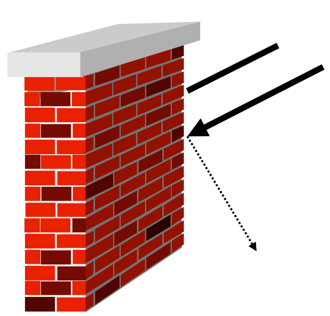
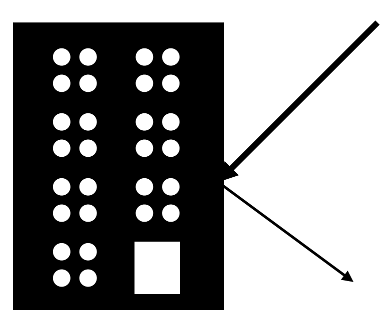
Probabilistic Link Properties

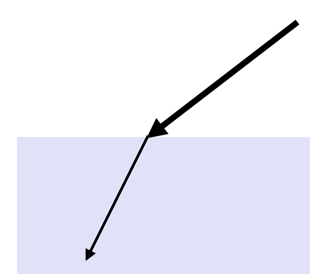
Octav Chipara

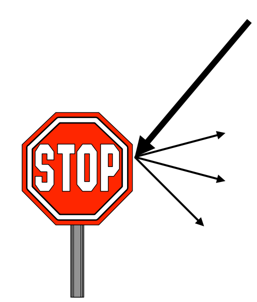
Signal propagation

- **Propagation in free space always like light (straight line)**
- **Receiving power proportional to $1/d^2$ in vacuum – much more in real environments (d = distance between sender and receiver)**
- **Receiving power additionally influenced by**
  - fading (frequency dependent)
  - shadowing
  - reflection at large obstacles
  - refraction depending on the density of a medium
  - scattering at small obstacles
  - diffraction at edges


