CS263: Wireless Communications and Sensor Networks

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Lecture 4: Medium Access Control
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Today's Lecture

Medium Access Control Schemes:

- FDMA
- TDMA
- CDMA
- Examples from cell phone technology: AMPS, GSM

Packet networks: ALOHA and Slotted ALOHA

Capture effect and hidden terminal problem

- Use of power control

Carrier Sense Multiple Access with Collision Detection (CSMA/CD)

Medium Access Control (MAC)

Many mobile devices must share limited spectrum

- e.g., 802.11b networks in the US operate in the frequency range 2.402—2.479 GHz
- Most GSM networks in the US operate at 1850-1910 MHz (uplink) and 1930-1990 MHz (downlink)
  - *This is not a lot of spectrum!!!*

So ... how do we carve up the spectrum to give multiple users access to it??

Three basic approaches:

- Divide the spectrum up by frequency
- Divide the spectrum up by time
- Divide the spectrum up by *code* (e.g., pattern of usage – more later!)

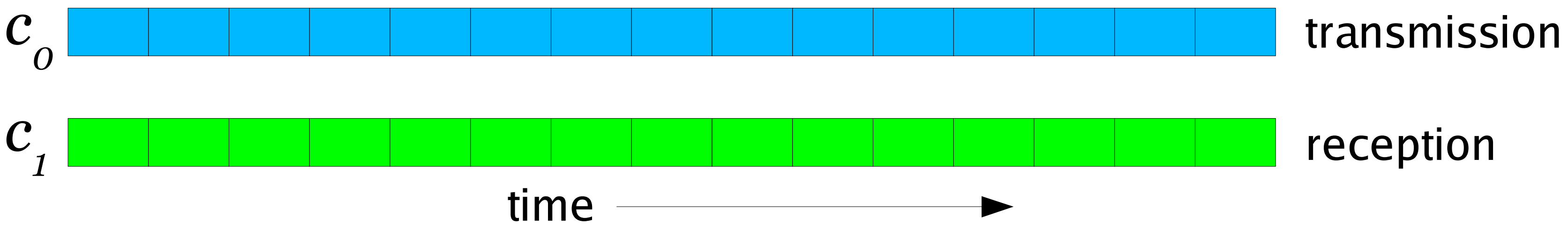
Duplexing

The first kind of multiple access is *duplexing*:

- Allowing simultaneous transmit and receive to a single user

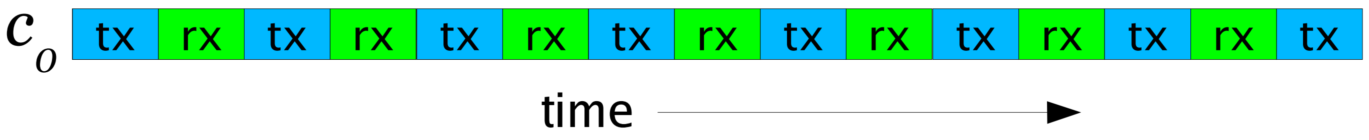
Frequency Division Duplexing (FDD)

- Each user assigned two *channels*
    - *Channel = range of frequencies for a single user to transmit or receive*
- One channel used for transmission, another used for reception



Time Division Duplexing (TDD)

- Uses only a single channel for both transmission and reception
- But, communication divided into time slots
- One time slot used for transmission, another used for reception



FDD vs TDD

Why use FDD or TDD?

FDD requires each user to be allocated multiple channels

- Less efficient use of spectrum

FDD requires slightly more complex electronics ($$$)

