Fundamentals of Wireless Communication

The Wireless Channel

Edward Kwao

Hanbat National University

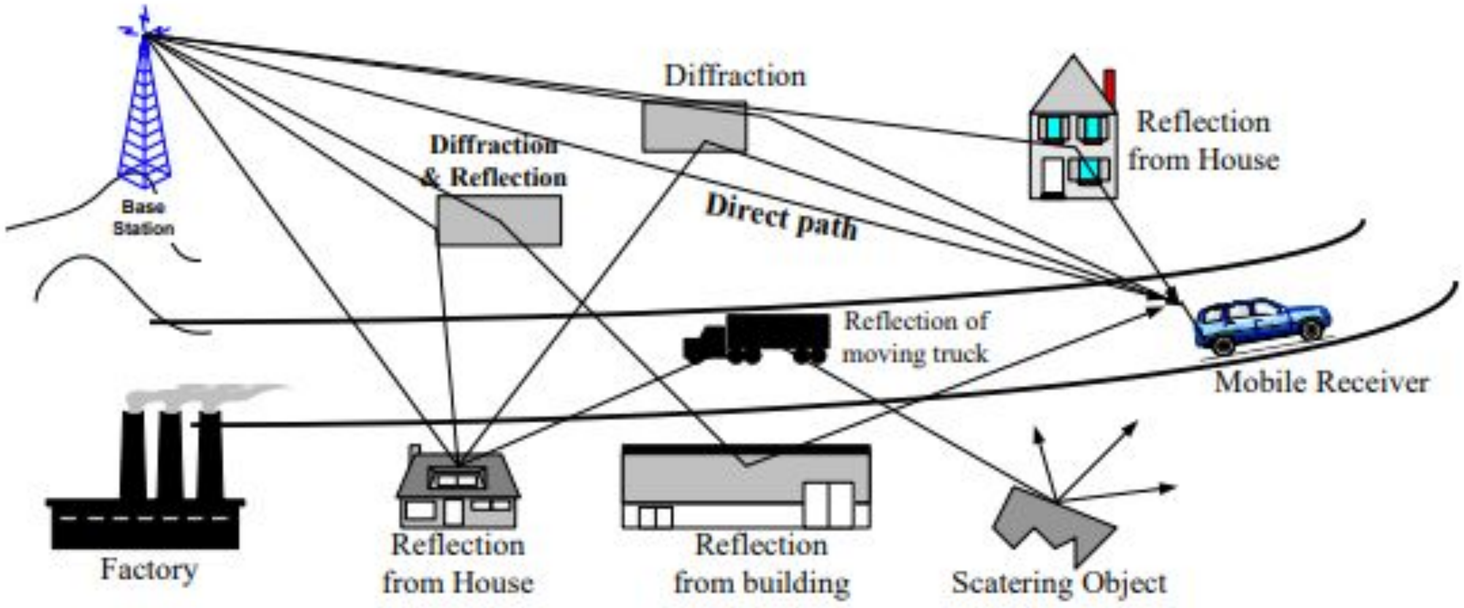
5th November, 2021

HANBAT NATIONAL UNIVERSITY

Contents

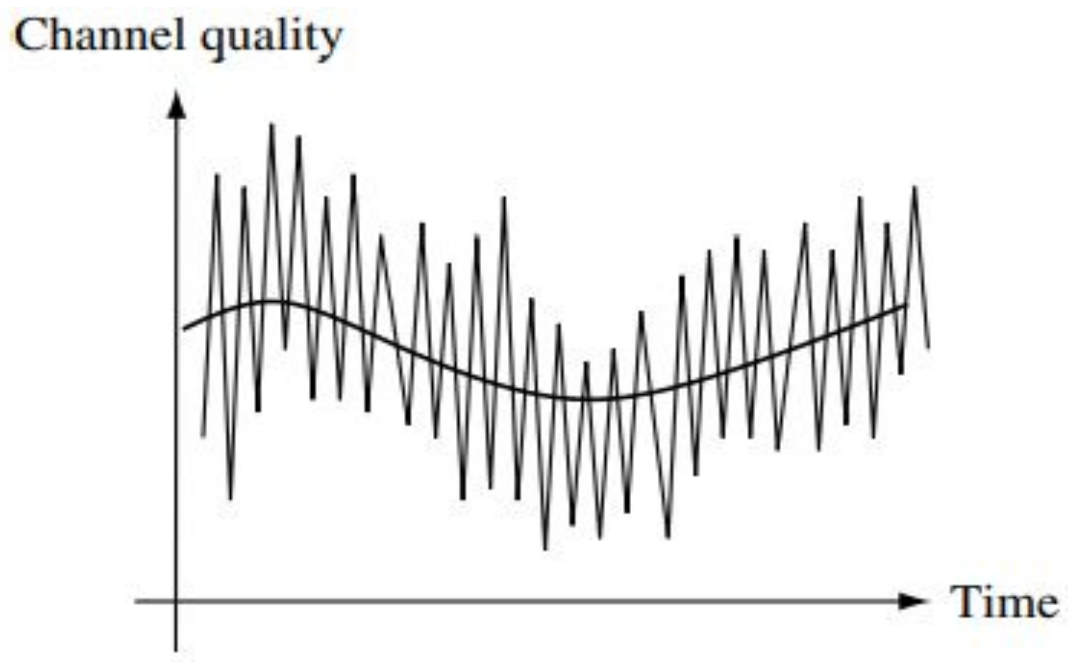
Physical Modeling for wireless channels

- Electromagnetic signals leaving a transmit antenna *propagate* through the wireless medium to reach the receive antenna.
- The random nature of a typical wireless channel causes signals to propagate mainly through *reflection, diffraction* and *scattering* known as ray tracing.



Comparison between small- and large-scale fading

- The random channel then places a fundamental limitation on signal coverage and data rates.
- This limitation is called fading and is classified into: large-scale and small scale.



Input-Output Model of the wireless channel

LTV nature of the wireless channel

- The attenuations and delays α_i and τ_i respectively of the i_{th} path of a multipath signal $x(t)$ in the channel can be modeled as linear time-varying.
- For a moving receiver moving in time , the received signal

$$y(t) = \sum_i \alpha_i x(t - \tau_i(t)) \ldots \ldots \ldots \ldots \ldots (1)$$

- Since (1) is linear, it can be described by the response $h(\tau, t)$at time, t to an impulse transmitted at time $t - \tau$. In terms of $h(\tau, t)$, the input/output relationship is given by:

$$y(t) = \int_{-\infty}^{\infty} h(\tau, t) x\big(t - \tau_i(t)\big) d\tau \ldots \ldots \ldots (2)$$

- Comparing (1) and (2), the impulse response is given by:

$$h(\tau, t) = \sum_i a_i(t) \delta(\tau - \tau_i(t))$$

Baseband equivalent model

- In typical wireless applications, communication occurs in a passband $[f_c - \frac{W}{2}, f_c + \frac{W}{2}]$ of bandwidth W around a center frequency f_c.
- However, most of the processing, such as coding/decoding, modulation/demodulation, synchronization, etc., is actually done at the baseband.
- The baseband equivalent channel is:

