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Wireless Networks

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Wireless vs. Wired Communication

Wired	Wireless
Each cable is a different channel	Wireless medium is a shared channel
Signal attenuation is negligibly small	Signal attenuation is significantly higher
Can be physically shielded from external interference	Interference is a major concern
Stations are fixed	Stations can be mobile
BER* ~10^{-9}	BER* ~10^{-4}

*BER: percentage of bits received in error

Wireless Importance

- Laying cables can be infeasible, e.g.
  - Cabling cost can be too high
  - Network lifetime is too short
- Mobility
- Flexible Connectivity

Wireless Challenges

- Limited bandwidth (since a shared channel)
  - Requires more efficient utilization of bandwidth
- High noise levels
- Attenuation
  - Requires higher power levels
- Security
  - Eavesdropping, false identities, … etc

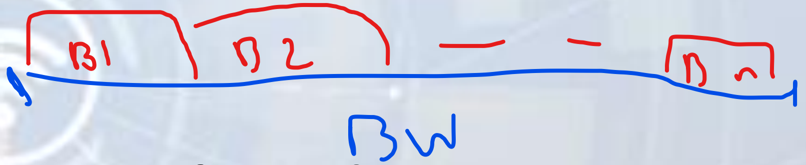
Electromagnetic Waves

- Wireless communication is through EM waves
- A wave is characterized by frequency
- EM wave propagation speed
  - Medium dependent
  - In vacuum = c = speed of light = 3 x 10^8 m/s
- Wavelength = Propagation Speed / Frequency
  - $C = \lambda f$

EM Spectrum

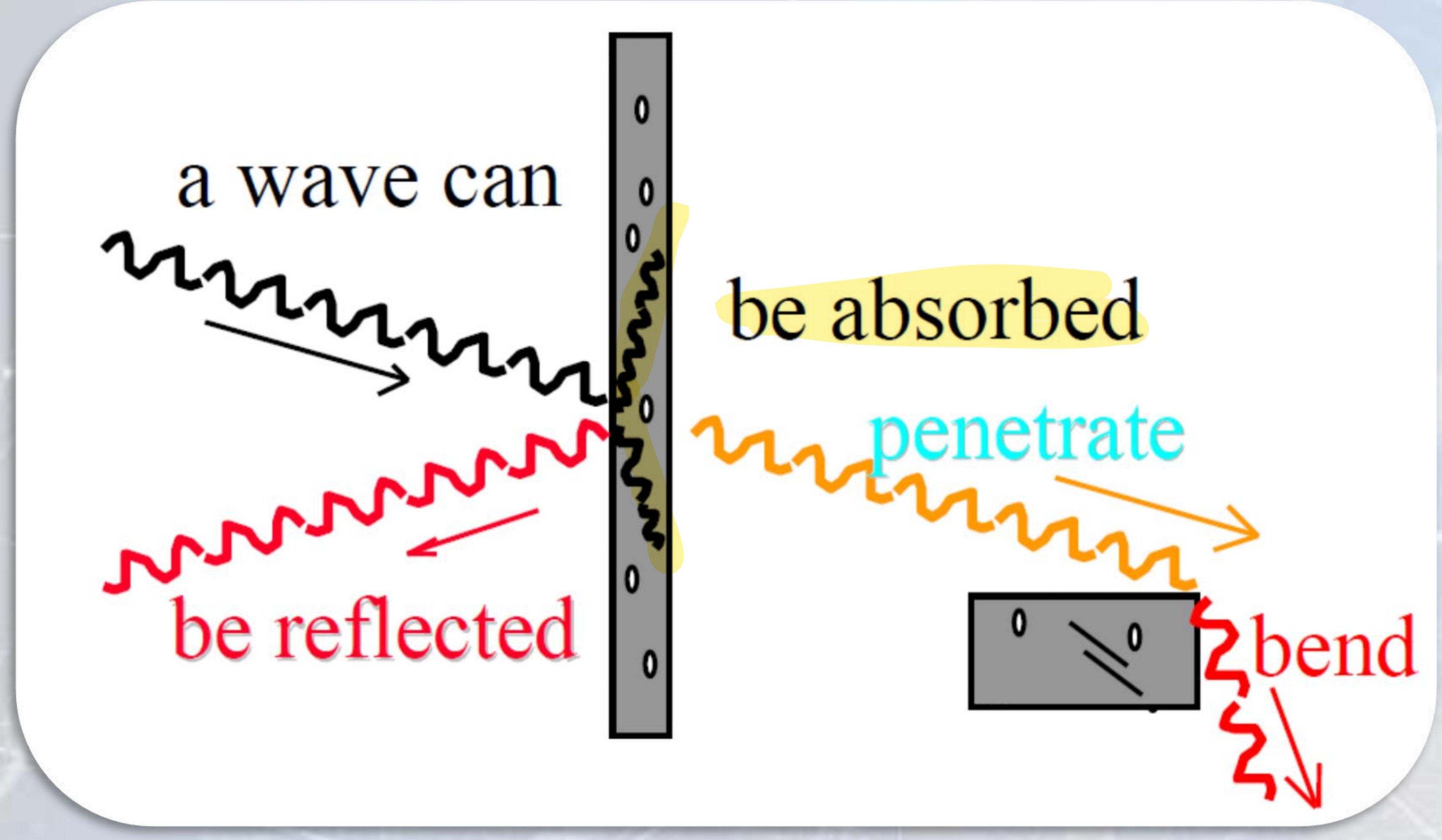
Wireless is a shared resource:

- Has to be tightly managed
  - International and national authorities (ITU-R, NTRA)
- Radio spectrum is divided into bands



  - band = name of a set of frequencies, e.g. 2.4GHz band
  - Bandwidth = the range of frequencies (max – min)
- Capacity is a function of bandwidth

EM Wave Propagation



Wireless Channel Characteristics

- Attenuation
  - Path loss
  - Absorption

DSF AI MP

- Multipath propagation
- Fading
- Interference
- Doppler Shift

Path Loss

- Reduction in signal power due to propagation

$$\boxed{\frac{P_r}{P_t}} = G_t G_r \left(\frac{\lambda}{4\pi d}\right)^2$$ – Friis formula

Path Loss

- Between two isotropic antennas in free space
  - P_r, P_t: Received and transmitted power
  - G_t, G_r: Transmitter and receiver antennas gain
  - λ : Wavelength
  - d: distance between transmitter and receiver

- Calculations in dB: decibel (a logarithmic unit)

$$P_r = P_t + G_t + G_r + 20 \log \left(\frac{\lambda}{4\pi d}\right)$$

- Original Friis transmission equation assumes:
  - the bandwidth is narrow enough for a single λ to represent it
  - $d \gg \lambda$ (not valid otherwise)

Absorption

- **Exponential decay** of signal power with distance travelled
- Depends on the medium and the frequency