TDD induces some latency between transmit and receive cycles

- Generally operates on level of milliseconds, so not generally noticeable

With TDD, propagation delays may limit the distance of a user to a station

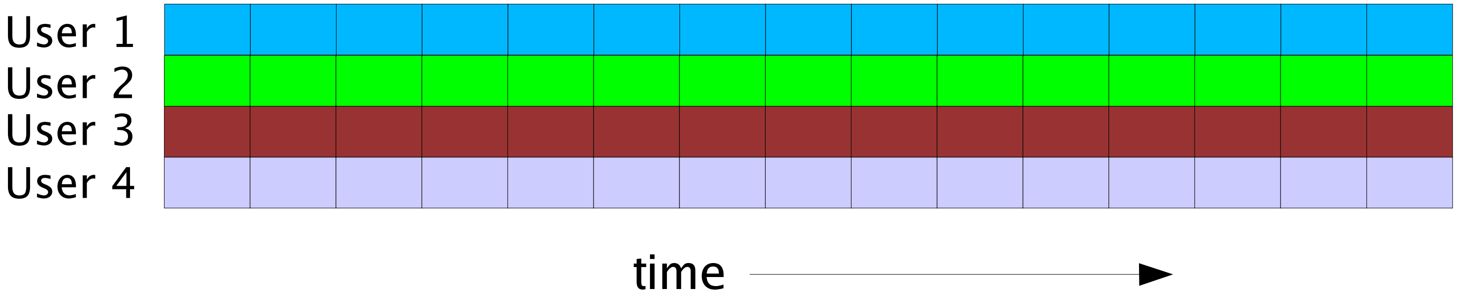
- e.g., In GSM, user must be < 35 km from the cell tower for timing to work out

Frequency Division Multiple Access

How to allocate spectrum to multiple mobile users?

Frequency Division Multiple Access (FDMA)

- Give each user her own channel (or pair of channels if using FDD)



Can be combined with either FDD or TDD

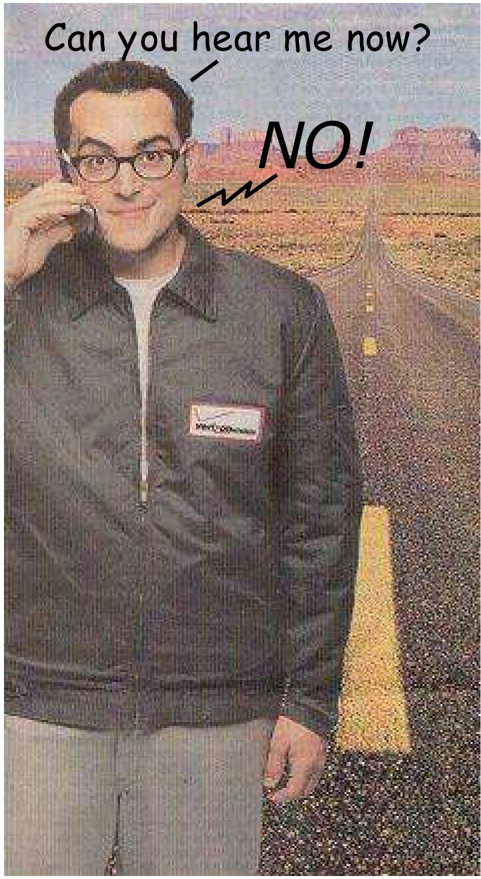
If channel is unused by that user, it sits idle

- Channel is effectively “wasted”

Must design system to avoid crosstalk across frequencies

- Increases cost of base – must use bandpass filters on each channel

Example: AMPS



First US analog cellular system, early 80's

While call in progress, phone occupies one channel in each of the uplink and downlink bands

- Base-to-mobile spectrum 869-894 MHz
- Mobile-to-base spectrum 824-849 MHz

Each channel is 30 kHz. So, how many simultaneous users?

Bandwidth = (894-869) = 25 MHz

- However, each operator allocated only half of this

12.5 MHz / 30 kHz per channel = 416 channels

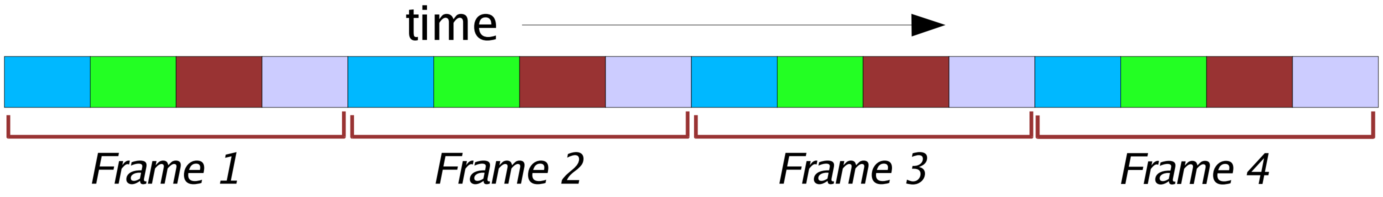
- However, 21 data channels used for control messages
- Leaving *395 simultaneous channels* available for voice

Time Division Multiple Access (TDMA)

Divide radio channel into *time slots*

- In each slot, a given user is allowed to either transmit or receive

TDMA typically uses a *cyclic frame structure*



- Each user allocated one time slot out of each frame
- Max number of users therefore bounded by number of slots in a frame

Each frame often has *preamble/postamble bits*

- Used for control, synchronization, etc.
- All nodes sharing a frame must be synchronized so they know when their slot begins!