shadowing


reflection

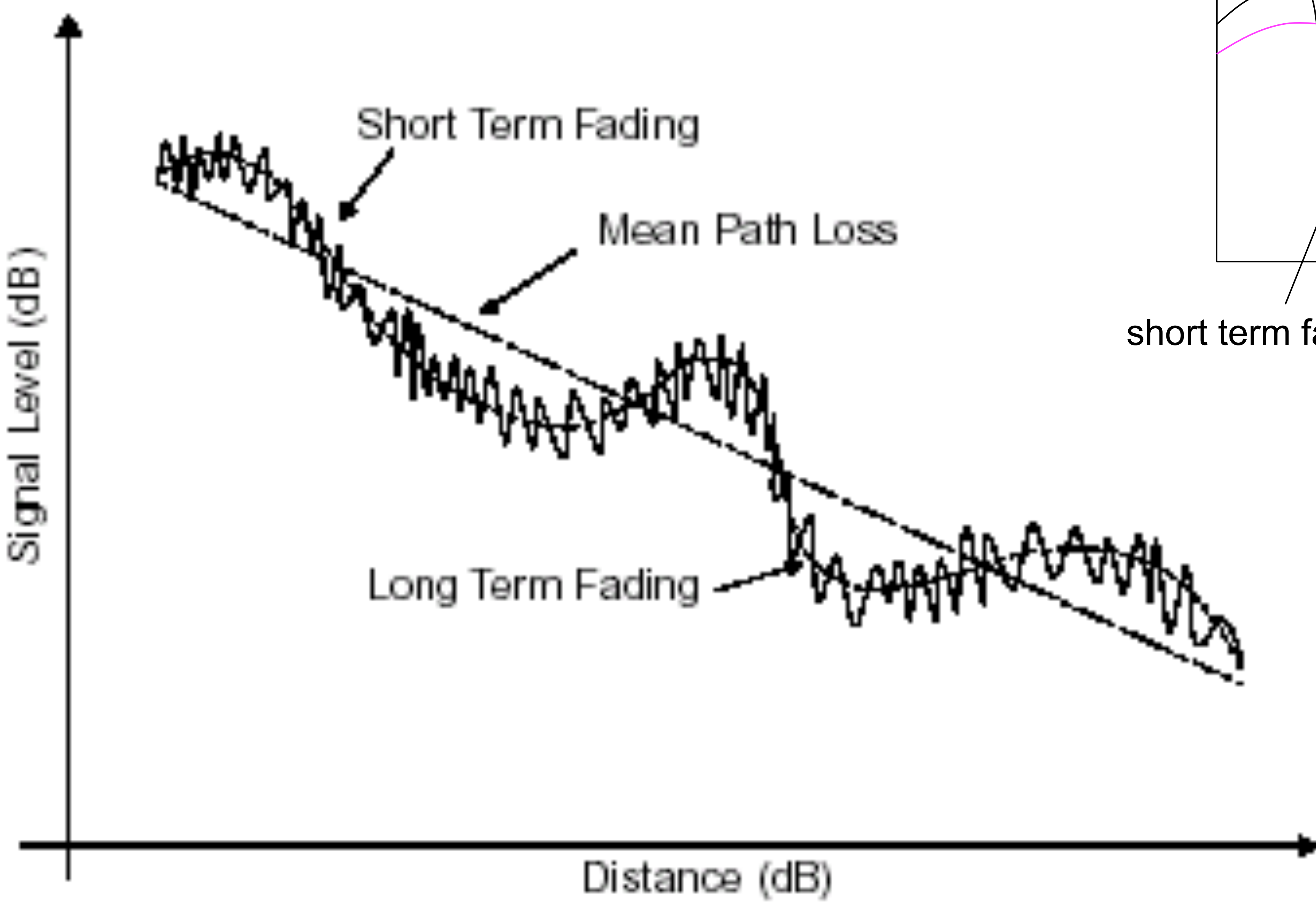

refraction

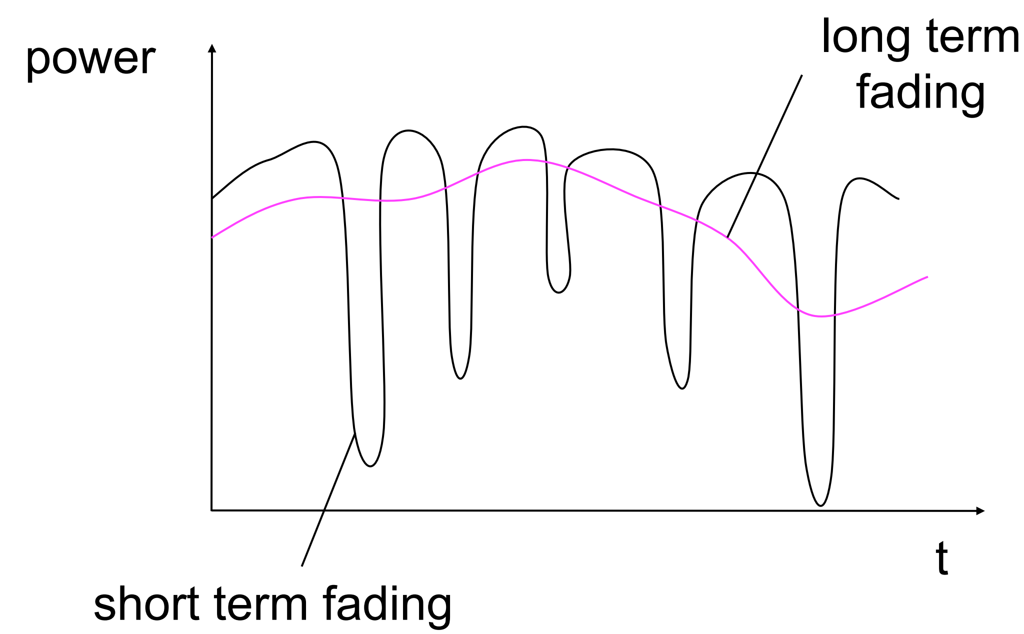


scattering


diffraction

Physical impairments: Fading (1)





Physical impairments: Fading (2)

- **Strength of the signal decreases with distance between transmitter and receiver: path loss**
  - usually assumed inversely proportional to distance to the power of 2.5 to 5
- **Channel characteristics change over time and location**
- **Slow fading:** slow changes in the average power received
  - distance, obstacles
- **Fast fading:** quick changes in the power received
  - signal paths change
  - different delay variations of different signal parts
  - different phases of signal parts

Physical Impairments: Noise

- **Unwanted signals added to the message signal**
- **Many potential sources of noise**
  - natural phenomena such as lightning
  - radio equipment, spark plugs in passing cars, wiring in thermostats, etc.
- **Modeled in the aggregate as a random signal in which power is distributed uniformly across all frequencies (white noise)**
- **Signal-to-noise ratio (SNR) often used as a metric in the assessment of channel quality**

