6.888 - Wireless Communication Systems
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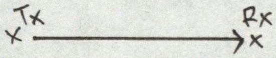
Lecture 3 Notes

Today:

- Broadcast nature of wireless channel → interference when you have multiple Tx
- rate region
- interference cancellation (IC)
- zigzag

So far we've talked about single channel.

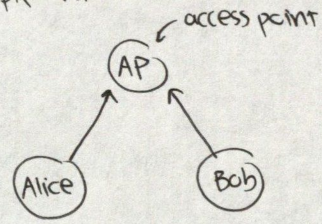
Single channel:



$$Rate \le C = \log\left(1 + \frac{P_{Rx}}{N}\right)$$

(C = capacity; P_{Rx} = received power; N = noise)

Multiple Tx:

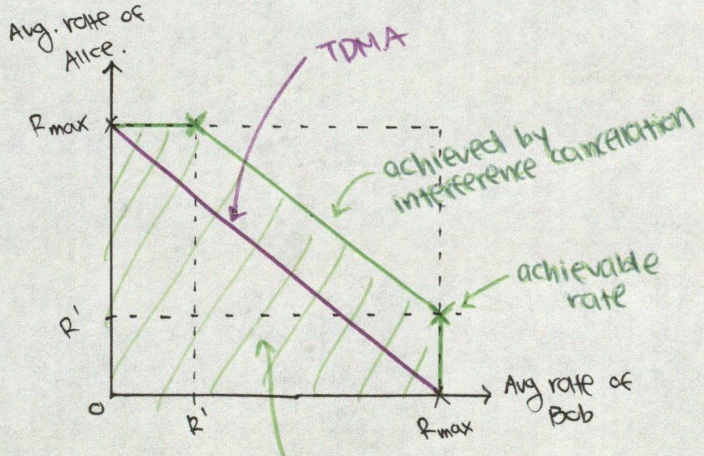


- limited by interference
- assume:

$$P^{Alice}_{Rx} = P^{Bob}_{Rx} = P$$

- can Alice & Bob transmit @ C?
  - ↳ if Bob is alone, can transmit @ max rate.
  - ↳ cannot both transmit @ max (would result in unbounded C.)
- rate of channel must be smaller than capacity

Rate Region:



Achievable rate region → if exceeded, either A or B is undecodable.

$$R_{max} = \log\left(1 + \frac{P}{N}\right)$$

- if Alice transmits @ R_{max}:

$$\underbrace{R_{Bob} \le \log\left(1 + \frac{P_B}{N + P_A}\right)}_{= R'}$$

(for Bob, A's signal is noise)

* any segment between 2 achievable points is achievable.

- Remark 1:

① Assume Alice is noise and decode Bob.

$$y(t) = \underbrace{y_A(t)}_{\text{signal from Alice}} + \underbrace{y_B(t)}_{\text{from Bob}} + \underbrace{w(t)}_{\text{noise}}$$

↳ get $\hat{x}_B(t)$ once decoded.

* if decoding Bob, assume $y_A(t)$ & $w(t)$ are same term (both noise): $w'(t) = y_A(t) + w(t)$

② subtract Bob's signal (already decoded) → $y_A(t) + w(t)$ → decode Alice.
(typically easier to decode bigger power first)

- Remark 2:

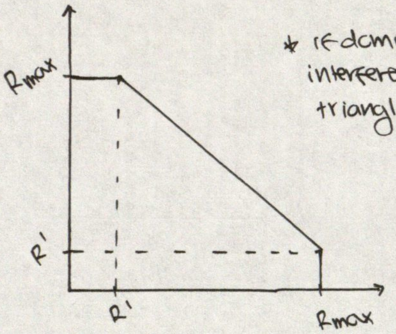
on rate region graph, purple line is achieved by TDMA or CSMA.

↳ TDMA / CSMA → alternating between 2 transmitters.

- Remark 3:

$N << P_{Rx}$ WiFi/LTE

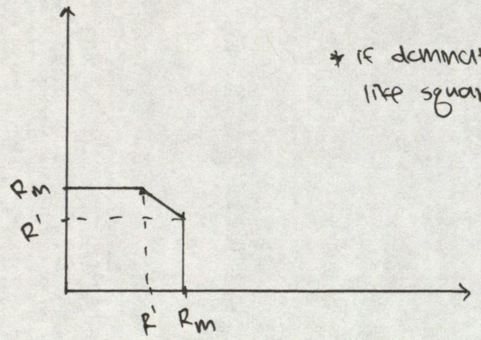
$R' << R_{max}$



* if dominated by interference, graph like triangle

$N >> P_{Rx}$ ← bigger or same order

$R' = \log(1 + \frac{P}{P+N}) \sim R_{max}$ ← P is negligible/close to noise.



* if dominated by noise, graph like square.

- Remark 4:

Generalize to more than 2 users.