Slots within a frame protected by *guard bits*

- Extra (unused) bits used to prevent two users from overlapping in time

Example: GSM

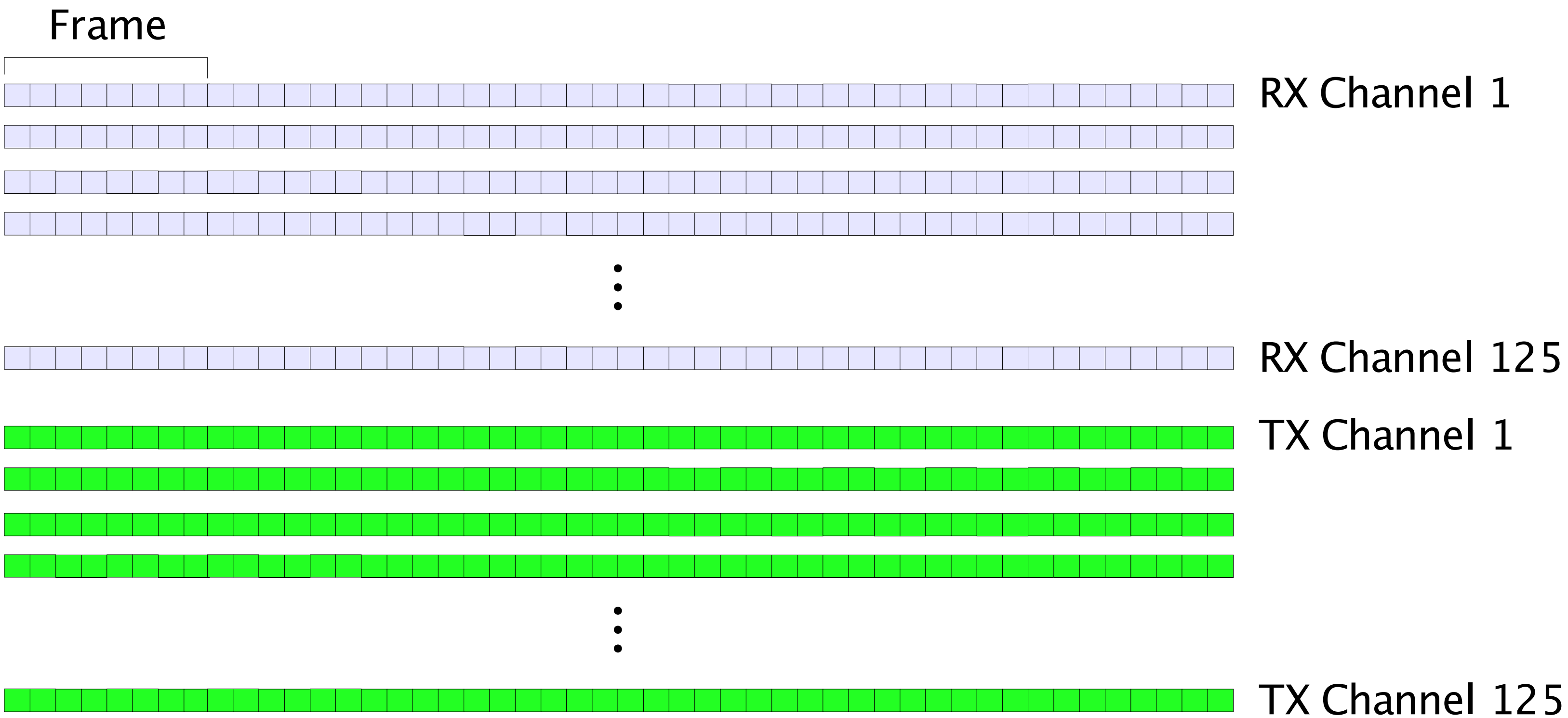
Global System for Mobile communications

- First commercial launch, mid-1991 in Europe

Digital cellular system, combination of FDMA and TDMA

Forward and reverse links each 25 MHz

- Broken into multiple channels of 200 kHz each == 125 channels total
- Each channel broken into 8 time slots of 0.577 ms each



GSM Capacity

GSM data transmission occurs at ~ 270 kbps

- Each user therefore gets 270 / 8 = 33.75 kbps of “bandwidth”
  - *Framing overhead limits this to 24.7 kbps per user*
- Slots are only 0.577 ms long!