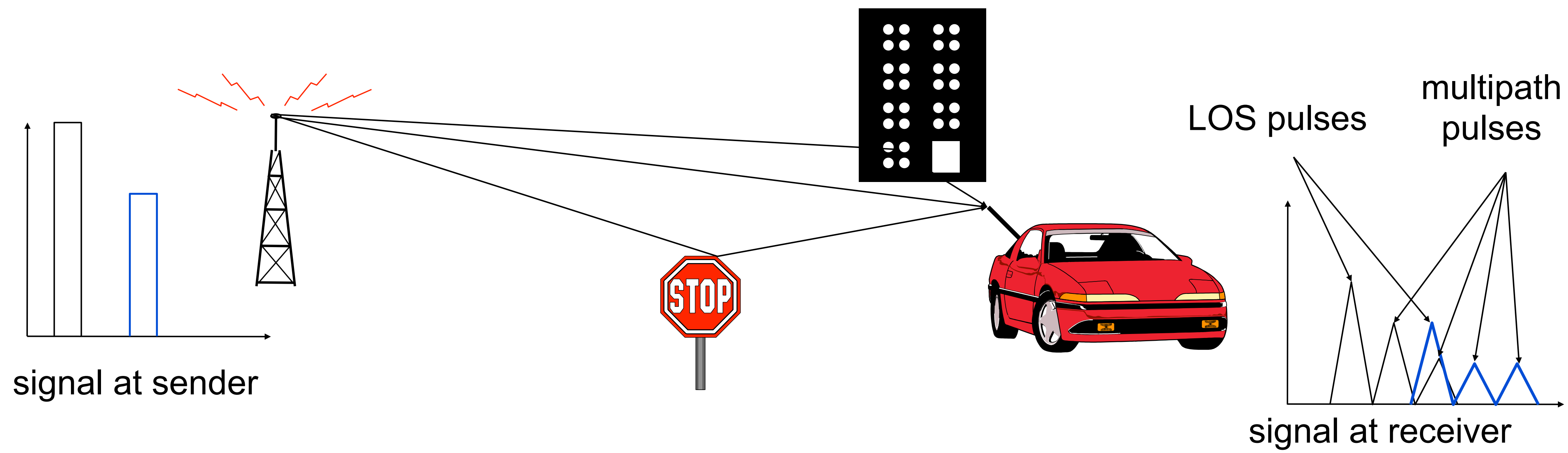
Physical Impairments: Interference

- **Signals at roughly the same frequencies may interfere with one another**
  - Example: IEEE 802.11b and Bluetooth devices, microwave ovens, some cordless phones
  - CDMA systems (many of today's mobile wireless systems) are typically interference-constrained
- **Signal to interference and noise ratio (SINR) is metric used in assessment of channel quality**

$$SNIR_{s,r} = \frac{RSS_{s,r}}{Noise + Interference}$$

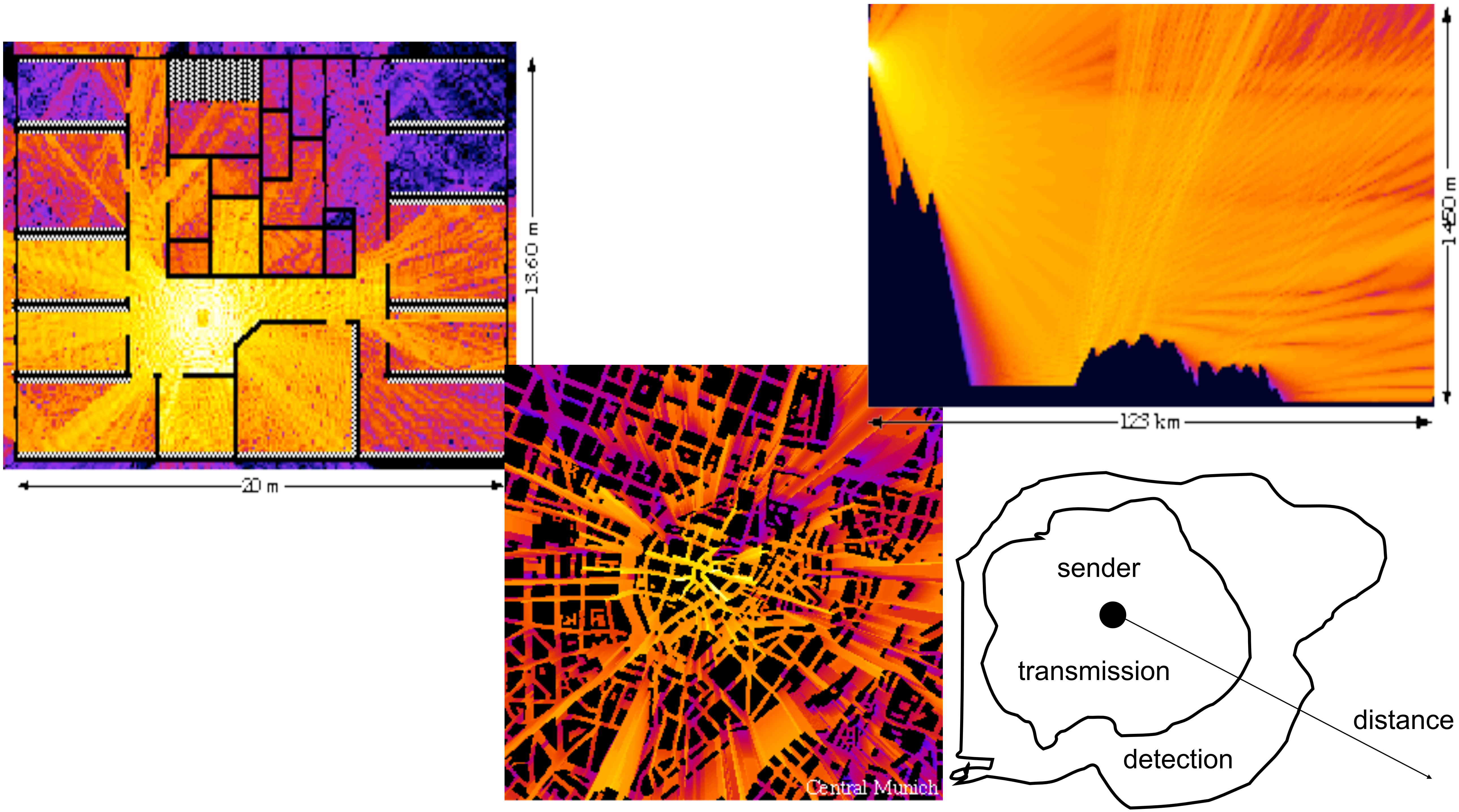
Multipath propagation

- **Signal can take many different paths between sender and receiver due to reflection, scattering, diffraction**