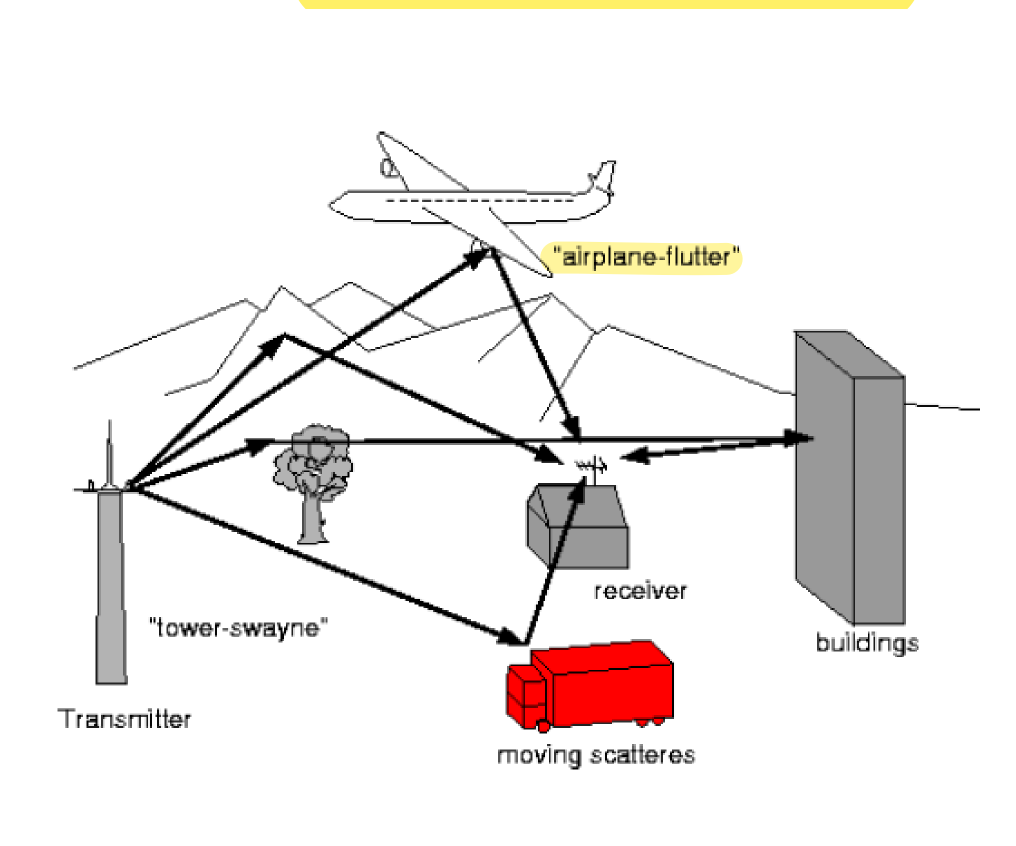
$$\text{Path Loss} = G_t G_r \left(\frac{\lambda}{4\pi d}\right)^2 e^{-\alpha d}$$

α: absorption coefficient

Multipath Propagation

- Multiple copies of the same signal received at slightly different times
  - Caused by reflection, diffraction, and scattering

- Delay spread: time between receiving the first and last copy of the same signal



Fading

- The variation in signal strength when received at the receiver.

Fast/Small Scale Fading

Slow/Large Scale Fading

Fast Fading

- Rapid fluctuations in **amplitude** or **phase**
  - Due to interference between multiple versions of the same Tx signal arriving at slightly different times.
  - Multipath propagation due to diffraction, reflection & scattering
  - Paths may add up constructively or destructively at Rx:
    - If phase difference=0, 2 signals adds up
    - If phase difference=180, 2 signals cancel each other

Slow Fading

- Objects that partially absorb the transmissions lie between Tx and Rx

- Slow because the duration of the fade lasts for a long time
  - Duration of the fade may last for multiple seconds or minutes

Countering Fading

- Diversity (Time, Frequency or Space)
  - Send same signal using multiple ways
  - Different ways experience different fading
  - Redundancy reduces probability of simultaneous destructive interference

➢ Time: send a signal and after some time send it again
➢ Frequency: use multiple channels simultaneously
➢ Space: use more than one antenna at different locations

- Adaptive Modulation
  - Channel characteristics estimated
  - Fed back to Tx for adapting the modulation of the signal

Interference

- Adjacent Channel Interference:
  - Signals in nearby frequencies have components outside their allocated ranges
  - Solution: introduce guard bands between allocated frequency ranges

- Co-channel (narrow band) Interference:
  - Other nearby systems using the same transmission frequency
  - Solution: allocate bands in intelligent way → no 2 close users use the same frequency.

- Inter Symbol Interference:
  - Temporal spreading and consequent overlapping of individual pulses in the signal due to multipath propagation.
  - The spreading of the pulse beyond its allotted time interval causes it to interfere with neighboring pulses
  - Solution: adaptive equalization:
    - Estimate the channel response (training using well known periodic pulses)
    - Compensate for the time dispersion

Doppler Shift

- The change in observed frequency of received signal due to relative motion of Tx and Rx with respect to each other.

- If they are moving towards/away each other, then the received frequency will be higher/lower

$$f_d = \frac{v}{\lambda}$$

– v: relative velocity between Tx and Rx

– f_d: The change in frequency

Thank You