How many simultaneous users can GSM support?

- 125 channels x 8 slots/channel = 1000 users
- However, each of the 1000 “physical channels” (FDMA channel plus TDMA time slot) can be assigned to different “logical channels” dynamically
- Example: voice data, control and signalling traffic, GPRS data, etc.

General Packet Radio Service (GPRS)

- Allows GSM time slots to carry digital data (21.4 kbps per slot)
- If one user took over all 8 timeslots, could get 172.2 kbps through
- Most phones support 4 downstream channels + 1 upstream channel
  - *85.6 kbps downstream, 21.4 kbps up*
- EDGE (Enhanced Data GSM Environment) pushes each slot to 48 kbps

Code Division Multiple Access

Recall Direct Sequence Spread Spectrum (DSSS)

- Original signal is modulated with a spreading code (pseudorandom bits)
- This effectively spreads the signal out over a wider bandwidth.

CDMA = Use different spreading codes for each user

- All users share same carrier frequency and can transmit simultaneously
- Use codewords (spreading sequences) that are *orthogonal*
  - *That is, avoid overlap between different spreading sequences*

Issue: The more users, the higher the noise floor

- All other users' signals appear as noise to a particular receiver
- Adding users makes it more difficult to differentiate individual users

Related problem: Weaker signals may be “drowned out”

- CDMA systems generally incorporate *transmission power control*
  - *Base may tell mobile unit to increase or decrease transmit power to equalize.*

Example: IS-95

CDMA standard used in North America (e.g., Sprint PCS)

Single 1.228 MHz (!!!) band shared by 64 code "channels"

  - *Mobile-to-base channel slightly different ...*
- One channel allocated for control data
- 8 channels allocated for "paging" data (special messages to mobile)
- 55 voice/data traffic channels

Voice data encoded at 8550 bps (9600 bps with error coding)

- Data rate is lowered when user is not speaking
- Forward error correction increases this to 19.2 kbps

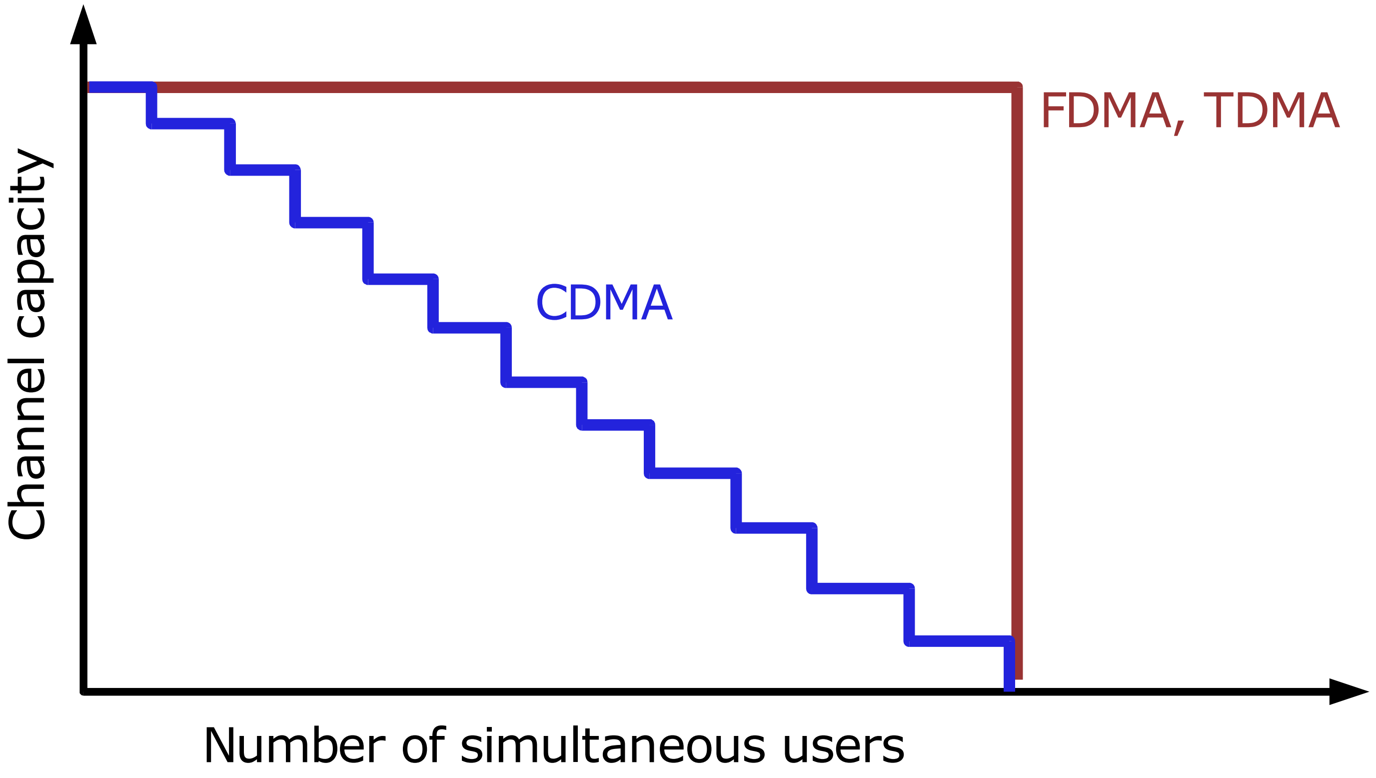
Data spread to a rate of 1.2288 Mbps using DSSS

