WIRELESS COMMUNICATION SYSTEMS-LECTURE 2

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OUTLINE (MAT. MODELING OF RADIO CHANNEL)

- Equivalent Lowpass Representation of Bandpass Signals
  - Doppler shift
  - Path-loss
- Free-space Path-loss Model
- Empirical Path-Loss Models
  - Okumura, Hata
  - Indoor Models
- Shadow Fading
- Combined Path-Loss and Fading
- Outage Probability

TRANSMITTING DATA USING RADIO WAVES

- Basic task : Transmit can send a radio wave, receive can detect whether such a wave is present, and also its parameters
- Parameters of a wave = sine function:

$$\boxed{s(t) = A(t)\sin(2\pi f(t)t + \phi(t))}$$

Parameters: amplitude A(t), frequency f(t), phase ϕ(t)

- Manipulating these three parameters allows the sender to express data; receiver reconstructs data from signal
- Simplification: Receiver “sees” the same signal that the sender generated – not true, see later!

EQUIVALENT LOWPASS REPRESENTATION OF BANDPASS SIGNALS (SEE THE WHITEBOARD AND APPENDIX A)

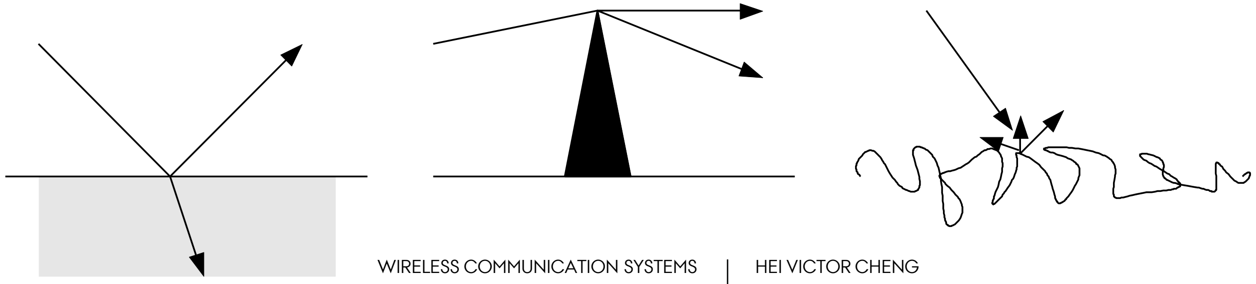
- We work with signals in different frequency bands due to propagation characteristics and antenna size.
- All transmitted and received signals are real. See page 29-30.
- For simplicity we use the equivalent lowpass representation of the bandpass signal.

- Transmitted signal (2.1):

$$s(t) = s_I(t)\cos(2\pi f_c t) - s_Q(t)\sin(2\pi f_c t)$$

TRANSMITTED SIGNAL <> RECEIVED SIGNAL !

- Wireless transmission ***distorts*** any transmitted signal
  - Received <> transmitted signal; results in ***uncertainty at receiver*** about which bit sequence originally caused the transmitted signal
  - Abstraction: ***Wireless channel*** describes these distortion effects
- Sources of distortion
  - Attenuation – energy is distributed to larger areas with increasing distance
  - Reflection/refraction – bounce of a surface; enter material
  - Diffraction – start “new wave” from a sharp edge
  - Scattering – multiple reflections at rough surfaces
  - Doppler fading – shift in frequencies (loss of center)



