Fundamentals of Wireless Communication

Point-to-Point Communication

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Contents

Detection

Noncoherent Detection in Rayleigh Flat Fading Model

- Given signal received in a fading channel:

$$y[m] = h[m]x[m] + w[m],$$

- where $w[m] \sim CN(0, N_o)$ is a complex noise and $h[m] \sim CN(0,1)$ is the channel impulse response in Rayleigh fading.
- In noncoherent detection, prior knowledge of the channel impulse response is not known at the receiver. This poses a threat to the detection of transmitted symbols at the receiver, hence increasing the bit error probability.
- In an orthogonal BPSK modulation scheme where the detector makes decision on which of two symbols were transmitted, the Probability of error,

$$P_e = \frac{1}{2(1 + SNR)}$$

- One would require SNR ≈ 500 (27 dB) to get $P_e = 10^{-3}$.
- An outrageous amount of power would be required for more reliable communication.
- So noncoherent detection of the BPSK signaling is not a suitable method of detection, especially in a fading environment.

Coherent Detection in AWGN and Rayleigh Flat Fading Model

- Comparing the result above to a nonfading AWGN model, where the channel gain is still not known by the receiver, the probability of error,

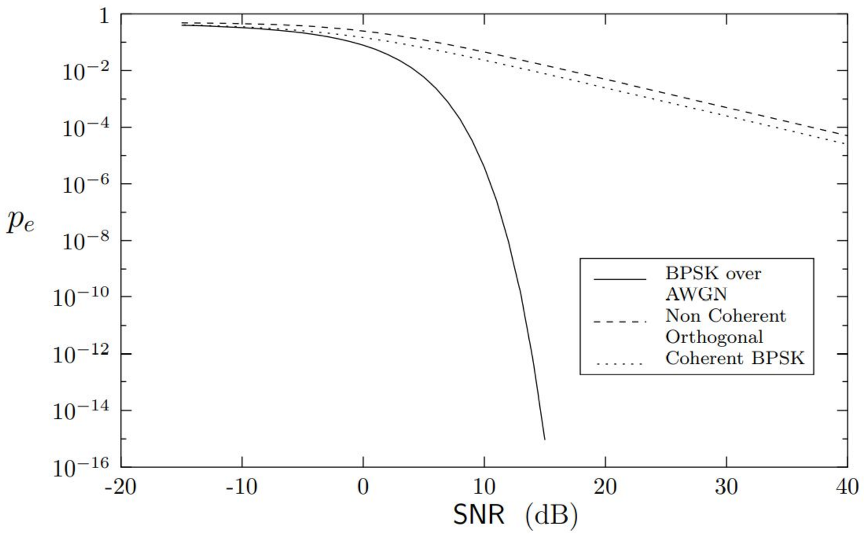
$$P_e = Q\left(\sqrt{2SNR}\right) = \frac{1}{2} erfc\sqrt{SNR}$$

- To get $P_e = 10^{-3}$, an SNR ≈ 5(7 dB) is required. Is it really ***all*** about the knowledge of the channel gain at the receiver?
- Now knowing the channel gains, coherent detection of BPSK can now be performed and the result compared to the two above.
- Given $y = hx + w$, if transmitted symbols $x = \pm a$, then for a given value of h, the error probability of detecting x is:

$$Q\sqrt{2|h|^2 SNR} \qquad (1)$$

- For Rayleigh fading when $h \sim CN(0,1)$, the $P_e = \frac{1}{2}\left(1 - \sqrt{\frac{SNR}{1+SNR}}\right) \approx \frac{1}{SNR}$ at high SNR
- For the same $P_e = 10^{-3}$ as above, SNR ≈ 250(24 dB)
- There is only a 3 dB difference in the required SNR between the coherent and noncoherent schemes

- We see that the main reason why detection in fading channel has poor performance is not because of the lack of knowledge of the channel at the receiver.
- It is due to the fact that the channel gain is random and there is a significant probability that the channel is in a phenomenon known as deep fade. How?