- Modulated using QPSK

What is the increase in "overhead" due to spreading?

- 1.2288 Mbps / 8550 bps = 143 X!!!

Capacity of different MAC schemes



FDMA and TDMA have a fixed capacity

- Once out of frequency or time slots, no more users can be admitted

CDMA capacity degrades with number of users

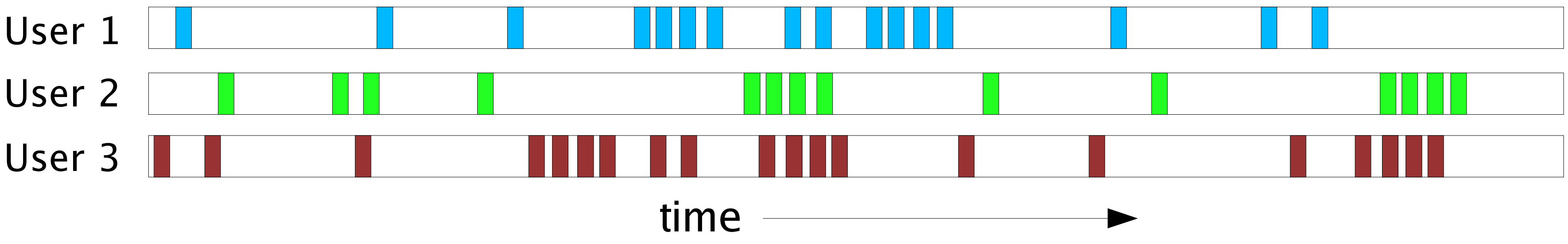
- Interference depends on degree of overlap between codes

What about bursty communication???

In many systems, communication is *bursty*

Would like to exploit *statistical multiplexing*

- Ability to share channel or time slots when no communication is happening



- Seems silly to allocate each user an entire frequency (or time slot)

Packet Radio schemes

Rather than carving up capacity for each user, allocate channel “on demand”

- All users share same channel (though FDMA, TDMA, or CDMA may be used as well)

Users transmit data in bursts, called *packets*

- This is called *contention-based access*

Multiple users might try to transmit at the same time

- Simultaneous transmissions result in a *collision*
    - *Typically will corrupt both transmissions*

Various schemes used to detect and avoid collisions

- e.g., Transmitter listens to channel before transmitting
- This is called *Carrier Sense Multiple Access (CSMA)*

Advantages and Disadvantages

Packet Radio schemes easy to implement

- No need for centralized allocation of channel capacity to individual users
- System can scale up to very large number of users
  - *Depending, of course, on how much they wish to transmit*

