e.g., AWGN, Fading, etc)



PROPAGATION CHARACTERISTICS

- Path Loss
- Shadowing
- Multipath Fading

PROPAGATION CHARACTERISTICS

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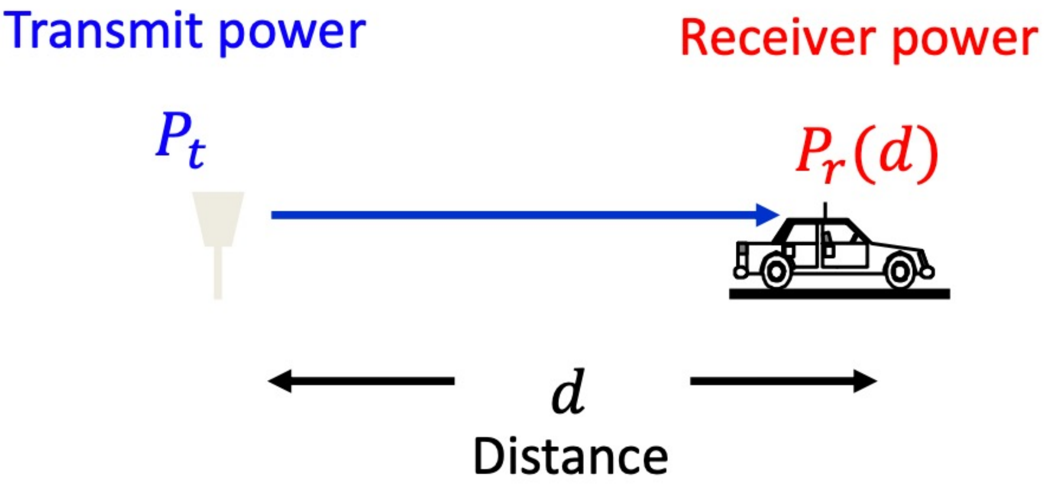
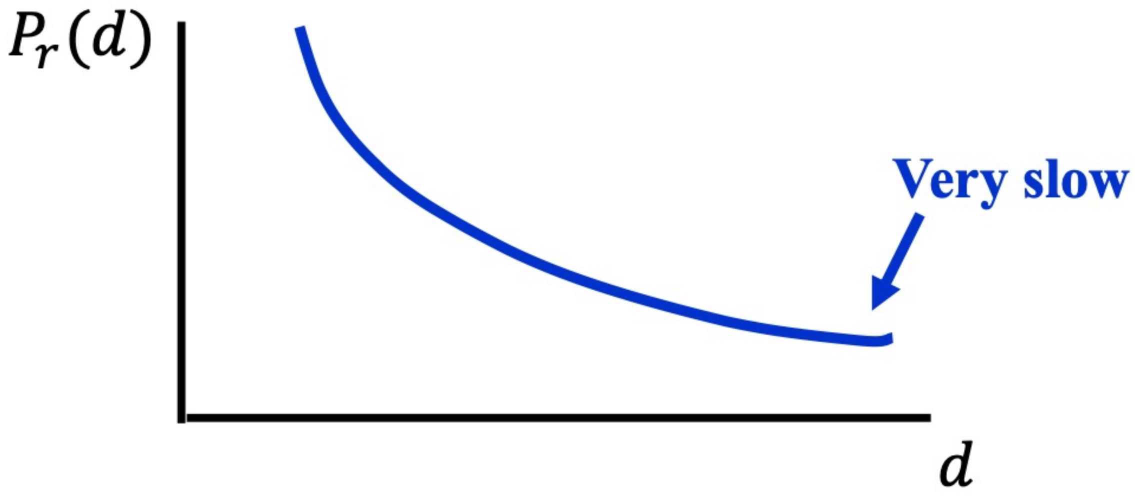
- Path Loss
- Also Known as "Large Scale Fading"
- A Function of Distance : $P_r(d)$