Deep fade event: $|h|^2 < 1/\mathrm{SNR}$

$P\{\text{deep fade}\} \approx 1/\mathrm{SNR}$

Scheme	Bit Error Prob. (High SNR)	Data Rate (bits/s/Hz)
Coherent BPSK	$\frac{1}{4\mathrm{SNR}}$	1
Coherent QPSK	$\frac{1}{2\mathrm{SNR}}$	2
Coherent 4-PAM	$\frac{5}{4\mathrm{SNR}}$	2
Coherent 16-QAM	$\frac{5}{2\mathrm{SNR}}$	4
Noncoherent orth. mod.	$\frac{1}{2\mathrm{SNR}}$	1/2
Differential BPSK	$\frac{1}{2\mathrm{SNR}}$	1
Differential QPSK	$\frac{1}{\mathrm{SNR}}$	2

Diversity

- *Why do we need diversity?* Communication over a flat fading channel has poor performance due to significant probability that channel is in deep fading.

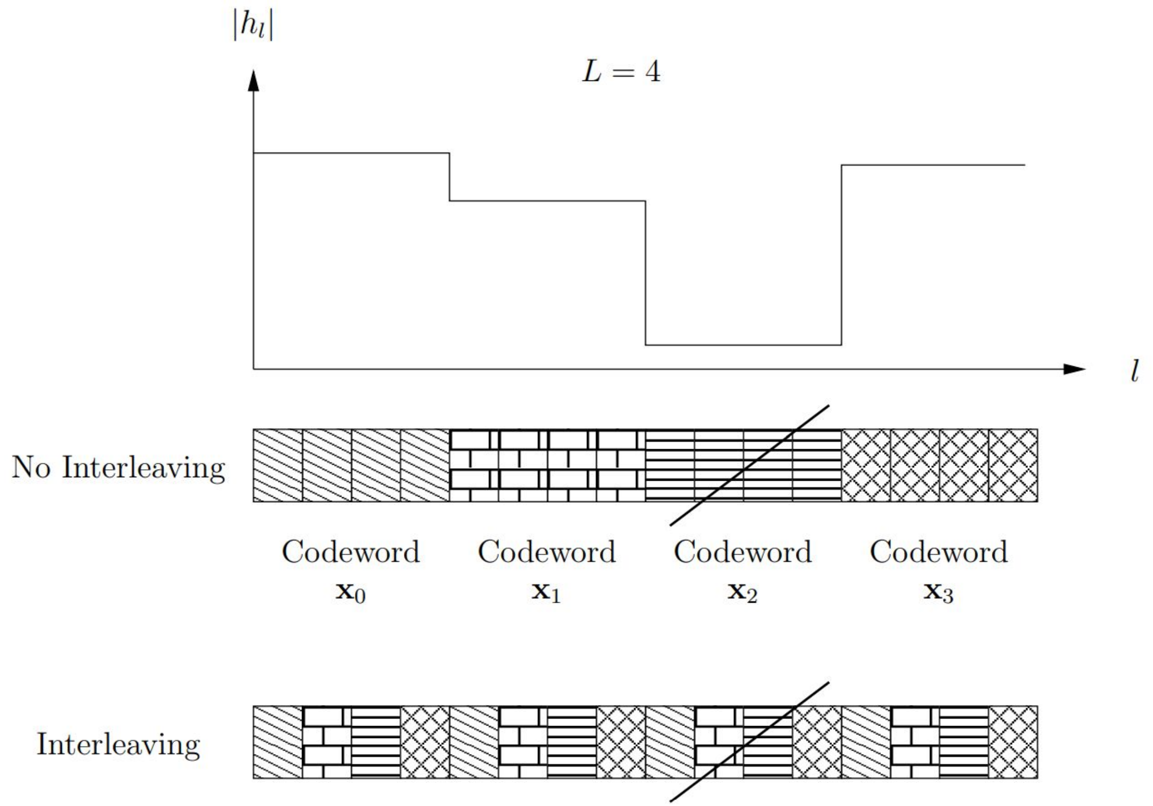
- *What will diversity achieve?* Improve the performance by ensuring reliable communication is possible.