- Ex: 3 users (Alice, Bob, Chris)

$R'_{Chris} \leq \log(1 + \frac{P}{2P+N})$

$R'_{Bob} \leq \log(1 + \frac{P}{P+N})$

$R'_{Alice} \leq \log(1 + \frac{P}{N})$

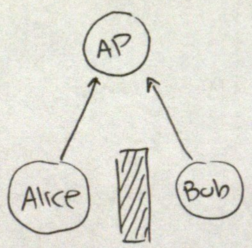
- Remark 5:

interference cancellation needs coordination.

- TDMA needs to coordinate on when to transmit (not at what rate)
- coordinating across transmitters → done by AP.
  - ↳ ex: if Alice decides to transmit @ Rmax, Bob must know, or will exceed rate region → undecodable.
  - ↳ AP/scheme needs to decide who's transmitting first.

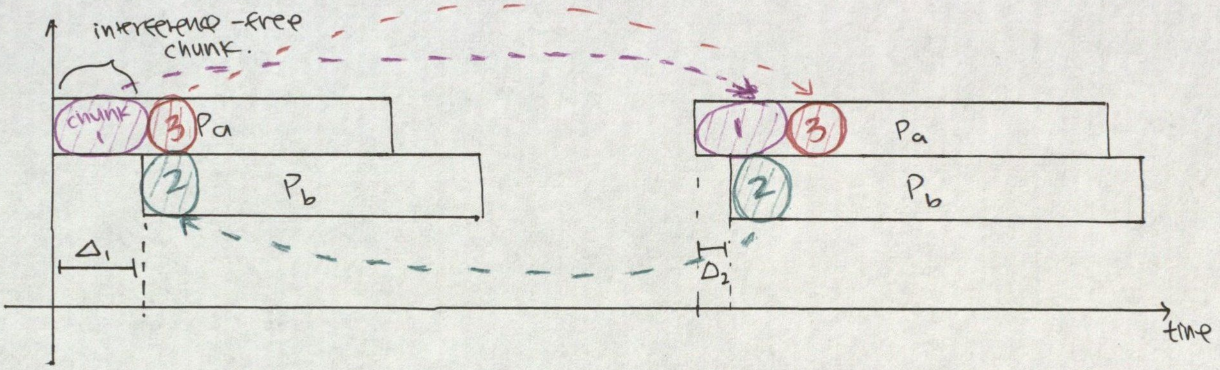
Zig Zag:

- tries to perform better but without coordination. (tries to not have AP do something specific)
- Problem: Hidden terminal

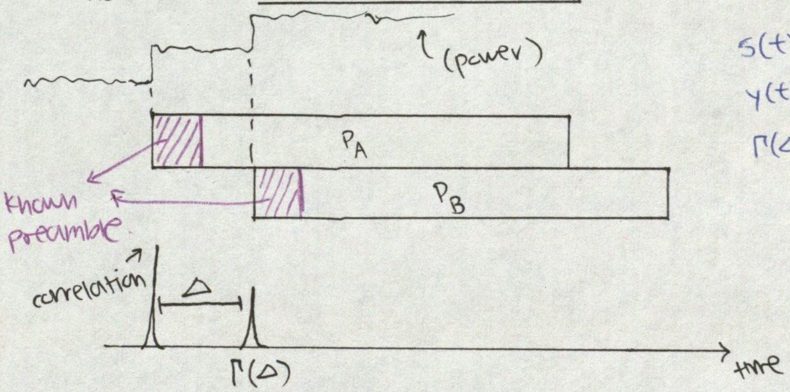


- users cannot hear each others' transmissions
  - ↳ Alice & Bob cannot tell when each one transmits in medium
  - ↳ can transmit at same time → collision (packets don't go through)
- how to solve HT problem?
  - ↳ if AP were to tell A&B when to transmit → a lot of overhead
    - ↳ must do for every packet for user
    - ↳ does not know if users still have packets to transfer.

- ZigZag solution: Basic Idea



- will listen before transmitting & randomize transmit time
  - ↳ $\Delta_1 \neq \Delta_2$ thanks to randomization.
- if successful transmission & decode, AP will send acknowledge
  - ↳ if collision → no ack.
- if collision, users send the same data. (same packets)
- can subtract **chunk 1** from 2nd collision (know from first collision)
  - ↳ now know Bob's chunk 2 and can subtract from collision 1.
  - ↳ find Alice's chunk 3 and subtract from second collision.
  - ↳ continue until finish decoding
- how do we detect collision and Δ?



$s(t) = s_1 \cdots\cdots s_k$ ← preamble.

$y(t) = y_A(t) - y_B(t)$

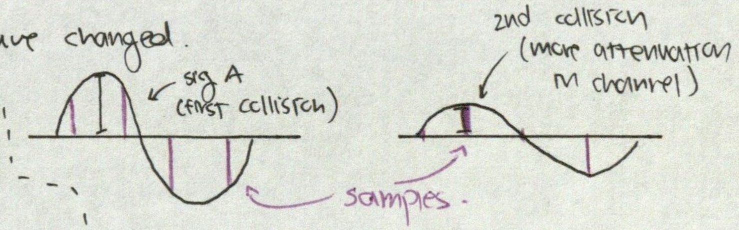
$\Gamma(\Delta) = \sum^{L} y(t_1+\Delta)\, s^*(t)$ ← summed over size of s.