PROPAGATION CHARACTERISTICS

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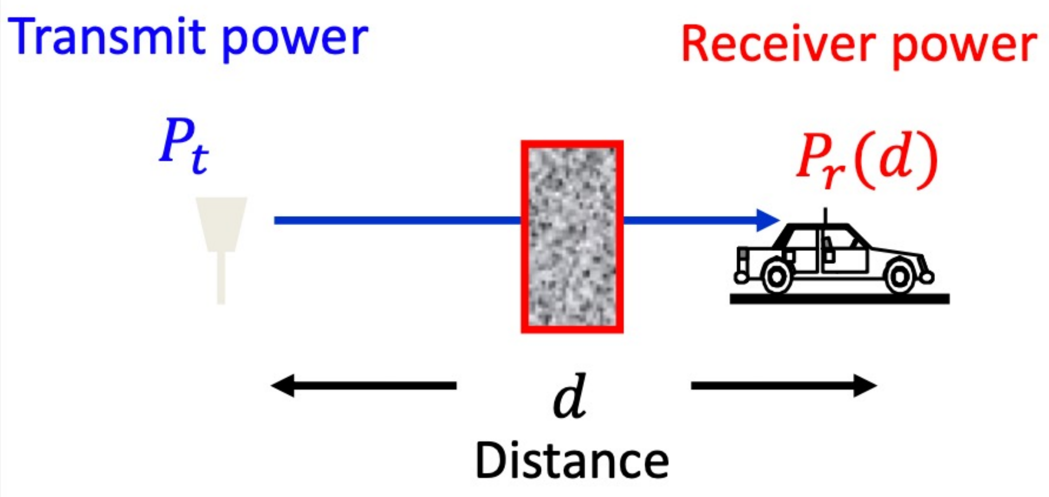
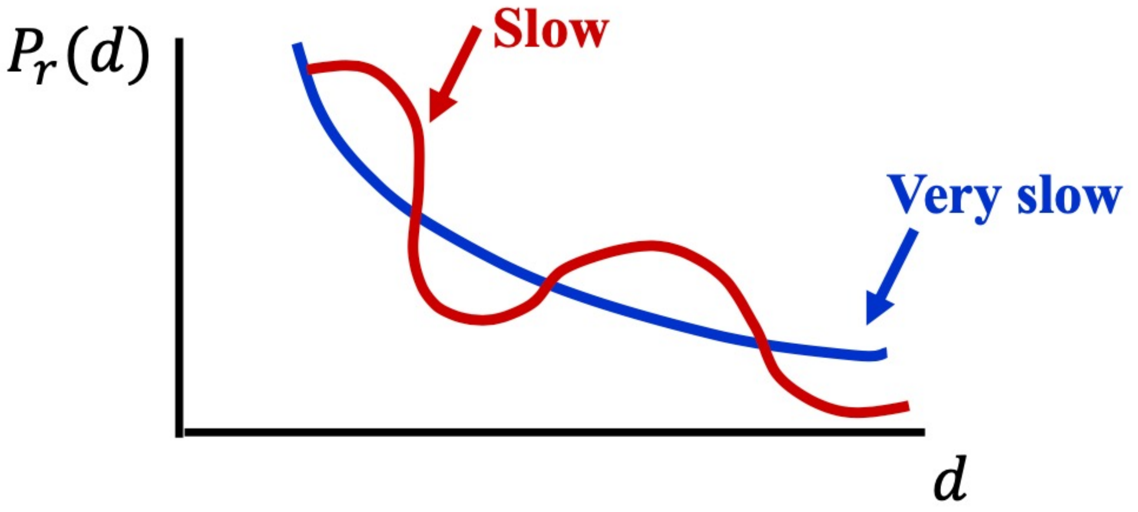
- Shadow Fading
- Objects in signal path causes random variation
- Affected by a Propagation environment
- Function of Distance