- **Time dispersion: signal is dispersed over time**
  - interference with “neighbor” symbols, Inter Symbol Interf. (ISI)
- **The signal reaches a receiver directly and phase shifted**
  - distorted signal depending on the phases of the different parts

Signal propagation: Real world example



Parametric propagation models

- **Free space propagation model**

$$PL(d) = PL(d_o) * \left(\frac{d_0}{d}\right)^2$$

  - when not in free-space, the path loss exponent (2) is higher

- **Log-normal propagation model**

$$PL(d) = PL(d_o) + 10nlog_{10}\left(\frac{d_0}{d}\right) + X_\sigma$$

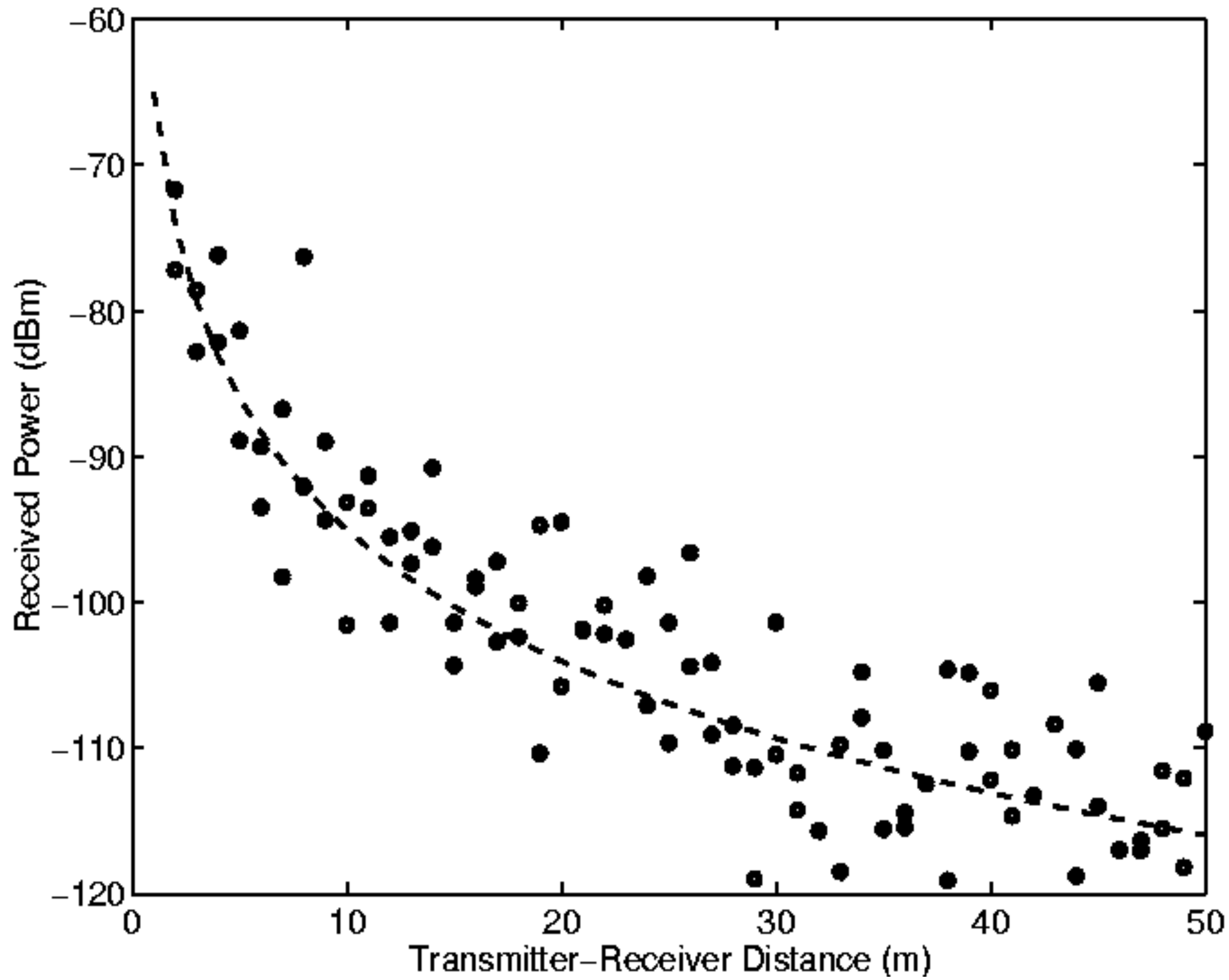
  - X_σ - Gaussian RV with mean zero, it accounts for shadowing
  - n - path loss exponent, depends on environment (e.g., 3--6 indoors)
  - d_0 - reference distance in far field
  - PL - path loss