$$y_b(t) = \sum_i a_i^b(t) x_b\left(t - \tau_i(t)\right),$$

where $a_i^b(t) = a_i(t) e^{-j\omega_c \tau_i(t)}$

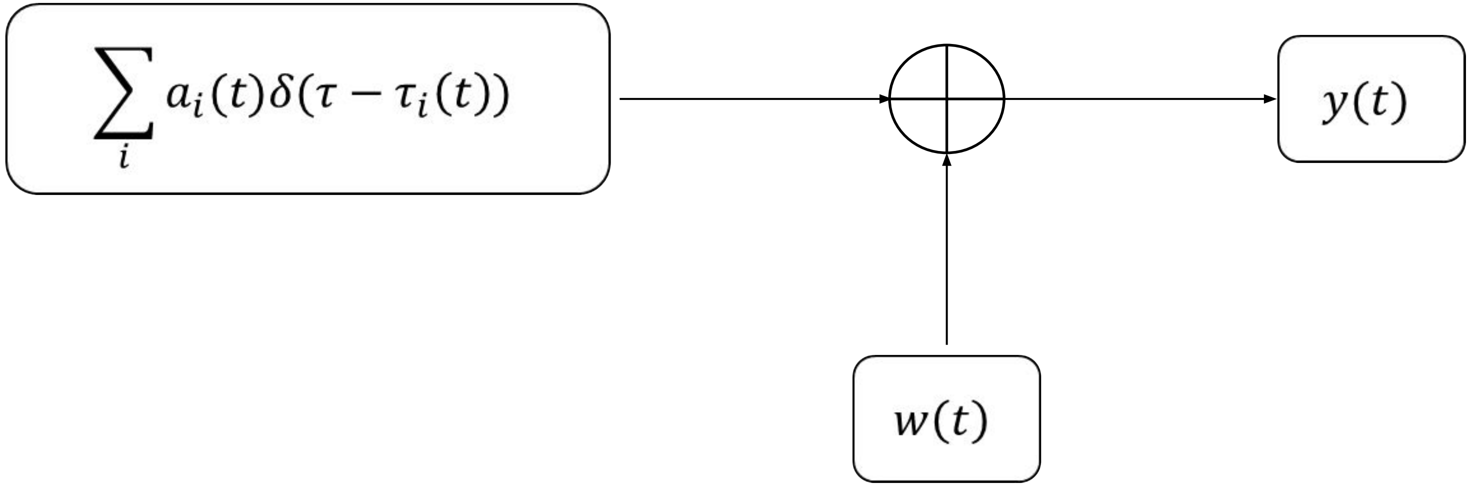
- The baseband equivalent impulse response is:

$$h_b(\tau, t) = \sum_i a_i^b(t) \delta(\tau - \tau_i(t))$$

HANBAT NATIONAL UNIVERSITY

Additive White Noise

- After developing the input-output model of the channel, additive white noise, $w(t)$ is incorporated.
- $w(t)$ is zero-mean Gaussian noise with power spectral density (PSD) of $\frac{N_o}{2}$



- The input-output model of the channel becomes:

$$y(t)=\sum_i \alpha_i x(t-\tau_i(t))+w(t)\ \ldots\ldots\ldots.(*)$$

- The channel in $(*)$ mimics real world channel.

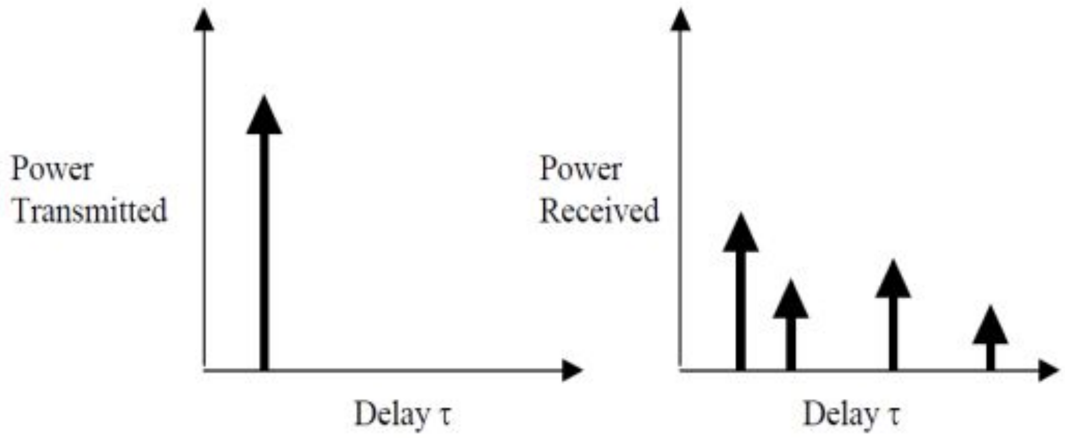
Time and Frequency Coherence

- If received signal arrives with different delays, it leads to time-dispersion of the transmitted signal.

- This is best characterized by Power Delay Profile. Two scalars namely Delay spread and coherence bandwidth are derived from the PDP.