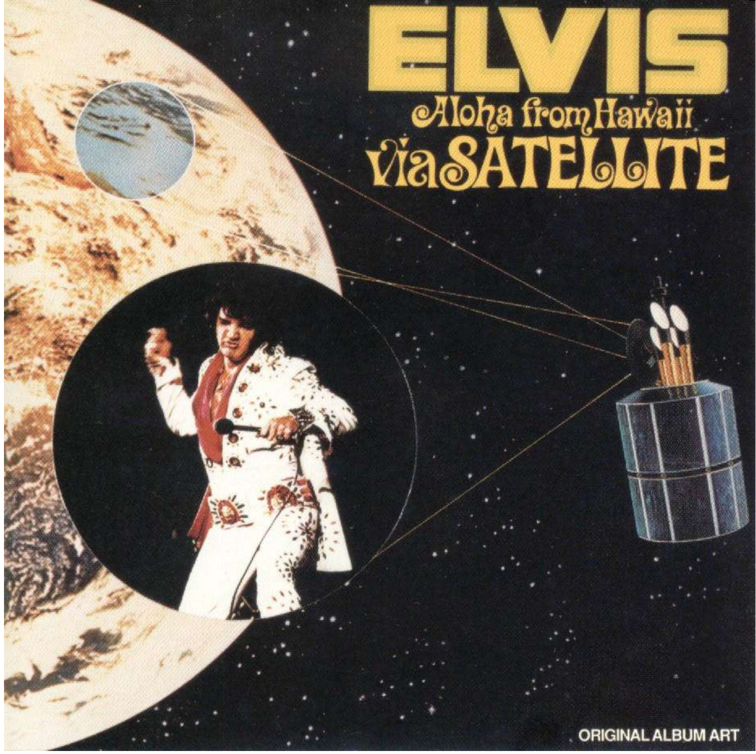
Can result in poor channel efficiency

- Overhead involved in detecting collisions, backoff before transmission, etc.
- This overhead can severely limit the total data rate that the channel can support

Contention-based access can induce delays

- One transmitter may delay transmissions by others
- May have to retransmit several times if lots of contention/collisions

ALOHA



One of the first Packet Radio protocols

- Developed for use in satellite systems by University of Hawaii (1970's)

“Pure” ALOHA: Ground stations transmit as soon as they have something to send

- No “carrier sense” before transmission
- Satellite detects collision and sets ACK bit when rebroadcasting message to other ground stations

Transmitter looks for ACK bit to decide if collision occurred

- If no ACK, wait a random time and retransmit

Pure ALOHA Efficiency

What is the efficiency of this approach?

- Assume fixed packet transmission time τ
- Assume Poisson packet transmissions at rate of λ packets/sec
- Channel utilization ratio R is: $R = \lambda \tau$
  - *If R > 1, packet transmission rate exceeds channel capacity, so system is overloaded*

Throughput is calculated as: $T = \lambda \tau \; Pr[no\ collision]$

- For Pure ALOHA, the time interval during which a collision might occur is 2τ

Assuming Poisson packet transmissions,

- Prob of n packets being generated during an interval of 2τ is:

$$Pr(n) = \frac{(2R)^n e^{-2R}}{n!} \qquad Pr(0) = Pr[no\ collision] = e^{-2R}$$

- Therefore, overall throughput is $T = Re^{-2R} = \lambda \tau e^{-2 \lambda \tau}$

Slotted ALOHA

Problem with Pure ALOHA: Stations can transmit any time

- Collisions become a problem as channel occupancy increases.