- How will it achieve this result? Information symbols pass through multiple signal paths, each of which fades independently but achieves reliability as long as one of the paths is strong.

- Diversity can be provided across *time, space(antenna) and frequency.*

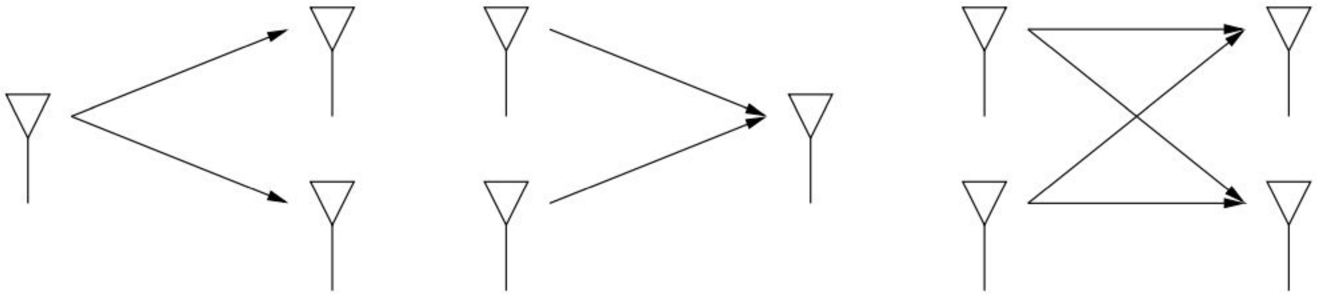
Time diversity

- Time diversity can be obtained by interleaving and coding over symbols across different coherent time periods.
- Information symbols are repeatedly transmitted at different times.
- Time spacing exceed the coherence time of the channel.



Space (antenna) diversity

- (a) By having L receive antennas and coherent combining at the receiver in a flat fading channel, the effective total received signal power increases linearly with L.
- (b) It is easy to get a diversity gain of L by transmitting the same symbol over the L different antennas during L symbol times.
- (c) Suppose both the transmit antennas and the receive antennas are spaced sufficiently far apart such that the fading gains, h_{ij}s can be assumed to be independent. There are four independently faded signal paths between the transmitter and the receiver, suggesting that the maximum diversity gain that can be achieved is 4.



(a) (b) (c)

Frequency diversity

- The aim is to transmit same information on different uncorrelated carrier frequencies that experience independent fades.
- Theoretically, if the channels are uncorrelated, then the probability of simultaneous fading will be the product of the individual fading probabilities.
- From the discrete-time baseband model of the wireless channel, the sampled output can be written as:

$$y[m] = \sum_{l} h_l[m]x[m-l] + w[m]$$

Here $h_l[m]$ denotes the l^{th}channel filter tap at time m.

- One symbol $x[0]$ is sent at time 0, and no symbols are transmitted after that. The receiver observes

$$y[l] = h_l[l]x[0] + w[l], \qquad l = 0,1,2,\ldots$$

- Full diversity is achieved by sending one symbol each L symbol time

- But this is inefficient as sending symbols more frequently may result in intersymbol interference(ISI).
- The problem is then how to deal with the ISI while at the same time exploiting the inherent frequency diversity in the channel.
- Mitigation approaches:

- Time-domain equalization: Linear equalizers attempt to detect the current symbol while l inearly suppressing the interference from the other symbols.
- Direct-sequence spread spectrum: In this method, information symbols are modulated b y a pseudonoise sequence and transmitted over a bandwidth W much larger than the da ta rate. Because the symbol rate is very low, ISI is small, simplifying the receiver structure significantly.