DOPPLER SHIFT – THE IMPACT OF MOVING …

- There will be a Doppler shift

  depending on the velocity, and

  the wavelength (lambda) : $f_D = \frac{v}{\lambda}\cos(\theta)$

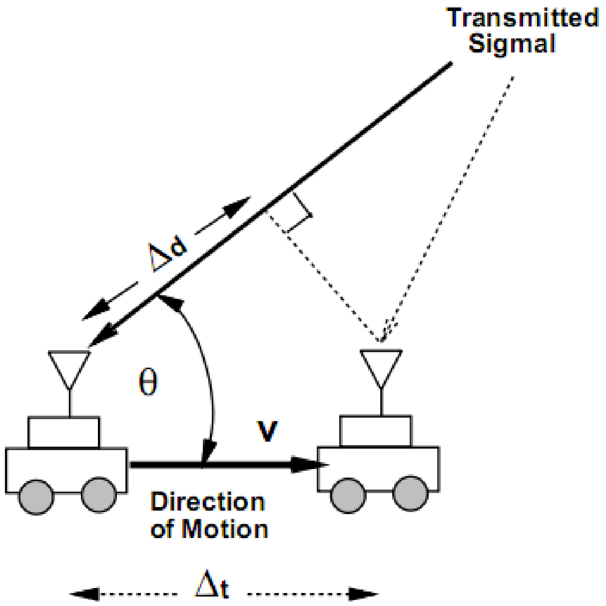
$\lambda = c \; * \; f_{carrier},\qquad c = 3 * 10^8 \text{ m/s}$

- For free-space comm. with

  typical speeds of 75 km/h and a

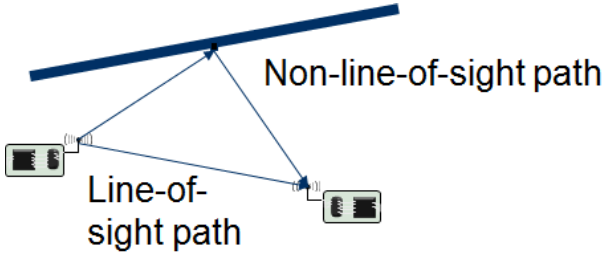
  carrier freq. at 1 GHz the

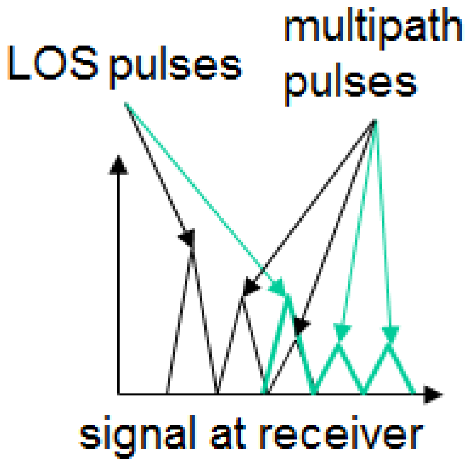
  Doppler frequency is 100 Hz.



DISTORTION EFFECTS: NON-LINE-OF-SIGHT PATHS

- Because of reflection, scattering etc. radio communication is not limited to direct line of sight communication
  - Effects depend strongly on frequency, thus different behavior at higher frequencies

