About the midterm exam:

Q2 & Q3
- inclined
  - modeling of the problem
  - identifying relevant expressions or conditions
  - formulating the optimization problem
- stochastic channels

needs the 503 prereq.

why do we bring in Probability into Wireless Networks?
How much do we really need?

E.1: (log normal fading) \( \sim \) channel quality is random
cell-edge user experiences the lowest SIR.

Waterfilling:

This is only suitable for slow fading channels.

For fast fading, the C/I ratios will be (stochastically varying).
Time constant of change determines whether we can solve the problem as a classical/deterministic optimization problem or as a stochastic/probabilistic optimization problem.

Typically: given some variable that has a distribution, the performance objective depends on its 'true' goal: max the Expected Performance.
a) \[ \text{SINR} = \frac{S}{I + N} \]

b) \[ P \left( \frac{R}{d_0} \right) \cdot N \cdot \text{Normal r.v.} \]

\[ P \left( \frac{x - R}{d_0} \right) \cdot N \]

\[ \text{WSS} = P_{dBm} - 10 \log_{10} \left( \frac{R}{d_0} \right) + \gamma \text{ dB} \]

\[ \text{WSS} = P_{dBm} - 10 \log_{10} \left( \frac{x - R}{d_0} \right) + \gamma \text{ dB} \]
\[ Y \sim N(0, 2\sigma^2) \]

\[ \mu = 4 \quad \sigma = 2 \quad \text{dB} \]

\[ -\eta_{10} \log_{10}(R) + \eta_{10} \log_{10}(R-x) \leq \text{Tab} \]

Normalized r.v.

\[ Y < \text{Tab} - \eta_{10} \log_{10}(R) + \eta_{10} \log_{10}(R-x) \]

For above

\[ \Phi \{ \text{pdf} \} \]

\[ \Pr(\text{above}) \]

\[ P \]

\[ \rightarrow k \rightarrow \]
93. \( \max \text{ the expected sum rate!} \) 
\[ \log \left( 1 + \frac{P_1 s_1}{n_1} \right) + \]
\[ 0.5 \log \left( 1 + \frac{P_2 s_2}{n_2} \right) \]
\[ 0.5 \log \left( 1 + \frac{P_2 G_2}{N_2} \right) \]

7. \( \log \left( 1 + 0.5 P_2 \frac{n_2}{n_2} + 0.5 P_2 \frac{s_2}{n_2} \right) \)

Expected rate for ch 2. Expected SNR.

\[ E[f(X)] \neq f(E[X]) \]
\[ \text{Expected} \left( \log(1+\text{SNR}) \right) \neq \log \left( 1 + E[\text{SNR}] \right) \]
can also formulate as:

\[ f(x) = \log \left( 1 + \frac{x^2}{h} \right) + \]

\[ \frac{1}{2} \left( \log \left( 1 + \left( \frac{P_{\text{tot}}}{\sqrt{N}} \right) \cdot \frac{x}{h} \right) + \log \left( 1 + \left( \frac{P_{\text{tot}} - x}{\sqrt{N}} \right) \cdot h \right) \right) \]

\[ 0 \leq x \leq P_{\text{tot}} \]

\[ \frac{df(x)}{dx} = 0 \]

more general case: arbitrary pdf for each channel.

Rate 1: \( E \left[ \log (1 + \text{SNR}) \right] \)

Rate 2: \( E \left[ \log (1 + \text{SNR}) \right] \)

\[ E \left[ f(x) \right] = \sum_{x \in X} P_X(x) \cdot f(x) \]

\[ \frac{1}{2} \log \left( 1 + \frac{P}{h} \right) \]
The design variables (i) which we can change (to improve performance) are uncertainty in the problem (only in max.)
In the water-filling plan:

\[ f(x, y) \]

metric: sum \& expected rates.

\[ E \left[ \log (1 + SNR_1) \right] + \]
\[ E \left[ \log (1 + SNR_2) \right] \]

\[ SNR_1 = \frac{P_1}{n} \quad SNR_2 = \frac{P_2}{n_2} \]

\[ x = \begin{cases} 0 & \text{if } n_1 < 1 \cr \frac{1}{2} & \text{if } n_1 = 1 \cr 1 & \text{if } n_1 > 1 \end{cases} \]

\[ E \left[ f(x, y) \right] \leq \hat{g}(y) \]

is expectation wrt to the (joint) distribution of \( X \).

\[ \text{goal: } \max_y \hat{g}(y) \]

\[ \text{deterministic function } \hat{g} \]

alone, has no dep. on \( X \) anymore.
Given uncertain environment $X$ design $Y$, performance metric $\mathbb{E}[f(x, y)]$

1. $\max \mathbb{E}[f(x, y)]$

2. Ensure that $\Pr[f(x, y) < \Theta]$ is as low as possible.
   
   Also $0 < \Theta < \infty$

---

Performance for a fixed $y_i$.

$E[f(x, y_1)] > E[f(x, y_2)]$

But $\Pr[f(x, y_2) < \Theta] < \Pr[f(x, y_1) < \Theta]$
Wrap up on Link/MAC layer

RTS-CTS mechanism for CSMA

Hidden Node/Terminal Problem.

T1 R T2

Un-expected collisions

T1 R1 R2

Packet occurs because sensor is at the sender

sender sends RTS - request to send

receiver sends CTS - clear to send

if channel is free at the receiver

reduces collisions but has higher overhead
New class of MAC protocols have been developed in the last 10-15 years for low-power wireless embedded devices that are a significant part of the future IoT systems - Internet of Things.

Often, these energy-constrained devices running on batteries that for long lifetimes must spend a lot of time asleep.

Option 1: schedule the sleep (syndrome sleep) periods & only communicate during known active times.

a) inexpensive devices are typically most cheap HW that do not synchronize
b) mobility

2
Option 2: Asynchronous sleep.

1. Transmitter-initiated schemes
2. Receiver-initiated schemes

1. Also called: Low Power Listen Mode
   Wakeup
   RX
   TX

Common case: (no data)

- Data
- Long preamble
- Duty cycle: wakeup
- Duty cycle: setup
- preamble length > total period length

TX

RX

Long

TX

RX
send out a pulse message & wait for an ack, sleeps if timeout occurs.

Many Asynchronous Duty Cycled Sleep band MAC protocols (LPL, XMAC, AMAC) exist for Low Power Wireless IoT devices.