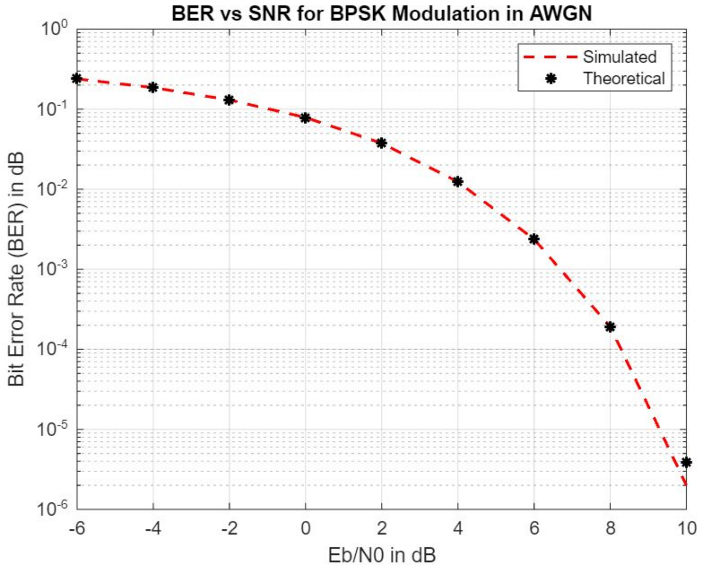
- Orthogonal frequency-division multiplexing OFDM: a bunch of non-interfering sub-chann els, one for each sub-carrier are used for transmitting data.

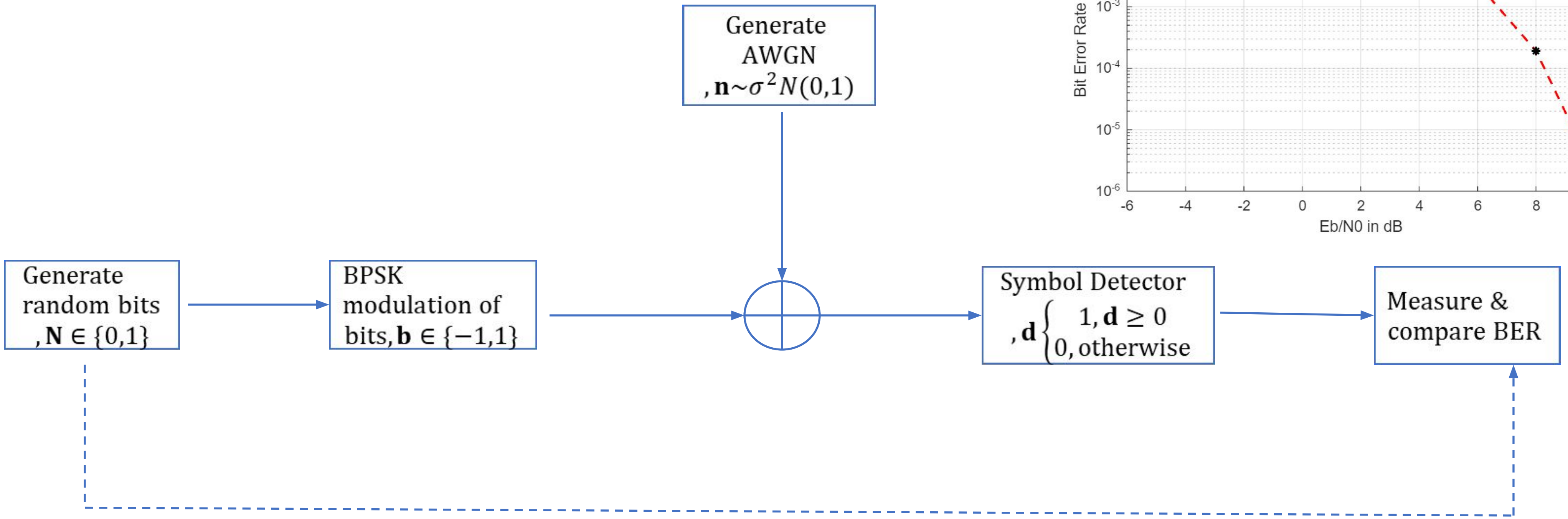
MATLAB Simulations objectives

- Generate a certain amount of random binary bits.
- Perform BPSK modulation on the bits and add white noise.
- Transmit resulting signal over non-fading AWGN and fading(Rayleigh) channel.
- Plot and analyze the bit error probabilities for arbitrary SNRs.