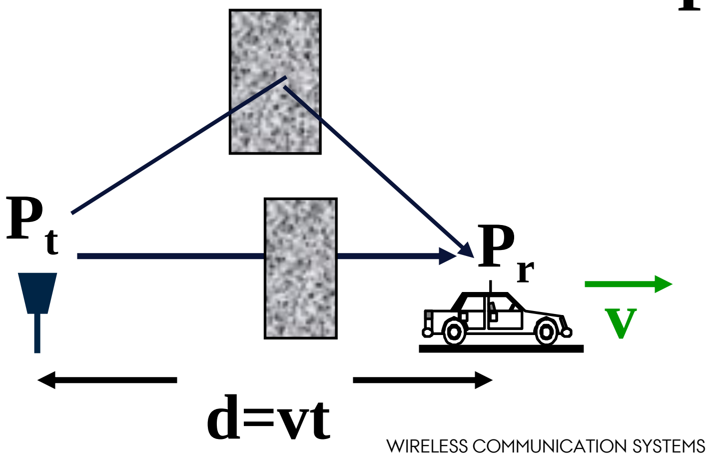


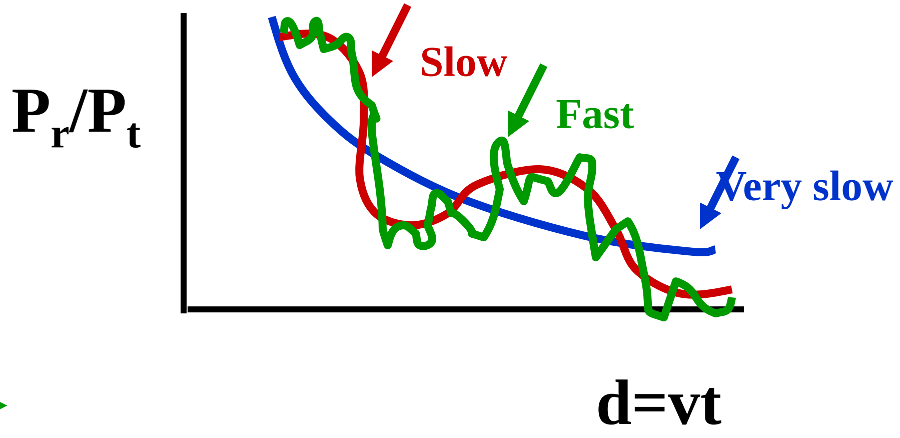


- Different paths have different lengths = propagation time
  - Results in ***delay spread*** of the wireless channel
  - Closely related to frequency-selective fading properties of the channel
  - With movement: ***fast fading***

PROPAGATION CHARACTERISTICS

- Path Loss (includes average shadowing)
- Shadowing (due to obstructions)
- Multipath Fading

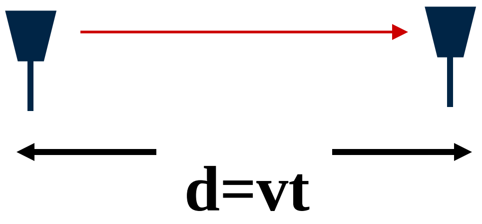




PATH LOSS MODELING (MATHEMATICAL)

- Maxwell's equations
  - Complex and impractical
- Free space path loss model
  - Too simple
- Ray tracing models
  - Requires site-specific information
- Empirical Models
  - Don't always generalize to other environments
- Simplified power falloff models
  - Main characteristics: good for high-level analysis

FREE SPACE (LOS) MODEL



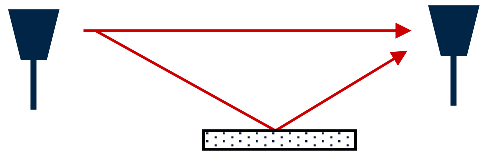
$$r(t) = \Re\{\frac{u(t)\sqrt{G_t G_r}\lambda e^{j2\pi d/\lambda}}{4\pi d} e^{j(2\pi f_c t}\}$$

- Path loss for unobstructed LOS path
- Power falls off :
  - Proportional to $1/d^2$
  - Proportional to λ^2 (inversely proportional to f^2)

RAY TRACING APPROXIMATION

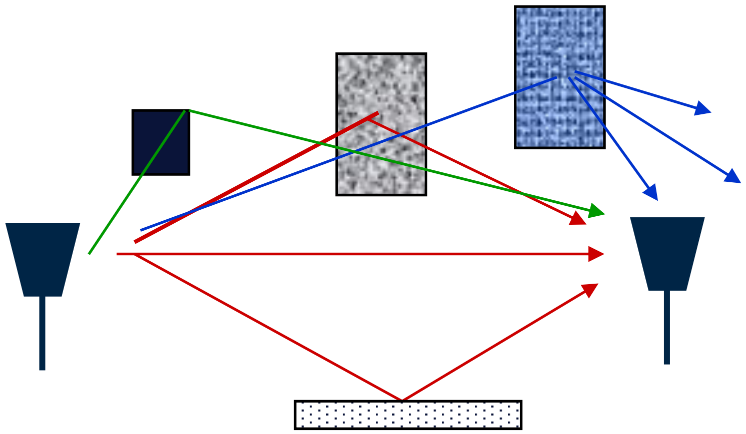
- Represent wavefronts as simple particles
- Geometry determines received signal from each signal component
- Typically includes reflected rays, can also include scattered and defracted rays.
- Requires site parameters
  - Geometry
  - Dielectric properties