PROPACATION CHARACTERISTICS

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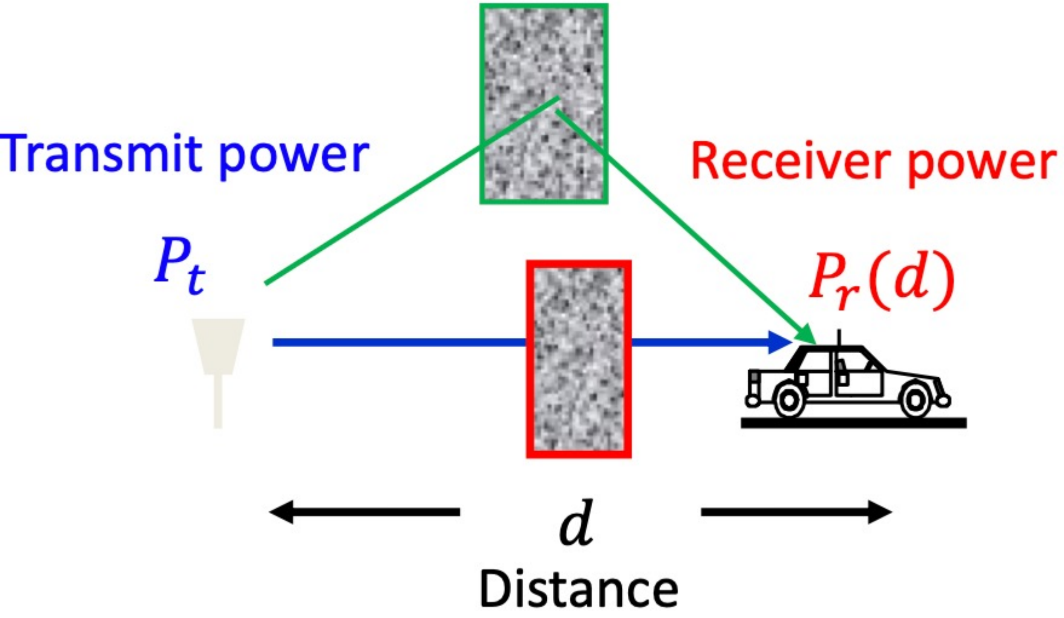
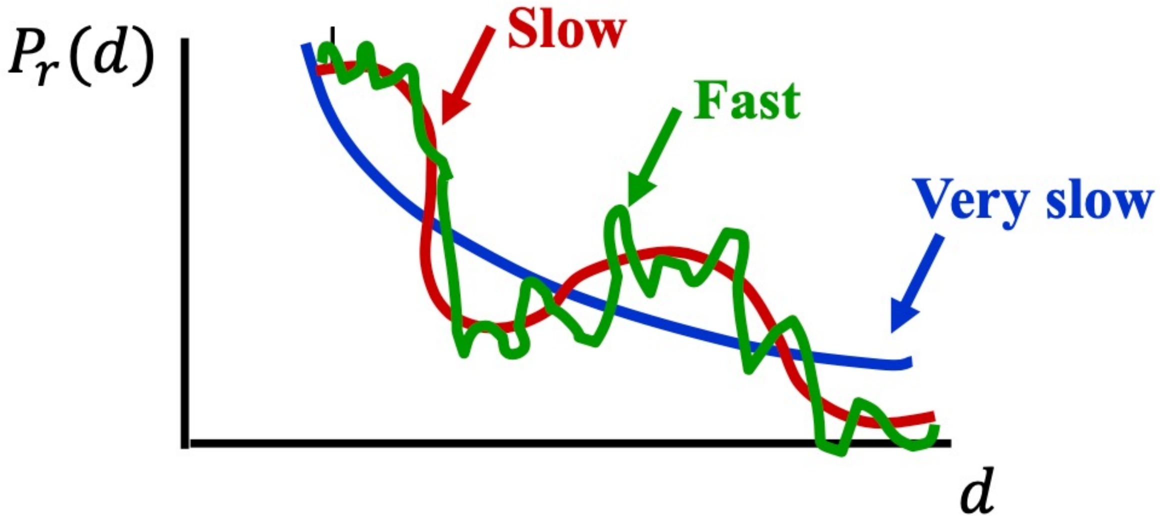
- Multipath
- Mathematically model the received power
- Function of transmit power and distance?





PATH LOSS MODELS

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- Free-space Path loss model
  - Simplest model / wisely used for system engineers
- Ray Tracing Model
  - Performance comparison in Standardization
  - Channel dependent technology
- Empirical Path-Loss Model

Free-Space Path Loss Model

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- Simple and good for satellite communcations
- Ratio of received and transmitted power is

Empirical measurements!

$$P_r(d) = P_t\left(\frac{\sqrt{G_i}\lambda}{4\pi d}\right)^2 \Rightarrow P_t K \left(\frac{d_0}{d}\right)^{\gamma}$$

Simplified (commonly) used for design

- In dB scale

$$P_r(d)dB = P_t dB + 10\log_{10} G_i + 20\log_{10}\lambda - 20\log_{10} d - 20\log_{10}(4\pi)$$

