MULTIPLEXING

Space, Frequency, Time, Code

Multiplexing:

- Goal: multiple use of a shared medium

Multiplexing in 4 dimensions:

- Space (s), Frequency (f), Time (t), Code (c)

Task:

- Assign space, time, frequency, code to each communication channel
- Minimize interference
  - Using “guard spaces”
- Maximize medium utilization
**Space Division Multiplex**

- A separate sender for each communication channel
  - With wide enough distance between senders
    - Guard spaces
- Used by FM radio stations
  - Many stations around the world use same frequency without interference
- What if several radio stations want to broadcast in same city?

**Frequency Division Multiplex**

- Subdivide the frequency dimension into several non-overlapping frequency bands
  - Senders can use their assigned band continuously
- Used for radio stations within same region
- Pros:
  - No dynamic coordination
- Cons:
  - Waste of bandwidth if usage is non-uniform
  - Limits # of senders
  - Inflexible assignment
**Time Division Multiplex**

- A sender gets the whole bandwidth for a certain amount of time

**Advantages**
- Only one carrier in the medium at any time
- Throughput high even for many users

**Disadvantages**
- Precise synchronization necessary

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**Frequency and Time Multiplex**

- Combination:
  - A sender can use a frequency band for a certain amount of time
  - Used by GSM

**Pros:**
- (weak) protection against tapping
- Protection against frequency-selective interference

**Cons:**
- Precise coordination required
**Code Division Multiplex**

- Each channel has a unique code
  - All channels use same spectrum at same time
  - “guard spaces” realized by using orthogonal code
- **Pros:**
  - Good protection against interference and tapping
  - Bandwidth efficient
- **Cons:**
  - Relatively complex receiver
  - Precise synchronization required
  - Precise power control required
    - All signals should reach receiver with nearly equal strength

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**DIGITAL MODULATION**

*Amplitude, Frequency, Phase*
Modulation

- **Digital modulation:**
  - Digital data is translated into an analog (baseband) signal
- **Analog modulation:**
  - Shifts center frequency up to that of radio carrier

**Why analog modulation?**
- Smaller carrier wavelength for smaller antennas
- To enable FDM
- To exploit/avoid frequency-dependent medium characteristics

**3 basic schemes:** AM (amplitude), FM (frequency), PM (phase)
Digital Modulation

- Modulation of digital signals known as Shift Keying
- Issues:
  - Spectral efficiency:
    - How efficiently is the frequency spectrum utilized
  - Power efficiency:
    - How much power is needed to transfer bits
    - Very important for portable devices
  - Robustness to multi-path propagation, noise, interference

Digital Modulation Methods

- Amplitude Shift Keying
  - Binary values are represented by different amplitudes
  - Low bandwidth requirements
  - Very susceptible to interference
    - Used only in directed infra-red beams
- Frequency Shift Keying
  - Needs larger bandwidth
  - Less susceptible to errors
- Phase Shift Keying
  - Uses shifts in the signal phase
    - $180^\circ$, if change in data
  - Synchronization required (freq, phase)
  - Most resistant to interference
  - Complex receiver/transmitter
Advanced Frequency Shift Keying

- Minimum Shift Keying (MSK): avoids abrupt phase changes
  - Bits durations doubled and divided into even, odd bits
    - Depending on the bit values (even, odd) the higher or lower frequency, original or inverted is chosen
  - Higher frequency is twice the lower frequency

![Diagram of MSK signal](image)

Advanced Phase Shift Keying

- Binary PSK: phase shift of 180°
  - Very simple, but low efficiency
- Quadrature PSK: phase shift of 45°
  - Codes two bits into one phase shift
    - Relative to phase of a reference signal
      - Requires frequent synchronization
    - Relative to phase of previous two bits
      - More efficient and less complex
  - Achieves high bit-rates for same bandwidth
- Can be extended to:
  - More angles
  - Combine with ASK
  - Leads to more receiver complexity
Multi-carrier modulation

- Splits high bit-rate stream into many with lower bit-rates
  - Each is sent using an independent carrier frequency
- Pros:
  - Independent frequencies do not interfere with each other
  - Frequency-selective fading doesn’t influence whole signal
  - Guard spaces used between symbol (groups)
    - Helps handle multi-path propagation, ISI mitigation
  - Computationally efficient based on FFT
- DAB uses 192-1536 sub-carriers