TWO PATH MODEL



- Path loss for one LOS path and 1 ground (or reflected) bounce
- Ground bounce approximately cancels LOS path above critical distance
- Power falls off
  - Proportional to d^2 (small d)
  - Proportional to d^4 ($d>d_c$)
  - Independent of ƛ (f)

GENERAL RAY TRACING



- Models all signal components
  - Reflections
  - Scattering
  - Diffraction
- Req. detailed geometry & dielectric properties of site
  - Similar to Maxwell, but easier math.
- Commercial software packages often used

SIMPLIFIED PATH LOSS MODEL

- Used when path loss dominated by reflections.
- Most important parameter is the path loss exponent γ, determined empirically.

$$P_r = P_t K \left[\frac{d_0}{d}\right]^{\gamma}, \qquad 2 \le \gamma \le 8$$

EMPIRICAL MODELS

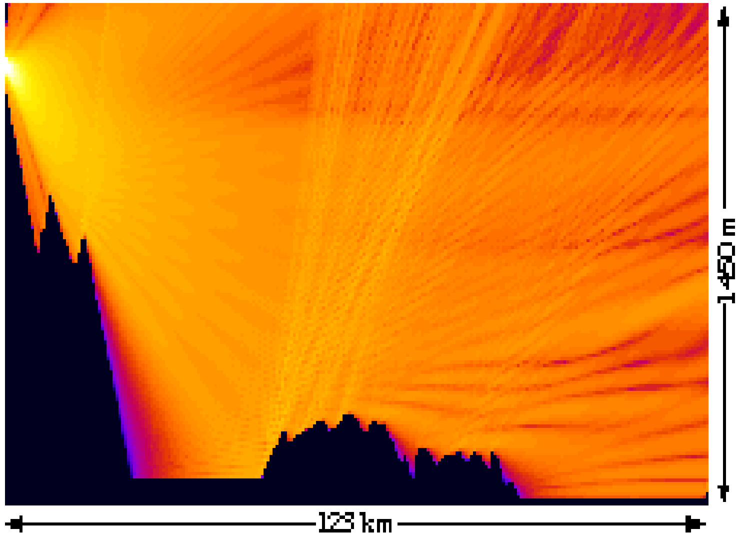
- Okumura model
  - Empirically based (site/freq specific)
  - Awkward (uses graphs)
- Hata model
  - Analytical approximation to Okumura model
- Cost 231 Model:
  - Extends Hata model to higher frequency (2 GHz)
- Walfish/Bertoni:
  - Cost 231 extension to incl. diffraction from rooftops

