Wireless Networks

Differences Between Wired

- Wireless has interference with different communication channels
  - In wired, you just have these shielded cables that are only mixed once you get to a router / switch
- Both wireless and wired have noise, but the type of noise is different
- Broadcasting is easier than wired because you can just send a message once versus 10 times
  - Fundamental difference: shared medium
- The distance between the sender and receiver can change constantly during wireless
  - This changes the noise / conditions / the signal strength

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- Two main things that guide the architecture of the system:
  - Adapting to different conditions
  - Sharing a medium
- In the electromagnetic spectrum, the amount of the spectrum is a scarce resource
  - Some of it is iicesnsed by things like the FCC in the US
  - Some of it is unlicensed like WiFi

Celllular

- We divide the world into cells
- Each cell has a base station responsible for covering that cell
  - Each is connected to a wired network via backhaul links
- Neighboring cells get allocated different frequencies
  - I.e. each will have a specific channel number, each of which is allocated a different i.e. 5 MHz part of the spectrum
  - There is a lot of flexibility in how much you allocate
- In WiFi, these are known as access points instead

Time Multiplexing

- We need to somehow figure out when each person is going to communicate
  - We can't have everyone shouting at once since they will all interfere with each other
  - We divide time into segments where only one person gets to talk
  - There are ways to get multiple people to talk at the same time but to a limited sense
- Someone has to decide when each device gets to speak
  - The base station knows when it has data, but not when any of its users have data to send
  - We don't want to waste time
- We could all try sending data
  - If we don't get an acknowledgement due to the interference, we set a random timeout and try again
- This was first done in the Aloha network which connected islands in Hawaii via a satellite backhaul link
- Some ideas for improving:
  - Dividing time into slots restricting to sending messages at the beginning of a time slot doubles the capacity of a network
    - Idea is that if two people were going to collide, you might as well collide fully by aligning the time slots
    - Network capacity utilization doubles from 1/2e to 1/e
  - Carrier sense:
    - Listen for a random amount of time (a contention window) before you transmit
      - If we see that the network is being used, you should back off exponentially and double the amount of time you wait before trying again

        - We should only count down when the channel is free
    - In total, this gives around 90% utilization empirically
- Unfortunately it isn't always possible to tell when a channel is free, so we still need acknowledgements
    - I.e. a case of hidden terminals where two peoplea are on opposite sides of the same cell and can talk to the base station, but not each other
- Exposed terminal problem is when S1 wants to send to R1 and S2 wants to send to R2 but S1 and S2 are next to each other
    - We could have both send successfully if R1 and R2 are far from each other
    - But carrier sense prevents this
    - We lose a bit of throughput, but in reality we don't care about this
        - The acknowledgements for these messages might have collided with each other so it is fine to not send this

Time Division Duplex

- We have a controller node that is controlling peripherals
- We split into time segments
    - Every odd segment is the controller broadcasting to a specific device
    - Then that device will respond
- Wastes some time because if I want to get data from someone, then I have to send them a fake packet and then get their response
    - Or I want to send to you and you have nothing to send back to me
    - Under high load, this works
        - For bluetooth, this often works well
        - Especially for bluetooth audio, which is periodic, so the controller can allocate timeslots accordingly

Adapting to Variability in Rates

- We want to extract the highest possible rate we can transfer at
- Modulation and coding scheme (MCS):
    - Idea is that when transmitting data, we need to specify a modulation type and coding rate
    - Modulation type: phase and amplitude modulation for transmitting bits
        - Idea is that each combination of phase / amplitude will convey some bits
        - I.e. we take the phase amplitude plane and we break it down into 16 regions, each of which corresponds to some sequence of 4 bits
        - When we get a signal, we look at what is the closest region and use that to get the bits out
        - Examples: QAM-16
    - Coding rate: how much of our bits is going to be used for the error correction
        - Higher values transfer more information but sacrifice reliability
- We need to have some policy for determining the MCS
    - Previously, people were trying things similar to congestion control
    - If a packet didn't get through, send it again at a lower speed
    - Problem is that if it didn't get through because of a collision, and now you send it with 1/2 the speed, it now takes twice as long
        - There is an even higher chance of collision now
        - We don't have the same kind of problem now because this is a very collision heavy network
- Instead, an extremely simple idea was to just try a bunch of different bitrates carefully and choose which leads to the lowest time to transmit

Scheduling

- The scheduling problem is different here as well since different clients will have different link rates
- Before, we were concerned with the bottle neck link rate
- Now, we want to send more data to the people with the higher link rates

    - So spending time equally among the people is a way to achieve proportional fairness
- This algorithm for achieving roughly proportional fairness is used almost everywhere:
    - For each person, the base station computes the instantaneous rate to them and maintains an exponential moving average
    - At each time step, select the user with the maximum instantaneous rate divided by average rate