CS 294-7: Radio Propagation

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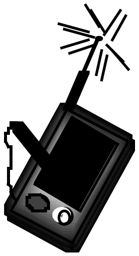
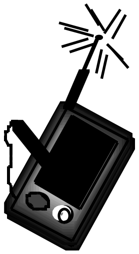


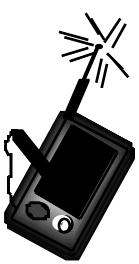
Outline

- A Little Physics
- Outdoor Propagation
- Indoor Propagation
- Propagation into Buildings



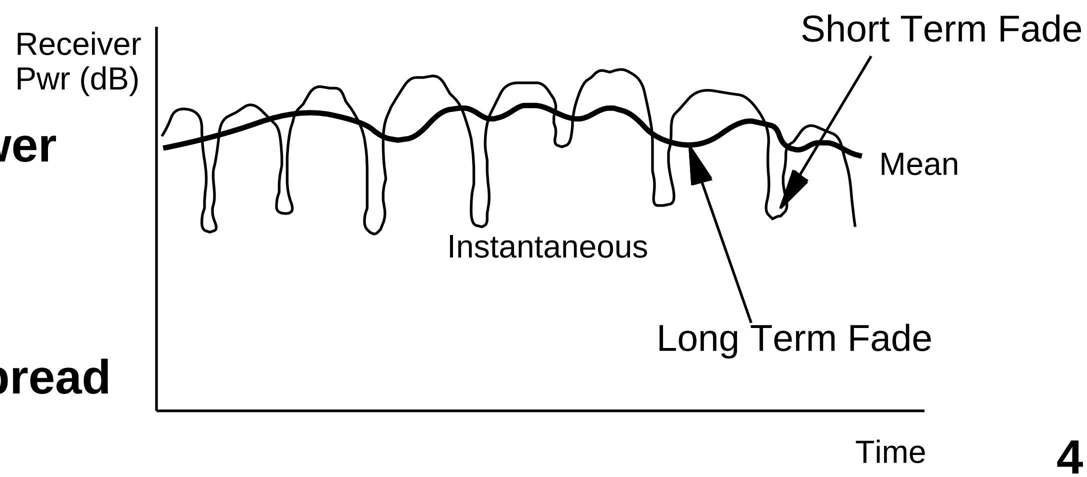
Propagation Mechanisms

- **Reflection**
  - Propagating wave impinges on an object which is large compared to wavelength
  - E.g., the surface of the Earth, buildings, walls, etc.
- **Diffraction**
  - Radio path between transmitter and receiver obstructed by surface with sharp irregular edges
  - Waves bend around the obstacle, even when LOS does not exist
- **Scattering**
  - Objects smaller than the wavelength of the propagating wave
  - E.g., foliage, street signs, lamp posts



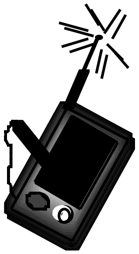
Radio Propagation

- **Effect of Mobility**
  - **Channel varies with user location and time**
  - **Radio propagation is very complex**
    - » **Multipath scattering from nearby objects**
    - » **Shadowing from dominant objects**
    - » **Attenuation effects**
  - **Results in rapid fluctuations of received power**