G_i : antenna gain

$\lambda = c/f_c$: signal wave-length

FREE-SPACE PATH LOSS

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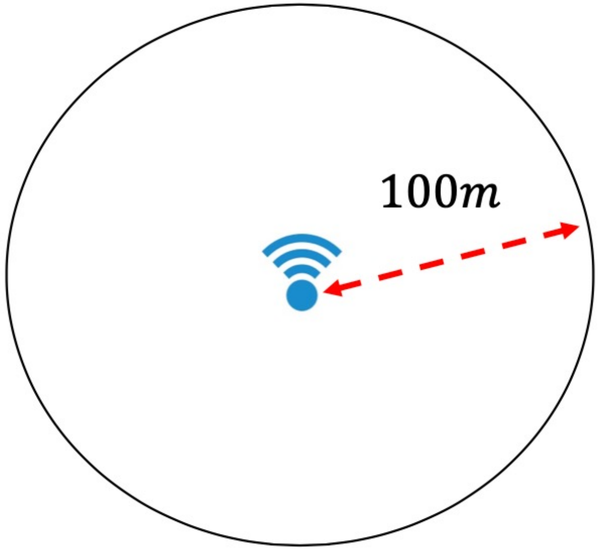
- We can easily compute the received power using the formula given
  - Carrier Frequency
  - Distance between receiver and transmitter

- Or we can calculate the Minimum power at access point in a certain wireless cell given
  - Carrier Frequency
  - Cell Radius
  - Required minimum power



We can simply show the impact of the carrier frequency (f_c) and the channel loss by substituting different frequencies
Ex) 20MHz, 500MHz, 2.4GHz, 50GHz

Shadowing

- Log-normal shadowing:
  - $\varphi = \frac{P_t}{P_r}$ is assumed to be a random variable following a log-normal distribution

$$p(\varphi) = \frac{\zeta}{\sqrt{2\pi}\sigma_{\varphi_{dB}}\varphi} \exp\left[-\frac{\left(10\log_{10}\varphi - \mu_{\varphi_{dB}}\right)^2}{2\sigma_{\varphi_{dB}}^2}\right], \qquad \varphi > 0$$

Where
$$\mu_{\varphi_{dB}} = \mathbb{E}[10\log_{10}\varphi]$$
$$\sigma_{\varphi_{dB}}^2 = \mathbb{E}\left[\left(10\log_{10}\varphi - \mu_{\varphi_{dB}}\right)^2\right]$$
$$\zeta = \frac{10}{\ln(10)}$$

Log-Normal Shadowing

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- Let $\varphi_{dB} = 10\log_{10}\varphi$
- We can show that

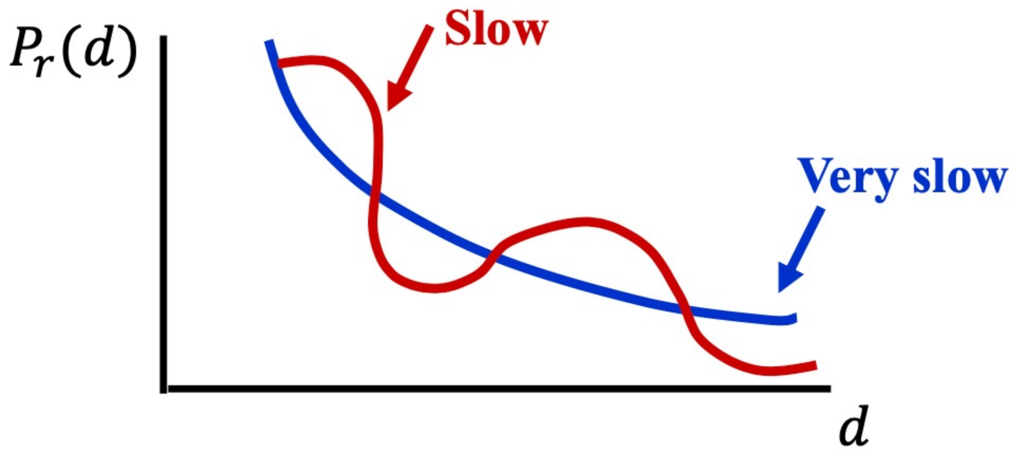
$$p(\varphi_{dB}) = \frac{1}{\sqrt{2\pi}\sigma_{\varphi_{dB}}}\exp\left[-\frac{\left(\varphi_{dB}-\mu_{\varphi_{dB}}\right)^2}{2\sigma_{\varphi_{dB}}^2}\right]$$