The relationship between these two scalars is:

$$\mathit{Coherence\ bandwidth},\ W_c = \frac{1}{\mathit{delay\ spread}, T_d}$$



- In a real world, the transmitter or receiver or the scatterers can be in motion relative to each other. This causes Doppler effect or frequency dispersion.
- Doppler effect causes frequency shift in the receiver and hence fluctuates the power received. This is known as Doppler Spread.
- If initially, an antenna is at a moving location, described by:

$$E(f, t, (r_0 + vt, \theta, \psi)) = \frac{\alpha_s(\theta, \psi, f) \cos 2\pi f(t - r_0/c - vt/c)}{r_0 + vt}$$

With doppler shift $-\frac{fv}{c}$ moves to a new location described by:

$$E_r(f, t) = \frac{\alpha \cos 2\pi f[(1 - v/c)t - r_0/c]}{r_0 + vt} - \frac{\alpha \cos 2\pi f[(1 + v/c)t + (r_0 - 2d)/c]}{2d - r_0 - vt}.$$

- The new location has doppler shift $+\frac{fv}{c}$, hence Doppler spread $+\frac{fv}{c}$ -($-\frac{fv}{c}$) = 2 $\frac{fv}{c}$

Rayleigh and Rician fading

- The highly random nature of the mobile wireless channel requires rigorous mathematical models to reflect its nature.
- Where Rice channel in small-scale fading environment propagates both multipath components and a direct LOS signal, Rayleigh channels propagate only multipath components.
- ***Stochastic models of these channels help us to predict what types of phenomena to expect when setting up transmitters and receivers for communication.***
- Rayleigh fading is used for scattering mechanisms where there are many small reflectors but is adopted primarily for its simplicity in typical cellular situations with a relatively small number of reflectors.

-

- The Rayleigh fading is modeled as a zero-mean Gaussian distribution and has phase evenly distributed between 0 and 2π radians.

- The Rayleigh fading has a probability density function: [2]

$$f_{Rayleigh}(x) = \frac{x}{\sigma^2} e^{-x^2/2\sigma^2}, \qquad x \geq 0 \text{.......................} (3)$$

Where σ^2 is the variance of the distribution

- The cumulative density function is:

$$F_{Rayleigh}(x) = 1 - e^{-x^2/2\sigma^2}, \qquad x \in [0, \infty) \text{.......................} (4)$$

- In Rice fading model, there is a dominant LOS path of known magnitude in the midst of large number of independent paths.
- This makes the model very popular in statistical channel modeling.

- The Rice fading has a probability density function:

$$f_{Rice}(x) = \frac{x}{\sigma^2} \exp\left(-\frac{\left((x^2+\beta^2)\right)}{2\sigma^2}\right) I_o\left[\frac{x\beta}{\sigma^2}\right], \quad x \geq 0 \text{.......................(5) [2]}$$

$$where\ \beta = amplitude\ of\ the\ LOS\ component,$$
$$I_0[.]\ is\ the\ 0th\ order\ modified\ Bessel\ function\ of\ the\ first\ kind$$

$$I_o[0] = 1 \quad \text{[3]}$$

-

A parameter, K which is defined as the ratio of the power in the LOS component to the power in the scattered components is given by:

$$K = \frac{\beta^2}{2\sigma^2} \ldots \ldots \ldots \ldots \ldots . . (6)$$

- This *K* parameter, so-called Rician *K-factor* determines the best-case and worst-case Rician fading channel.

Rayleigh and Rice Fading Simulation objectives

- Generate a certain amount of Gaussian distributed random samples, N.
- Pass these samples through a Rayleigh and Rice fading channel and estimate their PDF and CDF.
- Compare estimated PDF and CDF with theoretical PDF and CDF of both channels.
- Analyze results.