Radio signal propagation

- **Model signal strength (and its variation) at a distance**
  - useful for localization applications, coverage, etc
  - networks with mobile users

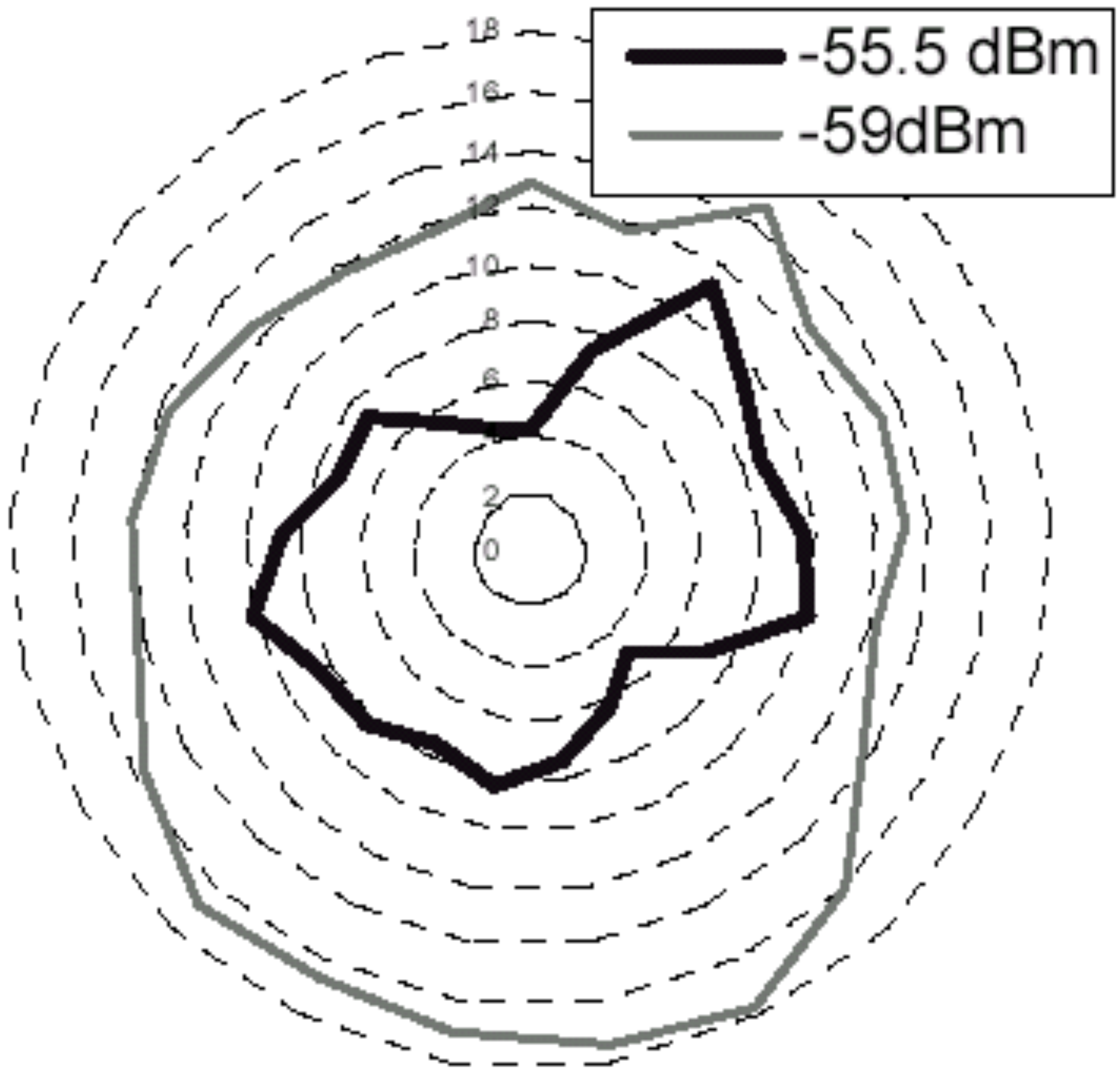
- **Model signal strength (and its variations) at a fixed distance**
  - useful for networking protocols (routing, ARQ, etc)
  - fixed networks