- In other words, φ_{dB} follows a normal distribution

PATH-LOSS + SHADOWING MODEL

- From the equation above from pathloss and the shadowing

$$P_r(d)dB = P_t dB + 10\log_{10} K - 10\gamma \log_{10}\frac{d}{d_0} - \varphi_{dB}$$



Outage Probability

- In wireless systems, there exists a minimum received power P_{min}
- With shadowing, the received power is a random variable
- To ensure that the received power is larger than P_{min} with probability 1, the transmit power should be extremely large, due to shadowing
- Define an outage probability p_{out}
  - Implies that the received power is larger than P_{min} with probability $1 - p_{out}$

Outage Probability

- Formally

$$p_{out}(P_{min}, d) = \Pr[P_r(d) < P_{min}]$$

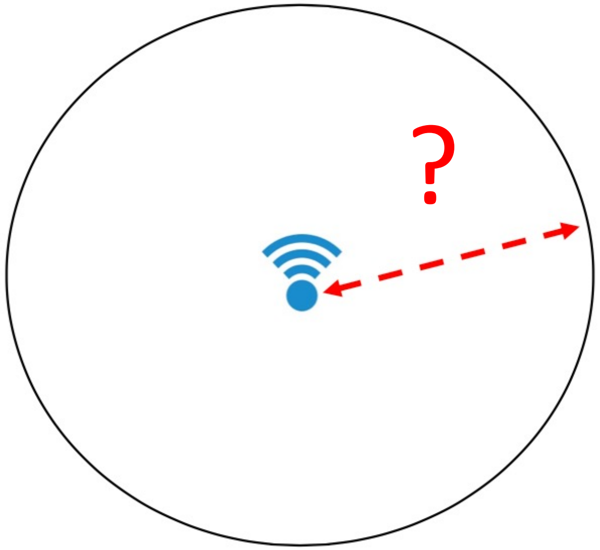
- Since $P_r(d)$ is a Gaussian random variable, we can compute the above probability with Q-function:

$$p_{out}(P_{min}, d) = \Pr[P_r(d) < P_{min}] = 1 - \Pr[P_r(d) \geq P_{min}]$$

$$p_{out}(P_{min}, d) = 1 - Q\left(\frac{P_{min} - \mu}{\sigma_{\varphi_{dB}}}\right)$$