Slotted ALOHA

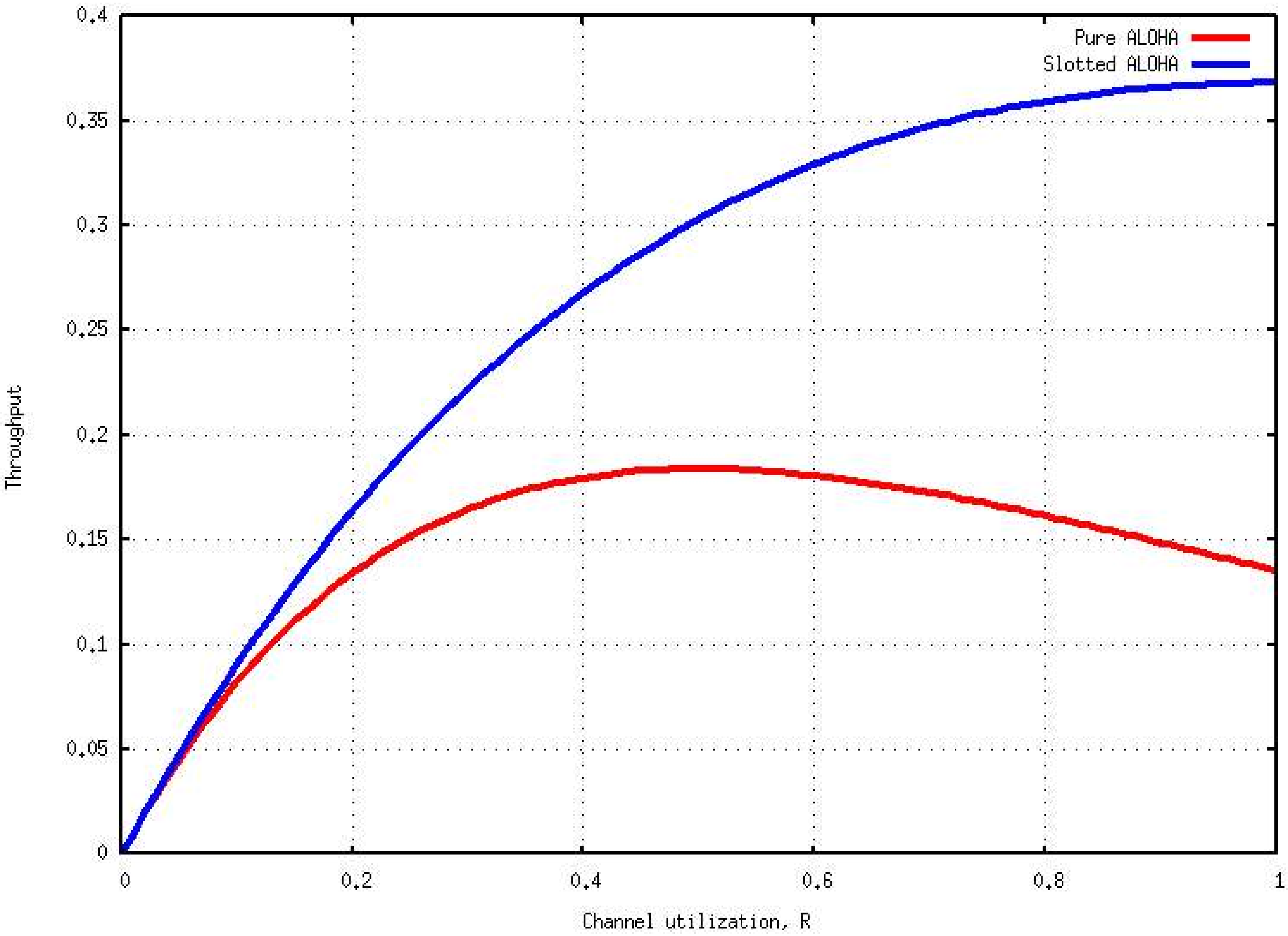
- Time divided into equal-sized epochs, longer than a single transmission interval
- All transmitters have synchronized clocks
- Users only transmit at the *beginning of an epoch*

Why is this better than Pure ALOHA?

- Prevents the end of one packet from colliding with the beginning of another
- So, this reduces the “vulnerability window” of a transmission

Resulting throughput is therefore: $T = Re^{-R} = \lambda \tau e^{-\lambda \tau}$

Pure vs. Slotted ALOHA Performance



Both protocols yield fairly low max channel utilization!

Capture Effect

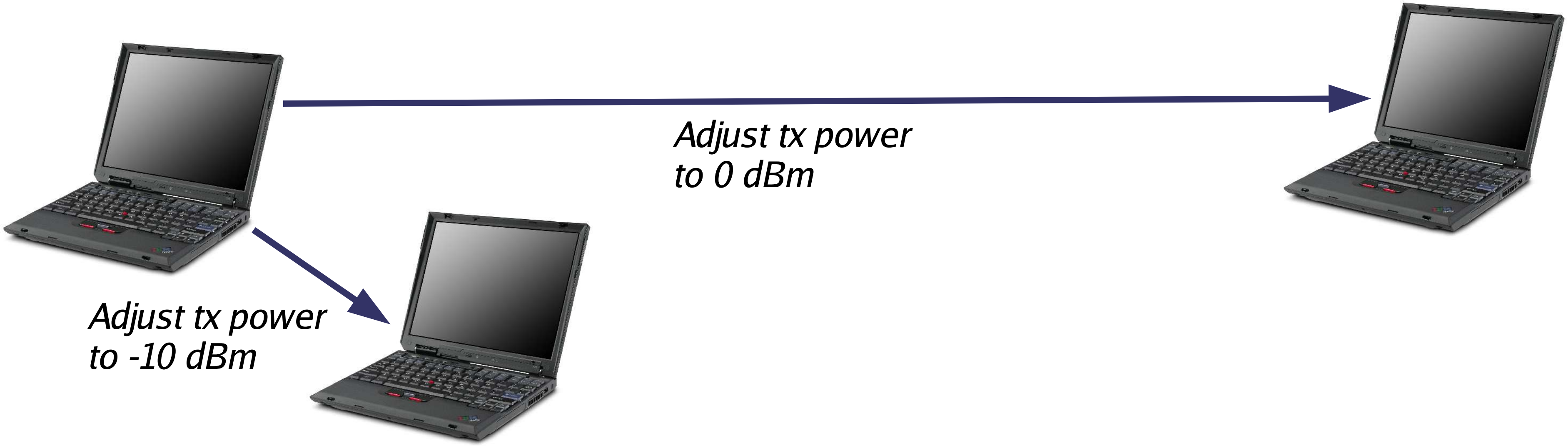
Problem with contention-based access:
Strongest transmitter can *capture* the receiver