Log-normal path model



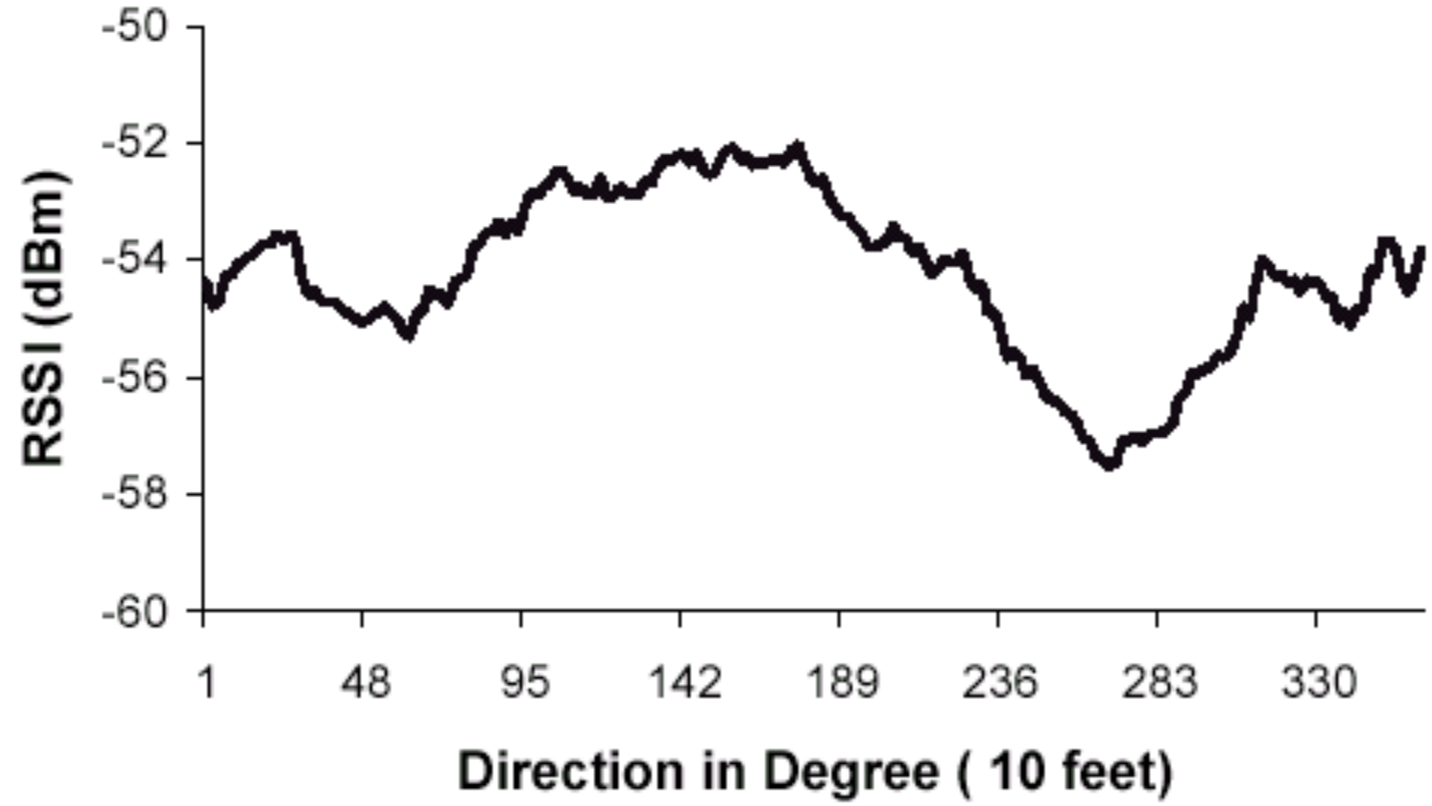
$$PL(d) = PL(d_o) + 10nlog_{10}\left(\frac{d_0}{d}\right) + X_\sigma$$