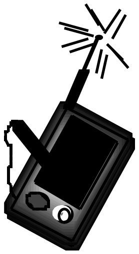
Less variation the slower you move

For cellular telephony:
-30 dB, 3 μsec delay spread



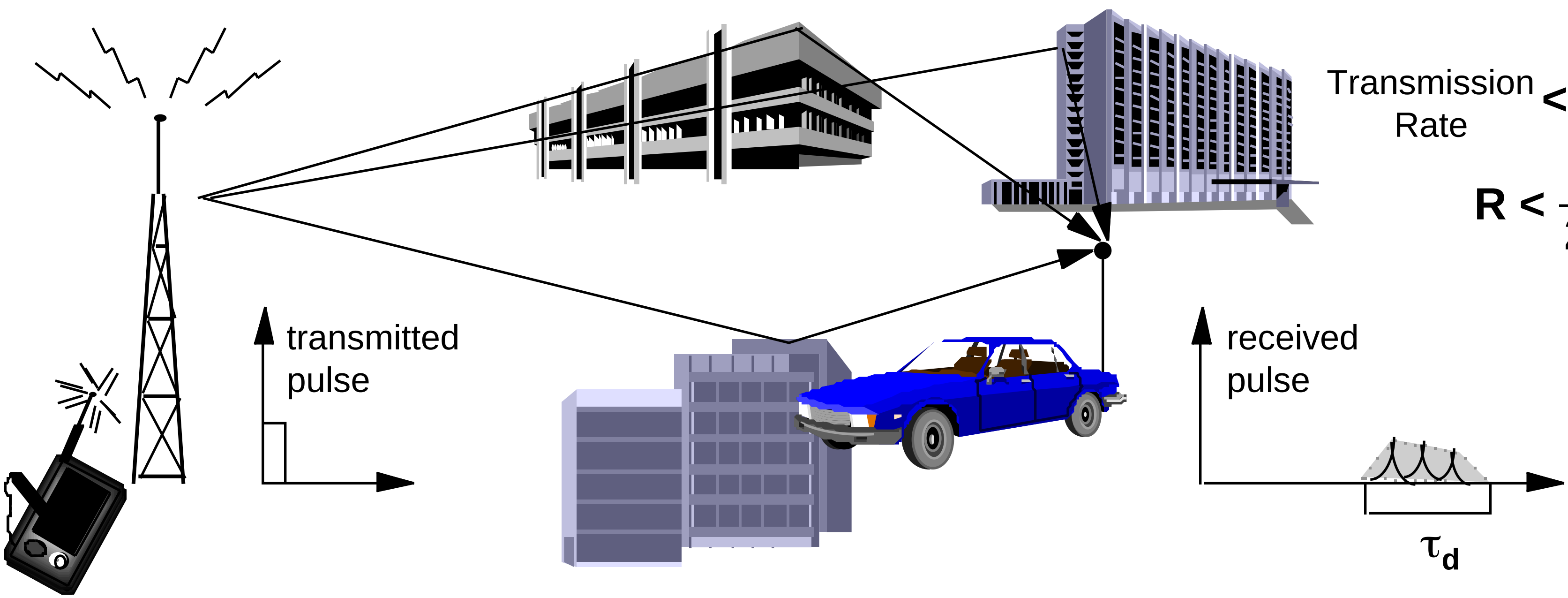
Radio Propagation

- **Large scale fades**
  - **Attenuation: in free space, power degrades by $1/d^2$**
  - **Shadows: signals blocked by obstructing structures**
- **Small scale fades**
  - **Multipath effects:**
    - » **Rapid changes in signal strength over a small area or time interval**
    - » **Random frequency modulation due to varying Doppler shifts on different multipath signals**
    - » **Time dispersion (echoes) caused by multipath propagation delays**
  - **Even when mobile is stationary, the received signals may fade due to movement of surrounding objects!**



Radio Propagation

- **Delay Spread**
  - **Multipath propagation yields signal paths of different paths with different times of arrival at the receiver**
  - **Spreads/smears the signal, could cause inter-symbol interference, limits maximum symbol rate**
  - **Typical values (µs): Open < 0.2, Suburban = 0.5, Urban = 3**