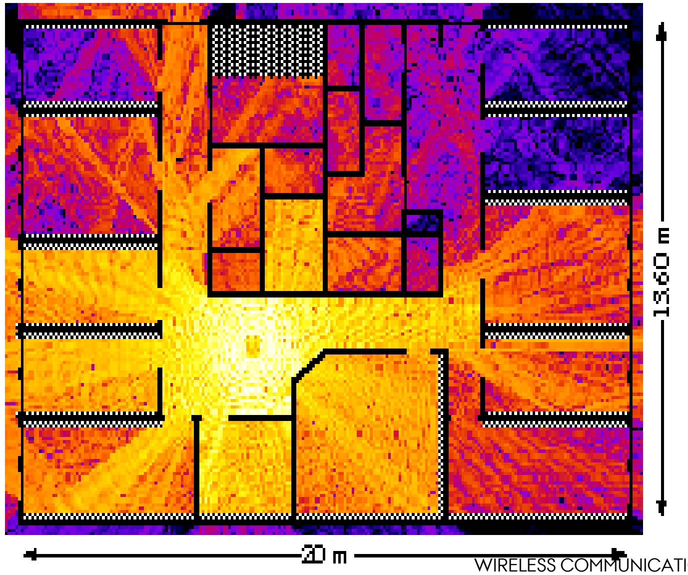
Commonly used in system simulations

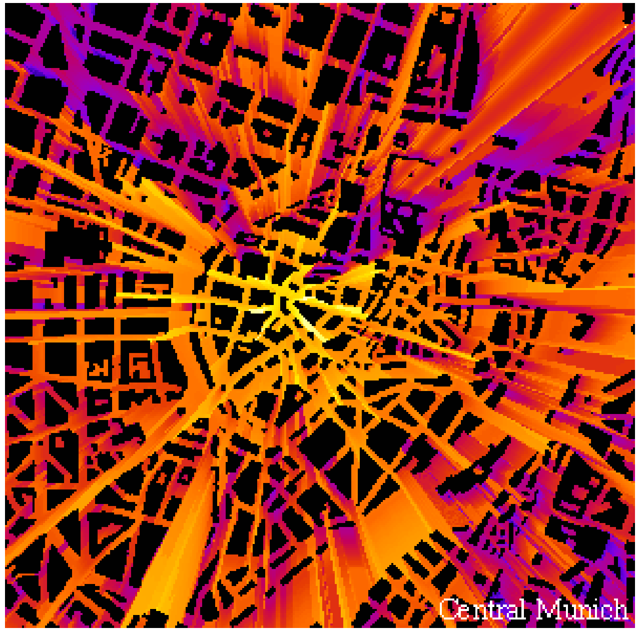
WIRELESS SIGNAL STRENGTHS IN A MULTI-PATH ENVIRONMENT

Simulation Models:

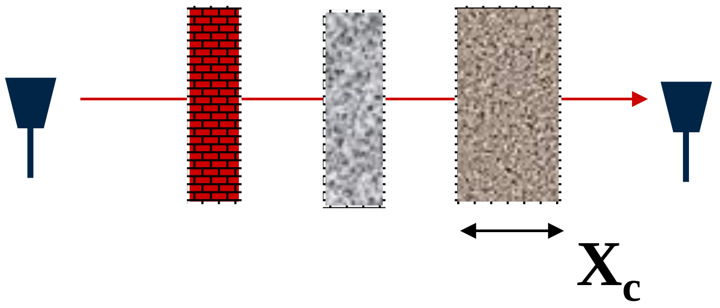
- Brighter color = stronger signal
- Obviously, simple (quadratic) free space attenuation formula is not sufficient to capture these effects







SHADOWING



- Statistical modeling of attenuation from obstructions
- Random due to random # and type of obstructions
- Typically follows a log-normal distribution
  - dB-value of power is normally distributed
  - mean = 0, 4 < standard deviation < 12 (empirical)
  - Decorrelated over decorrelation distance X_c

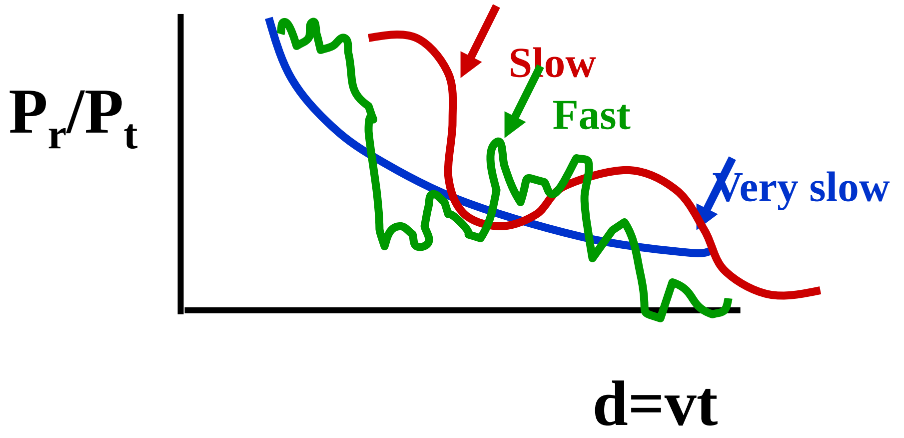
- Equation (2.46)

$$p(\psi_{\mathrm{dB}}) = \frac{1}{\sqrt{2\pi}\sigma_{\psi_{\mathrm{dB}}}} \exp\left[-\frac{(\psi_{\mathrm{dB}} - \mu_{\psi_{\mathrm{dB}}})^2}{2\sigma^2_{\psi_{\mathrm{dB}}}}\right]$$