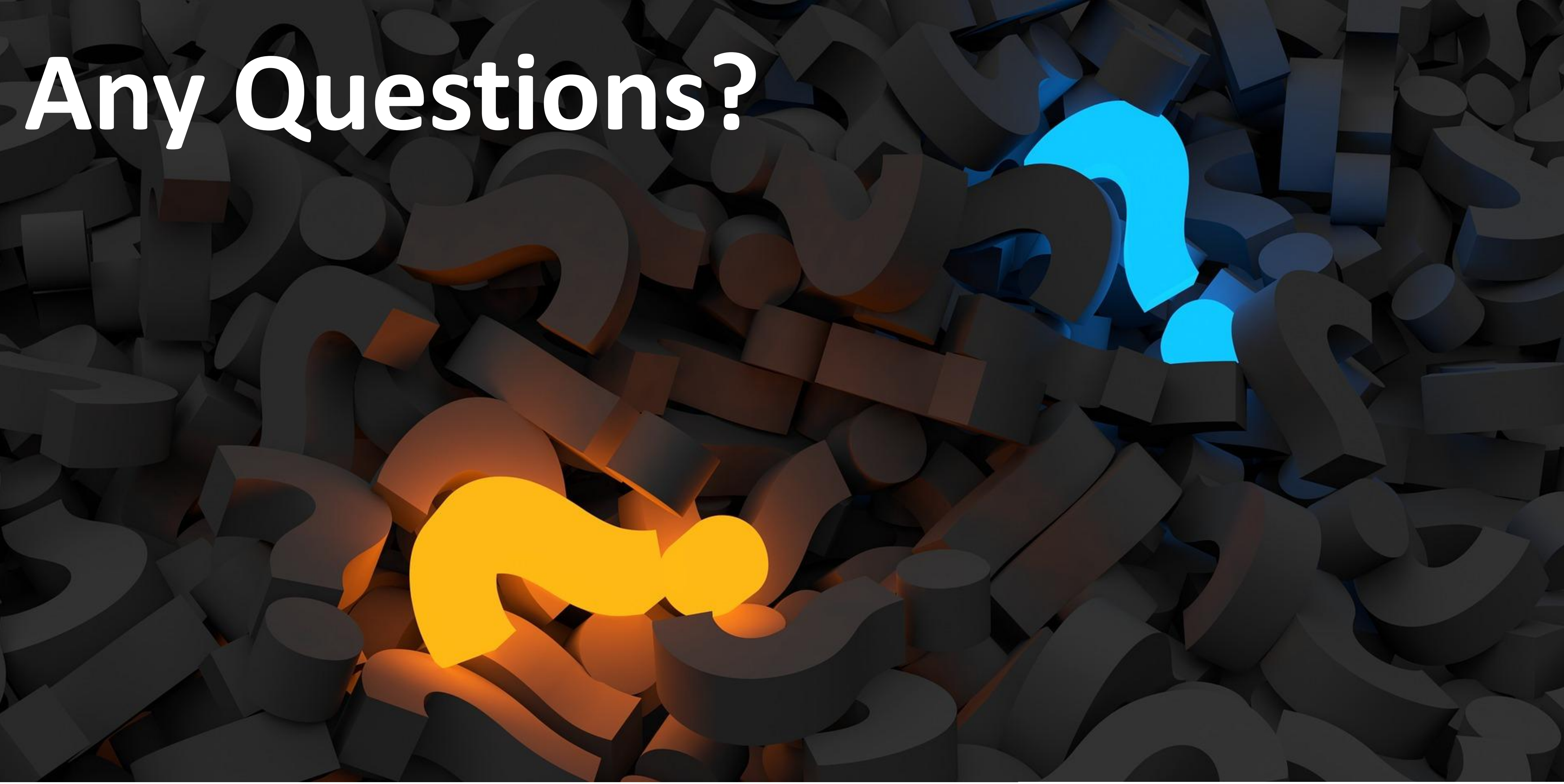
References

[1] D. Tse and P. Viswanath, Fundamentals of Wireless Communications., Cambridg e Univ. Press, 2005.

[2] Nikolay Kostov, "Mobile Radio Channels Modeling in MATLAB", *Radioengineering*, vol. 12, no. 4, pp. 12-16, December 2003.

[3] Bessel Function Calculator https://keisan.casio.com/exec/system/1180573474

Any Questions?



HANBAT NATIONAL UNIVERSITY

E-mail: edkwao10@gmail.com