MATLAB Simulations
BPSK over AWGN

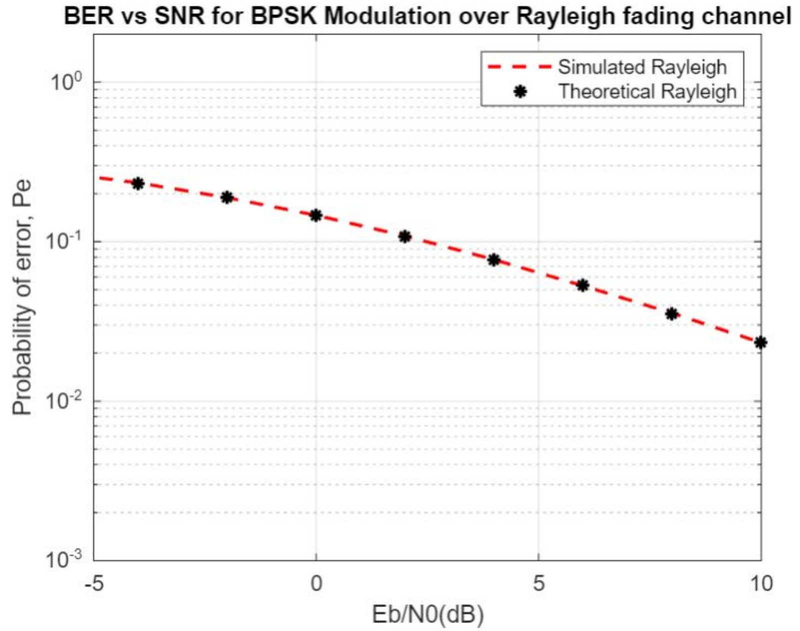
For SNR 6 dB, a probability of error, $P_e \approx 0.0024$