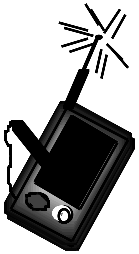


Transmission Rate **<** Coherence Bandwidth

$$R < \frac{1}{2\tau_d}$$

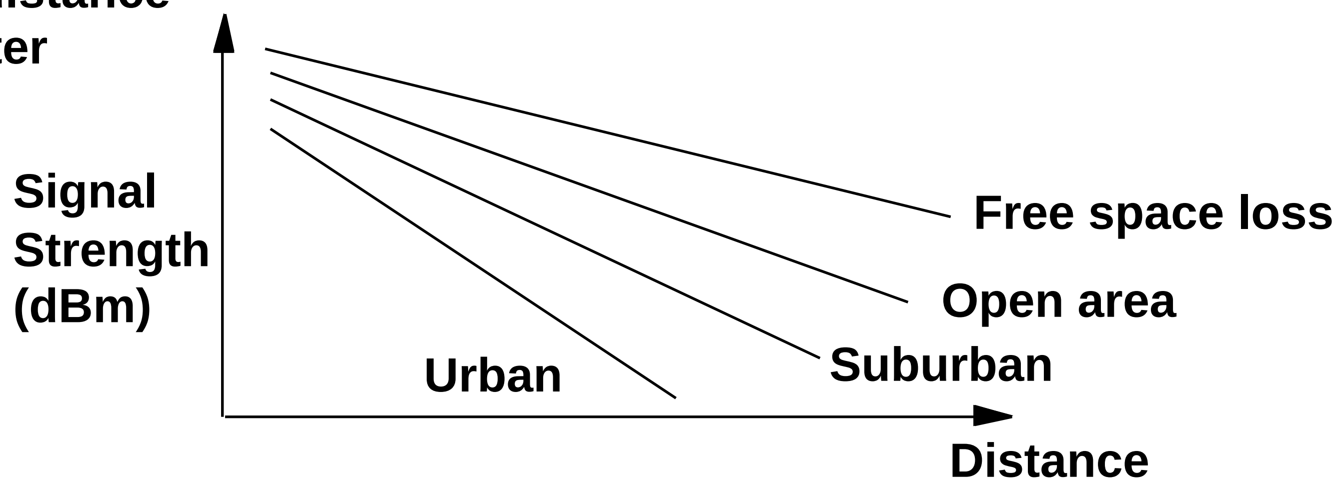
Radio Propagation

- **Impairments to the Radio Channel**
  - **Multipath dispersion/delay spread**
    - » **Signals related to previous bit/symbol interfer with the next symbol**
  - **Frequency selective fading/Rayleigh fading**
    - » **Combination of direct and out-of-phase reflected waves at the receiver yields attenuated signals**
    - » **Antenna diversity: use two antennas quarter wavelength separated to combine received signals**
    - » **Equalization: Subtract delayed and attenuated images of the direct signal from the received signal—adaptive determine what these subtractions should be, as they change as the mobile moves around**



Outdoor Propagation

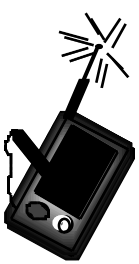
Rel. pwr of received signal compared to power at ref. distance from transmitter



Received Power $P_r = Kd^{-n}$,
$n = 2$ in free space, $3 \le n \le 4$ typically

BER = f(signal stength)

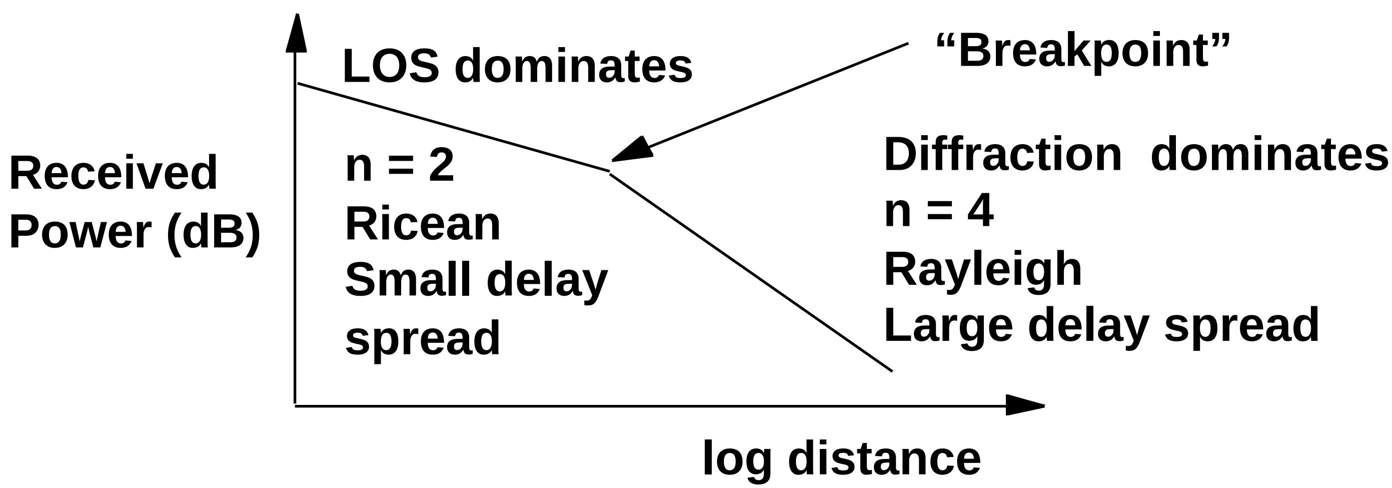
Error rates increase as SNR decreases

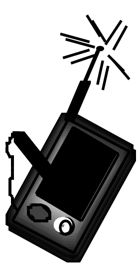


Outdoor Propagation

- **Macro versus Microcells**

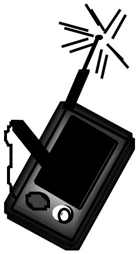
Item	Macrocell	Microcell
Cell Radius	1 to 20 km	0.1 to 1 km
Tx Power	1 to 10 W	0.1 to 1 W
Fading	Rayleigh	Ricean
RMS Delay Spread	0.1 to 10 µs	10 to 100 ns
Max. Bit Rate	0.3 mbps	1 mbps