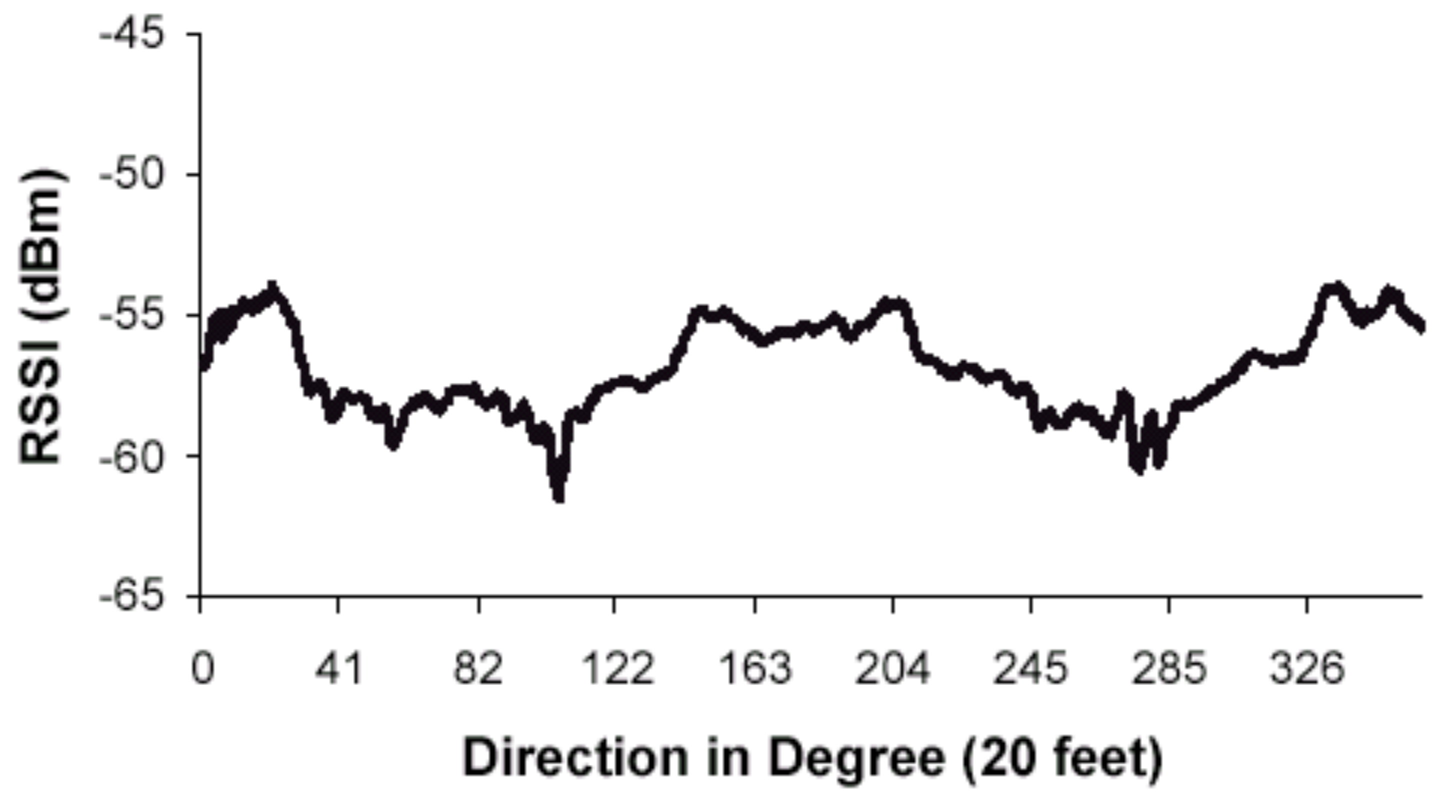
Non-isotropic connectivity



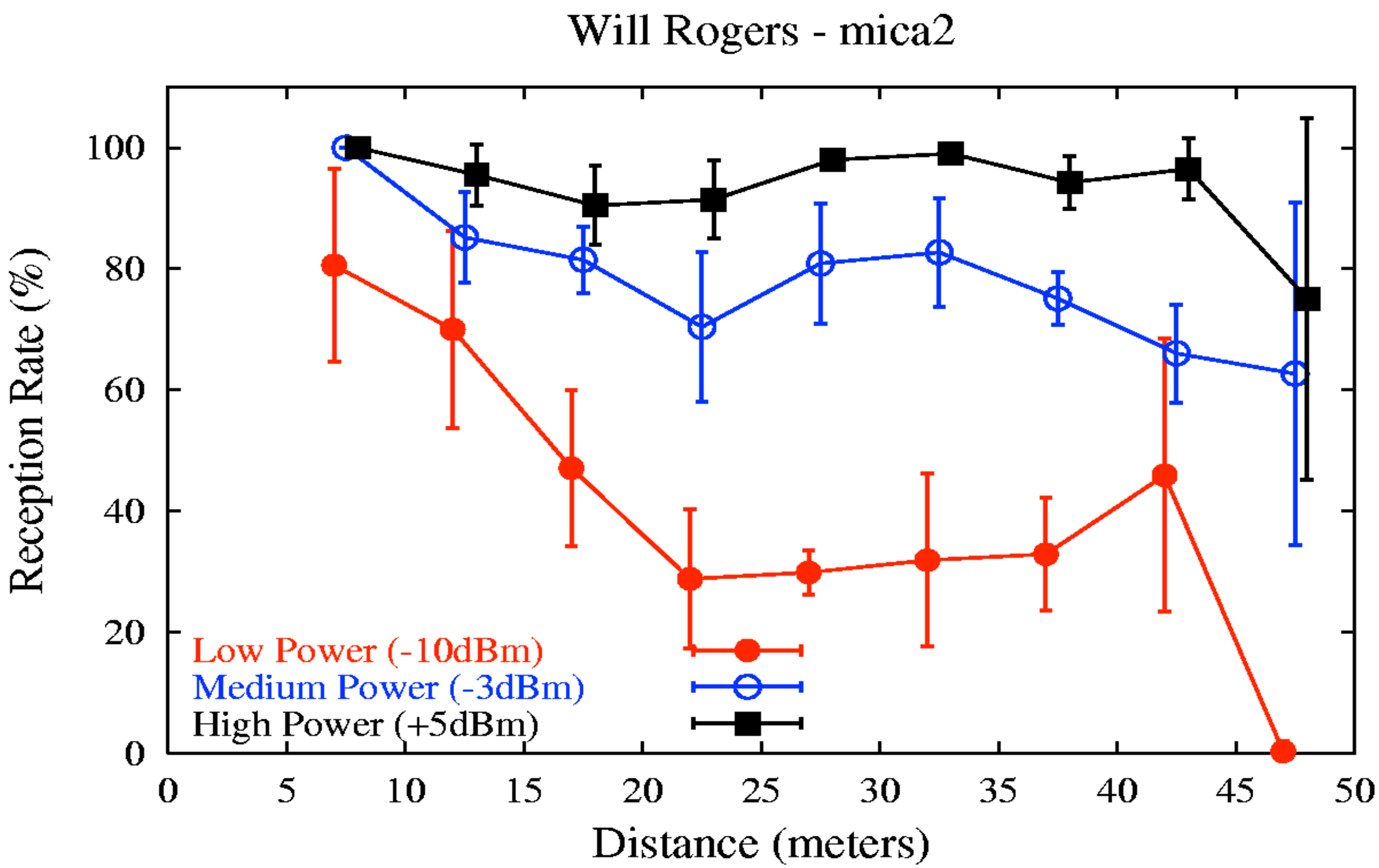