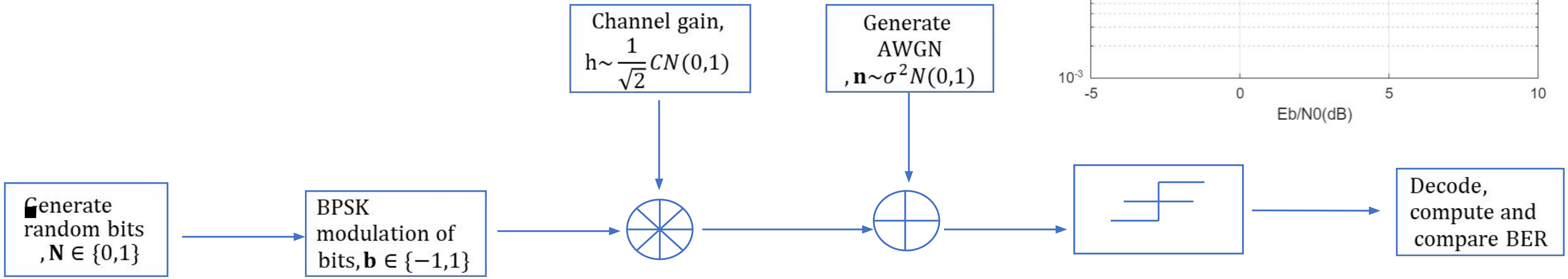




BPSK over Rayleigh Fading

For SNR 6 dB, a probability of error, $P_e \approx 0.053$





References

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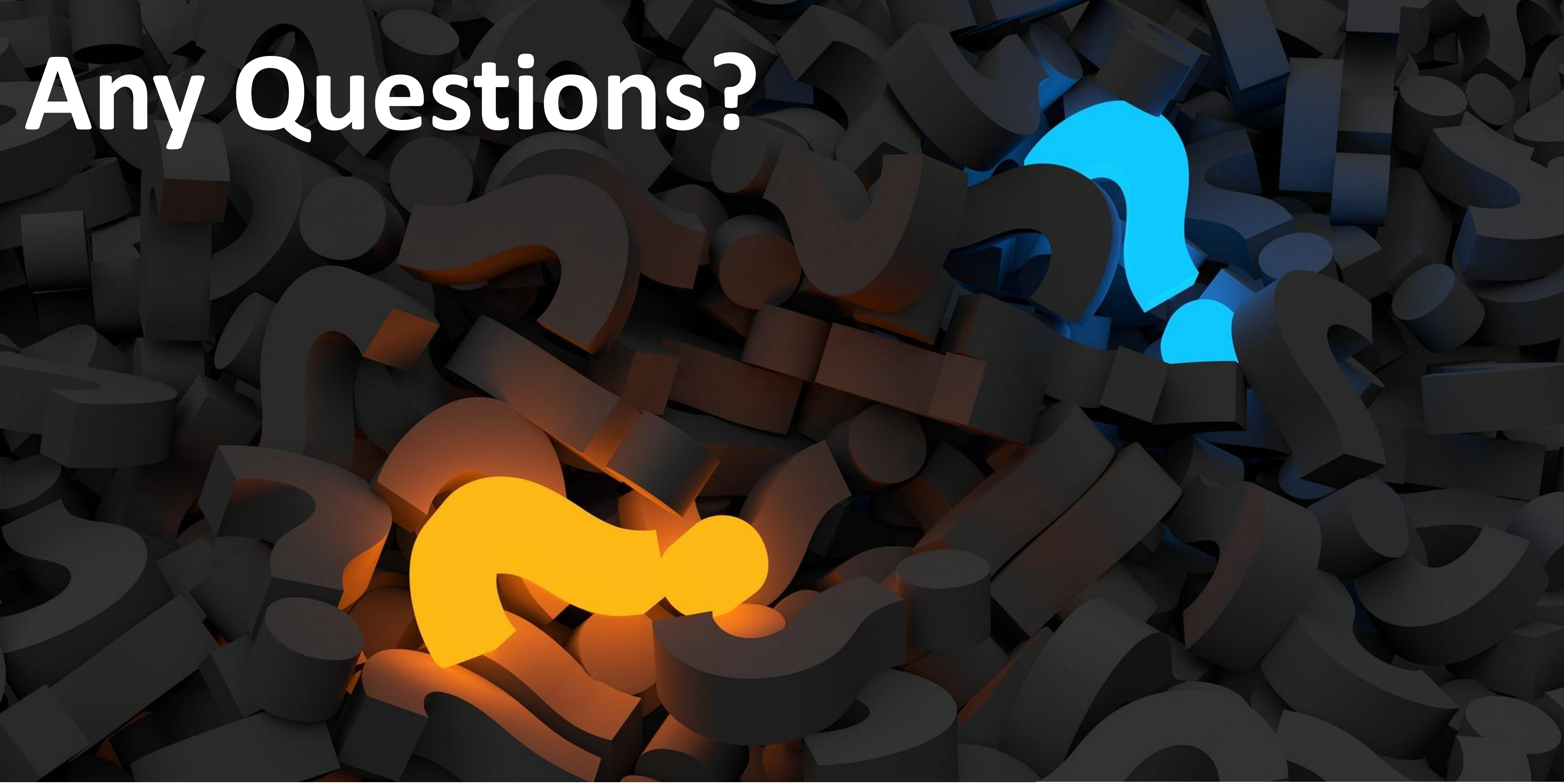
[2] T. S. Rappaport, "*Wireless communications—Principles and practice.*"

[3] A. J. Goldsmith, Wireless Communications, Cambridge University Press, 2005.

Any Questions?



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