Outdoor Propagation Measurements

- **Urban areas**
  - RMS delay spread: 2 μsec
  - Min 1 μsec to max 3 μsec
- **Suburban areas**
  - RMS delay: 0.25 μsec to 2 μsec
- **Rural areas**
  - RMS delay: up to 12 μsec
- **GSM example**
  - Bit period 3.69 μsec
  - Uses adaptive equalization to tolerate up to 15 μsec of delay spread (26-bit Viterbi equalizer training sequence)



Indoor Propagation

- **Physical Effects:**
  - Signal decays much faster
  - Coverage contained by walls, etc.
  - Walls, floors, furniture attenuate/scatter radio signals
- **Path loss formula:**

Path Loss = Unit Loss + 10 n log(d) = k F + l W

where:

Unit loss = power loss (dB) at 1m distance (30 dB)

n = power-delay index

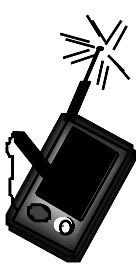
d = distance between transmitter and receiver

k = number of floors the signal traverses

F = loss per floor

l = number of walls the signal traverses

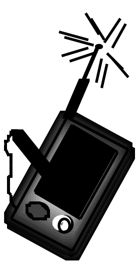
W = loss per wall



Indoor Propagation

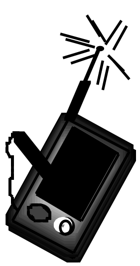
Building	Freq (MHz)	n	σ dB
Retail Stores	914	2.2	8.7
Grocery Stores	914	1.8	5.2
Office, Hard Partitions	1500	3.0	7.0
Office, Soft Partitions	900	2.4	9.6
Office, Soft Partitions	1900	2.6	14.1
Factory LOS			
Textile/Chemical	1300	2.0	3.0
Textile/Chemical	4000	2.1	7.0
Paper/cereals	1300	1.8	6.0
Metalworking	1300	1.6	5.8
Suburban home			
Indoor to street	900	3.0	7.0
Factory OBS			
Textile/chemical	4000	2.1	9.7
Metalworking	1300	3.3	6.8

measure of accuracy of simple model; the larger the σ, the less accurate the model



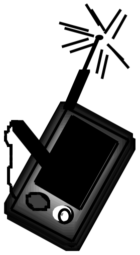
Indoor Propagation

- **Other Effecting Factors**
  - **People moving around:**
    - » **Additional multipath induced attenuation of 10 dB**
  - **Buildings with few metal and hard partitions: RMS delay spread of 30 to 60 ns (several mbps w/o equalization)**
  - **Buildings with metal/open aisles: RMS delay spread of up to 300 ns (100s kbps w/o equalization)**
  - **Between floors:**
    - » **Concrete/steel flooring yields less attenuation than steel plate flooring**
    - » **Metallic tinted windows yield greater attenuation**
    - » **15 dB for first floor separation, 6 - 10 dB for next four floors, 1 - 2 dB for each additional floor of separation**



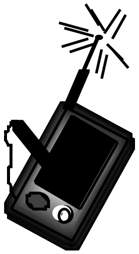
Indoor Measurements

- **Received signal strength depends on:**
  - Open plan offices, construction materials, density of personnel, furniture, etc.
- **Path loss exponents:**
  - Narrowband (max delay spread < bit period)
    - » Vary between 2 and 6, 2.5 to 4 most common
    - » Wall losses: 10 dB to 15 dB
    - » Floor losses: 12 dB to 27 dB
  - Wideband (max delay spread > bit period)
    - » Delay spread varies between 15 ns and 100 ns
    - » Can vary up to 250 ns
    - » Requires sophisticated equalization techniques to achieve acceptable bit error rates



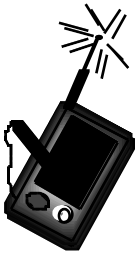
Outdoor-to-Indoor Measurements

- **Penetration/"Building Loss"**
  - **Depends on building materials, orientation, layout, height, percentage of windows, transmission frequency**
    - » **Received signal strength increases with increasing height of building (less urban clutter at upper floors)**
    - » **Penetration loss decreases with increasing frequency**
    - » **6 dB less loss through windows**
- **Rate of decay/distance power law: 3.0 to 6.2, with average of 4.5**
- **Building attenuation loss: between 2 dB and 38 dB**



Error Mechanisms

- Error Burst
  - Results of fades in radio channels
    - » Doppler induced frequency/phase shifts due to motion can also cause loss of synchronization
    - » Errors increase as bit period approaches delay spread
  - Region of consecutive errors followed by stream of consecutive error-free bits
    - » Voice communication: 10^{-3} BER, 1 error bit in 1000
    - » Data communications: 10^{-6} BER, 1 error in 1,000,000