COMBINED PATH-LOSS AND SHADOWING

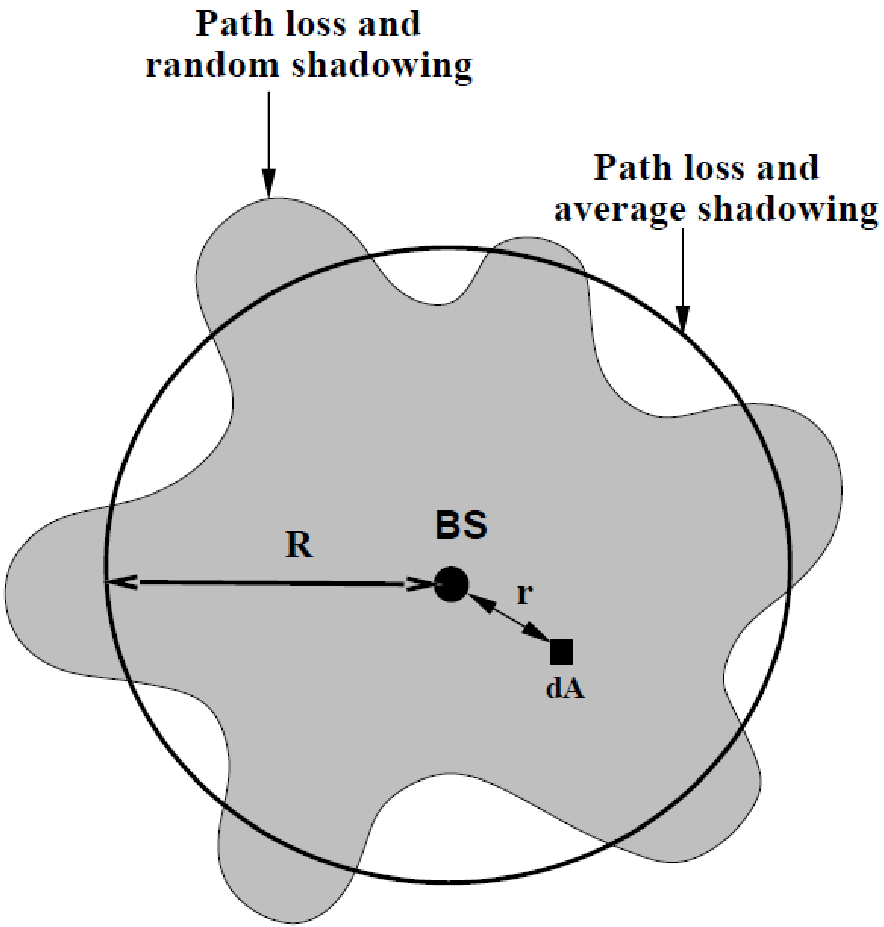
- Statistically path-loss and shadowing can be superimposed as shown in equation (2.51) page 51.

$$\frac{P_r}{P_t}\text{ dB} = 10\log_{10} K - 10\gamma\log_{10}\frac{d}{d_0} - \psi_{\text{dB}}$$



OUTAGE PROBABILITY - WITH PATH-LOSS AND SHADOWING

- $P_{out}(P_{min}, d)$ is the probability that the received power at a given distance (d) falls below P_{min}.



NEXT LECTURE

- Fading (small-scale fading, fast fading)
- Statistical Fading Models
- Narrowband Models

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