$= \sum s_B(t) H_B e^{j2\pi\Delta f t} s^*(t) = \sum |s(t)|^2 e^{j2\pi\Delta f t}$

- correlation w/ preamble.
  - ↳ second spike smaller due to interference.
  - ↳ Δ usually > preamble.

- correlation can be used to determine if 2 collisions are between 2 packets.
  - ↳ correlate each packet w/ each other → if big spike, same packets.

- what does it mean to subtract a chunk from second collision?
  - between first & second collision, channel may have changed.
    - ↳ don't sample 2 collisions @ same time.



① decode signal (Rx) → bits.

② generate a channel free signal

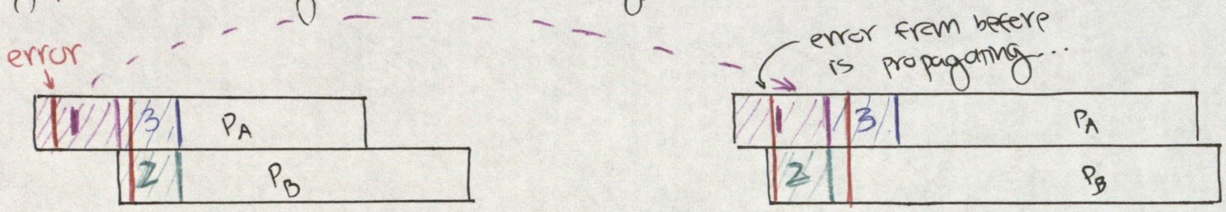
③ apply channel during 2nd collision to channel free signal (pretend sig went through channel @ time of 2nd coll.)

④ sample as in 2nd collision.

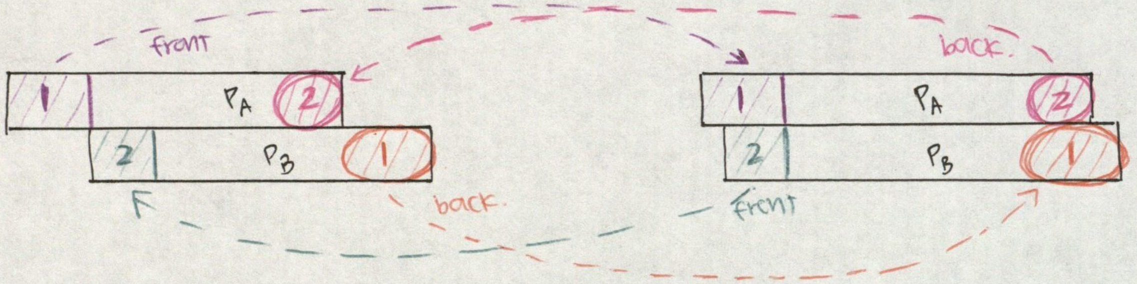
- since sampling may be different, cannot simply subtract sample by sample.

- Error Propagations

- Big problem if decoding has error → decoding is iterative.

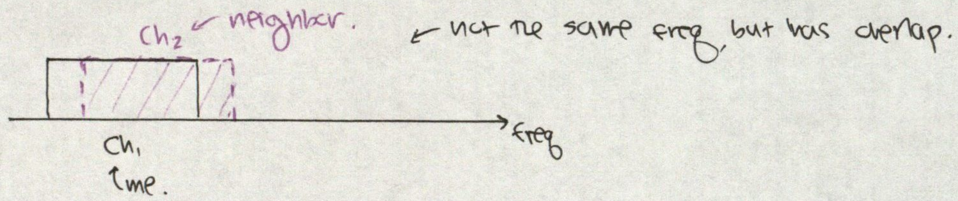


- how to fix this? ⇒ also decode from back of packets.

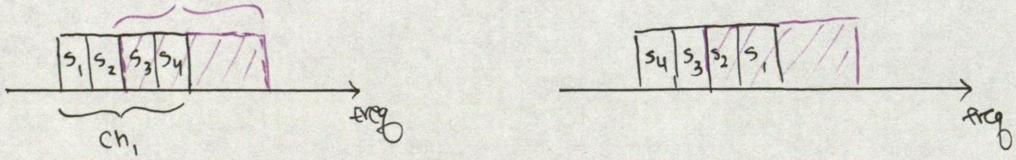


- after decode from front to back, compare.
  ↳ to increase reliability → add preamble to back.

- In freq
  - 802.11 has overlapping channels.



- dealing w/ collisions in freq → randomize what's transmitted in subcarriers.
  ↳ no Δ randomization ($\Delta_1 = \Delta_2$), since same channel.



- switch which bits collide with which.