Error Mechanisms

- **Average Duration of a Fade**

$$\mathrm{ADF} = \frac{\sqrt{2\pi}\,[e^{R^2} - 1]}{\beta\, v\, R}$$

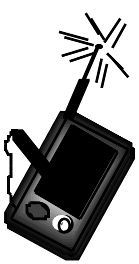
β: Depends on *f*

v: Speed of mobile (m/s)

R: Fade depth (ratio of RMS in dB)

- **Some examples:**
  - **900 MHz, 50 km/hr -- undergoes ave fade depth of 20 dB**
  - **ADF = 0.962 ms**

  - **0.5 m/s, ADF becomes 26.7 ms**
  - **Portables reside in fades for much longer time periods**
  - **Renders FEC techniques inoperative**



Error Mechanisms

- **Average Duration of a Fade (approximation)**

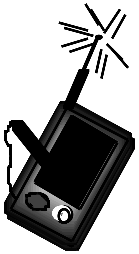
$$\tau(R) = \frac{\lambda}{v} \frac{\rho}{\sqrt{2\pi}} \qquad \rho = R/R_{RMS}$$

- **Some examples:**

Frequency (Mhz)	900	Wavelength	0.33
Speed (km/h)	50	Speed (m/s)	13.9
Fade Depth (dB)	-20	Rho	0.1
Avg Duration of Fade (ms)	**0.957**		

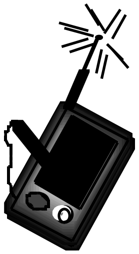
Frequency (Mhz)	900	Wavelength	0.33
Speed (km/h)	2	Speed (m/s)	0.56
Fade Depth (dB)	-20	Rho	0.1
Avg Duration of Fade (ms)	**23.94**		

Frequency (Mhz)	900	Wavelength	0.33
Speed (km/h)	24	Speed (m/s)	6.67
Fade Depth (dB)	-10	Rho	0.32
Avg Duration of Fade (ms)	**6.308**		



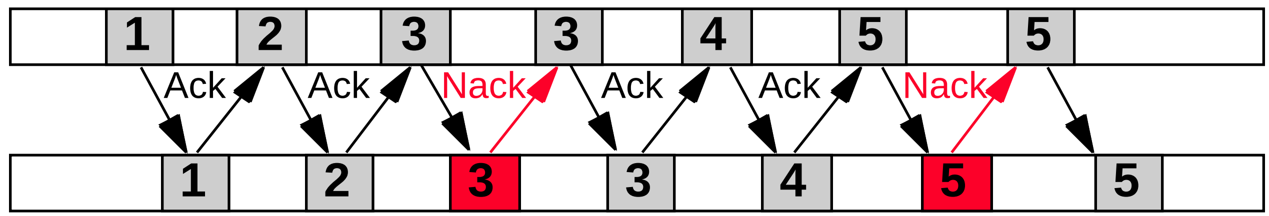
Error Mechanisms

- Strategies for Overcoming Errors
  - Antenna diversity (+10 dB)
    - » Dual antennas placed a λ / 2 separation
  - Forward error correction (FEC)
    - » Improve fade margin through coding gain
    - » Coding gain = signal energy per bit-to-noise ratio required to attain a particular error rate with and without coding
    - » Not very effective in slowly varying radio channels
    - » Block vs. Convolutional Codes, Interleaved vs. Non-Interleaved
  - Automatic Repeat Request (ARQ)
    - » Retransmission protocol for blocks in error
    - » Stop and Wait, Go Back N, Selective Repeat

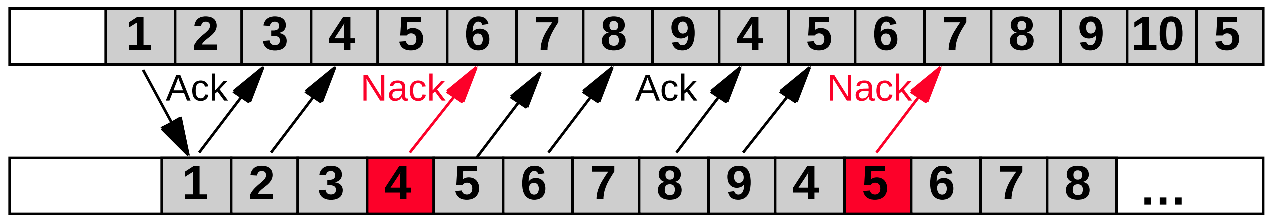


Error Mechanisms

Stop & Wait



Continuous ARQ w/Pull Back



Selective Repeat ARQ