Cell Planning – Choosing Cell Size

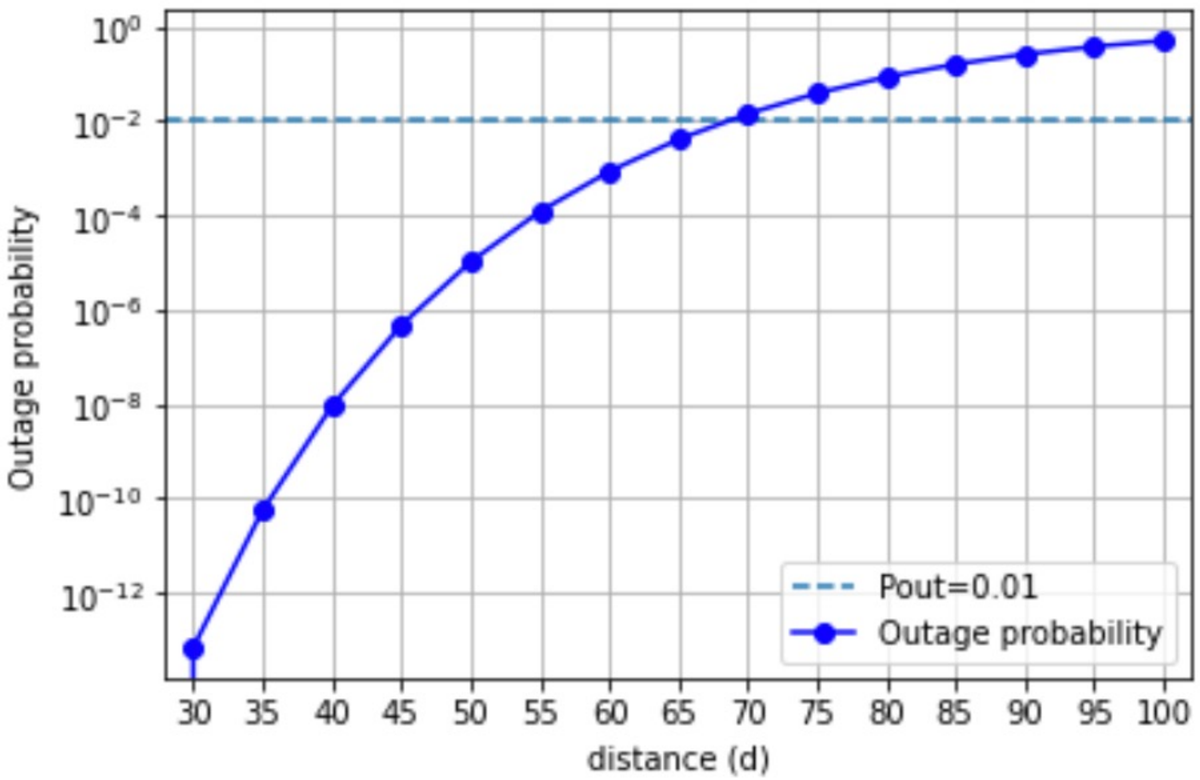
- Fixed maximum transmit power P_t



- System Requirements:
  - Minimum Received power P_{min}
  - Outage Probability p_{out}
- Cell Coverage (We need to solve)
  - Compute $P(P_r(d) < P_{min}) = f(d)$
  - Find the largest distance that $f(d) < p_{out}$, which is the largest cell coverage

Cell Planning

- Consider given all the parameters and Transmitted power,
  - Transmit Power : 100 dBm
  - Path-loss model: $P_r(d)dBm = P_t dBm \; - 40\log_{10} d - \varphi_{dB},\; \varphi_{dB} \sim N(0,8)$
  - Required received power: 10dBm



The Cell Coverage distance with outage probability of approximately 0.01 can be figured out by the following plot (which is a curve by the outage probability formula)