- Packets from nearer transmitter may survive despite collisions!
- However, receiver may never detect presence of weaker transmitter
  - *Hidden transmitter problem*

Power control

How to resolve the capture effect?

- Dynamically adjust transmit power of each transmitter



Adjust tx power
to 0 dBm

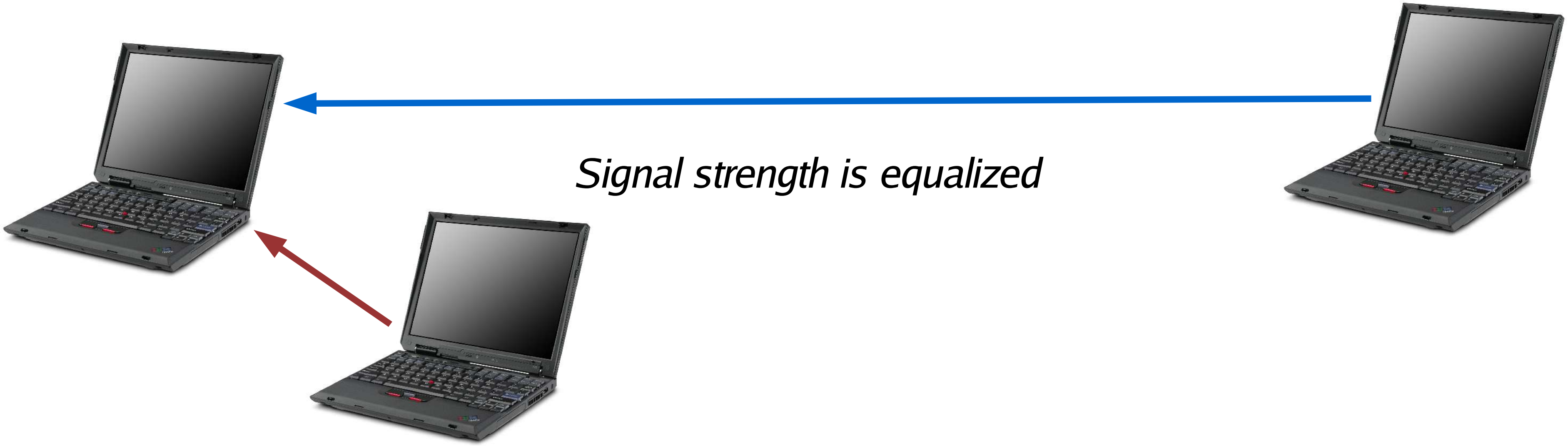
Adjust tx power
to -10 dBm

- Base station instructs stations to dynamically adjust transmit power
- Attempt to equalize received signal strength from individual transmitters

Power control

How to resolve the capture effect?

- Dynamically adjust transmit power of each transmitter



Signal strength is equalized

- Base station instructs stations to dynamically adjust transmit power
- Attempt to equalize received signal strength from individual transmitters

CSMA/CD

A better approach to contention-based access: *Carrier Sensing*

- Each station listens on channel before transmitting
- If channel is busy, waits before transmission

What happens as soon as the channel is clear?

- Transmit immediately?
  - *Good for minimizing delays....*
- Wait for some random period of time?
  - *Avoids collisions from multiple stations detecting clear channel at the same time*

How do you determine whether the channel is clear?

- Must estimate *noise floor* or actively decode incoming data

How do you determine if a collision has occurred?

- Transmitter listens for another packet immediately after its own transmission
- Or, wait to receive an ACK from the receiver, which implies no collision

Carrier Sense Multiple Access with Collision Detection (CSMA/CD)

Next Lecture

The 802.11 Wireless LAN Standard

Reading: Stalling Chapter 14