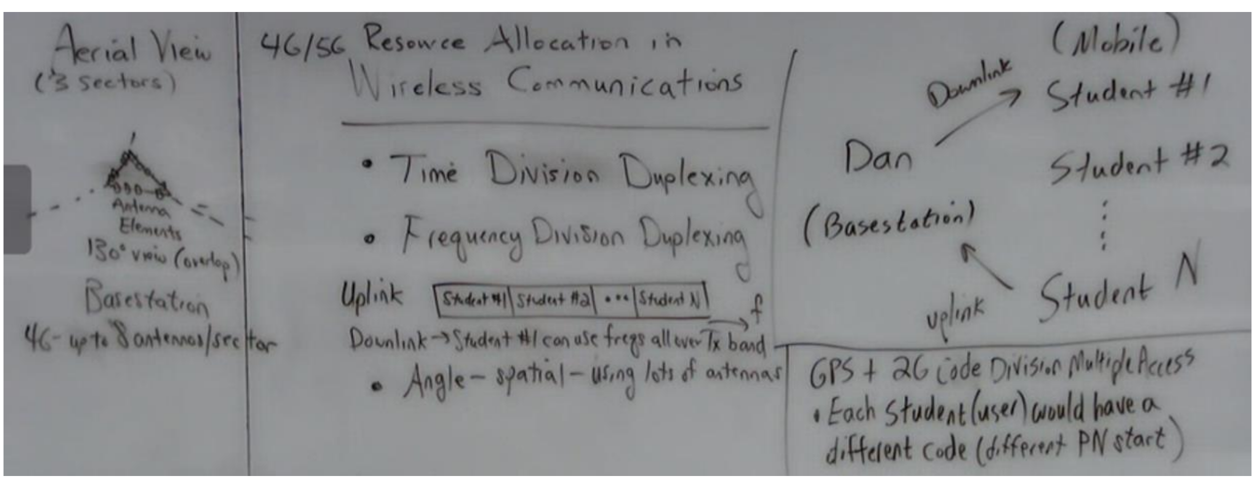
[10:30am] Wireless resources and CDMA (related to lab #4)

- In wireless communications, we have multiple resources. For multiple users to communicate simultaneously, we can divide these resources.
  - Time (Time division duplex) *used in 4G/5G cellular systems*
    - Each user gets a time slot and uses the entire transmission band.
    - Only one user communicates at any given time.
    - Schedule each user, e.g. rotate among the different users
  - Frequency (Frequency division duplex) *used in 4G/5G cellular systems*
    - Each user gets own frequency band within the transmission band
    - All users transmit at the same time
  - Space (Multiple antennas to perform directional filtering) *used in 4G/5G*
    - Each user gets a cone (set of angles) – 30° for frequencies below 7 GHz (4G/5G) and 2-7° for millimeter wave frequencies (5G)
    - Can be used with either time or frequency division duplex to improve communication performance
  - Code (CDMA, code division multiple access)
    - Each user gets own initial value for linear shift feedback register (LSFR) to generate the psuedonoise (PN) sequence
    - Use pseudonoise sequences to get the codes (lab #4)
    - To transmit a bit of one, transmit the next 32 values of your PN sequence using your LSFR value
    - To transmit a bit of zero, transmit the logical complement of the the next 32 values of your PN sequence using your LSFR value
    - Basestation correlates with the known sequences
      - Other users appears to be noise
    - Allows multiple users to transmit at the same time and frequency
- See Appendix L



[11:00 am] Conclusion to FIR and IIR filtering

- An LTI system is uniquely defined by its impulse response
- Complex exponentials are eigenfunctions of LTI systems
- System must be initially at rest (zero initial conditions) as a necessary condition for linearity to hold
- Linear phase requires even or odd symmetry about its midpoint.
    - Group delay is negative derivative of phase
    - Linear phase gives constant group delay
    - FIR filters can be easily designed to have linear phase by enforcing the symmetry
    - Phase is also important if multiple transmitters or receivers are present
        - Example: phase difference between two ears is used to identify different directions of sound
- Several common FIR filters
    - Averaging filter
        - Lowpass
        - Linear phase
        - Impulse response is a rectangular pulse
    - First order difference
        - Highpass
        - Linear phase
- IIR filters
    - For a given frequency selective specification, IIR filters can have lower order
    - Nonlinear phase, but may have approximately linear phase over a range
    - Can become unstable due to numerical errors
        - Implement as cascade of biquads

[11:20] Sampling and Aliasing

- Examples of aliasing
    - Helicopter video demonstrating aliasing
        - Helicopter rotor is between 6 and 10 Hz, but has between 2-7 blades
        - Camera frame rate is between 24 and 30 hz
        - Motor appears still because frame rate is an integer multiple of rotor rate times the number of blades.
    - Water and sound experiment

- Sampling theorem: in order to sample a signal $x(t)$ whose maximum frequency is $f_{\max}$ and reconstruct it perfectly, we must sample at a rate f_s such that
$$f_s > 2f_{\max}$$
    - We can place an analog lowpass filter before the sampler to enforce this condition
- Sampling can be modeled by multiplication of a signal with an impulse train
$$\underbrace{x(t)}_{\substack{\text{continuous}\\ \text{signal}}} \cdot \underbrace{s_T(t)}_{\text{impulse train}}$$
- In the frequency domain, this creates replicas of the spectrum shifted by multiples of the sampling rate
$$\mathcal{F}\{s_T(t)\} = \frac{1}{T} s_{1/T}(f)$$
$$\mathcal{F}\{x(t)s_T(t)\} = f_s \sum_{k=-\infty}^{\infty} X(f - kf_s)$$
- To reconstruct, we must apply an ideal lowpass filter to remove these replicas