CELL PLANNING

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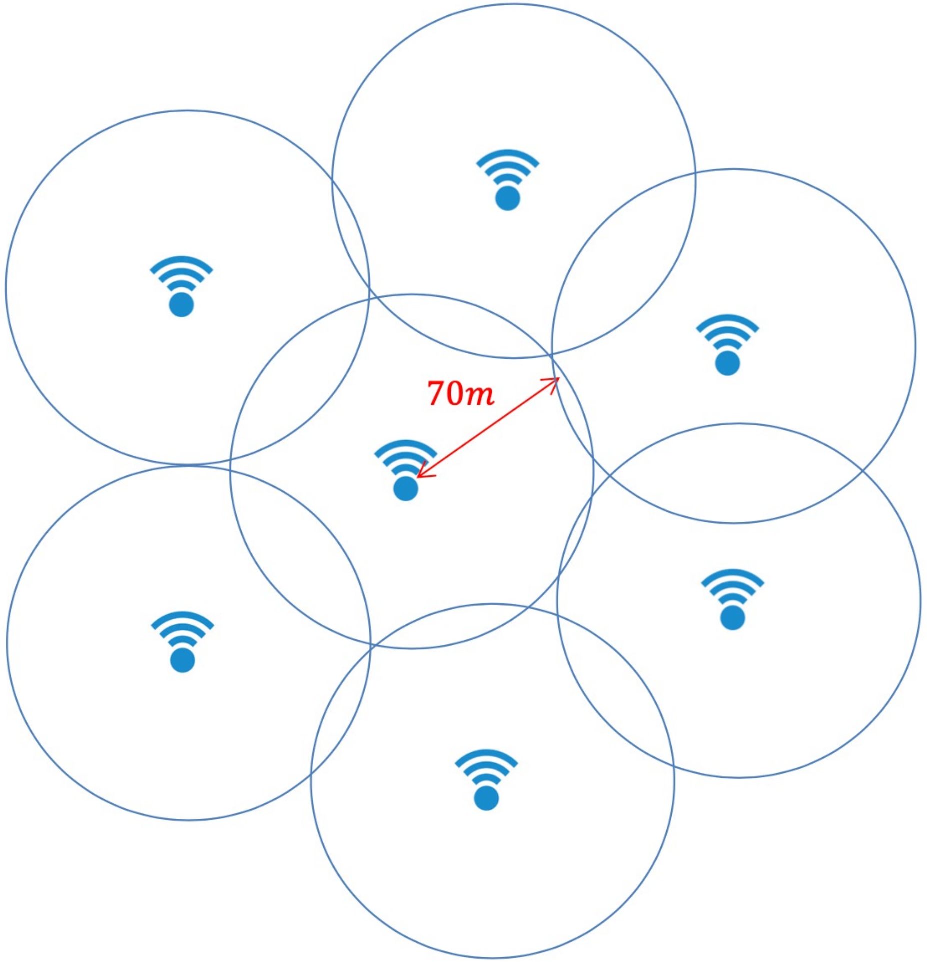
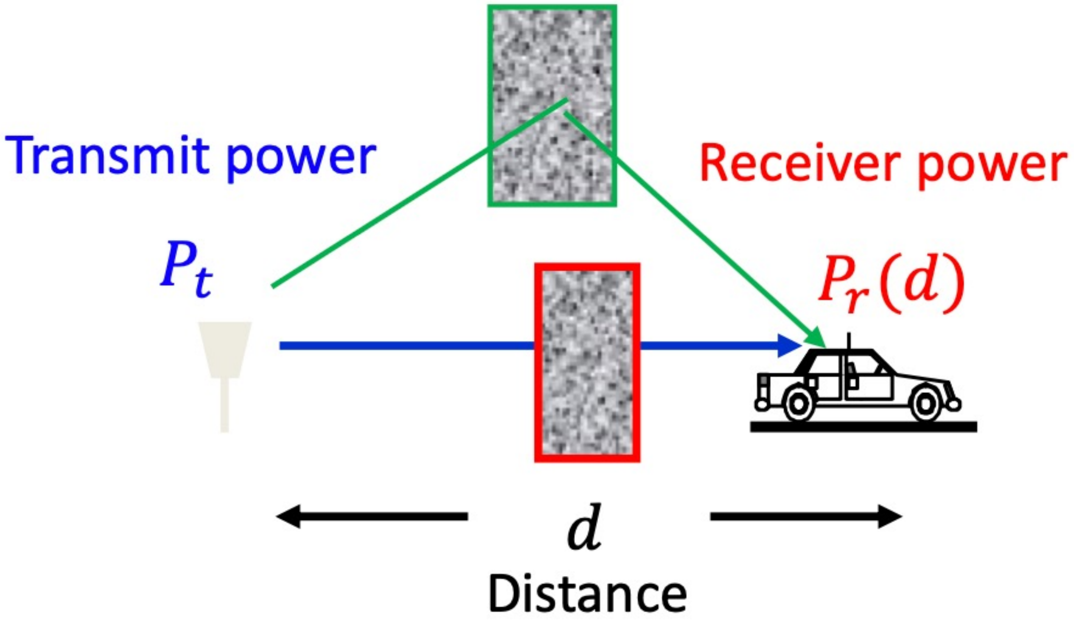


SMALL SCALE FADING



- Due to Constructive and destructive multipath
- Time domain or frequency domain

Mobility Multipath

SMALL SCALE FADING

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- The Channel can be classified in to
  - Frequency Flat or Frequency Selective Channel
  - Time invariant or Time Fading Channel

Coherence BW becomes a smaller than signal BW "multipath"

Coherence Time becomes a smaller than symbol duration "mobility"		
	Slow fading Frequency-flat fading	Slow fading Frequency-selective fading
	Fast fading Frequency-flat fading	Fast fading Frequency-selective fading

- And can be formulated as
  - Frequency Flat / Slow Fading Channel (at time domain)

$$y[n] = hs[n] + v[n]$$

  - Frequency Flat / Fast Fading Channel (at time domain)

$$y[n] = h[n]s[n] + v[n]$$

  - Frequency Selective / Slow Fading Channel

$$y[n] = \sum_{l=0}^{L} h[l]s[n-l] + v[n]$$

  - Frequency Selective / Fast Fading Channel

$$y[n] = \sum_{l=1}^{(L)} h[n,l]s[n-l] + v[n]$$

REFERENCE

- ECE 432 Mobile Communications_Lecture2_Ajou_university lecture notes by S.N. Hong
- Goldsmith, Andrea. *Wireless communications*. Cambridge university press, 2005.

QnA

Thank You