*Zhou et. al. 04

Non-isotropic connectivity (2)



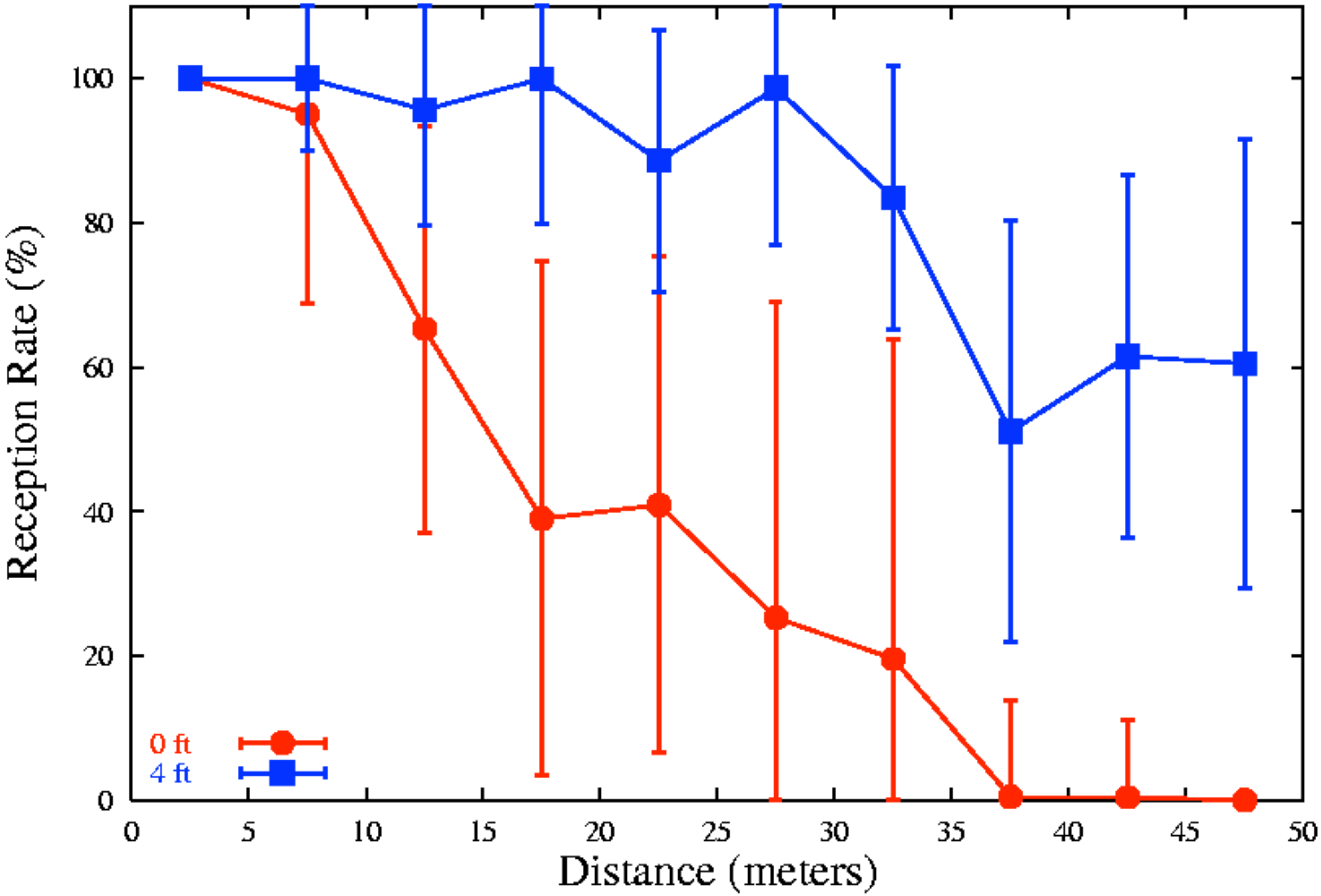


Attenuation over distance

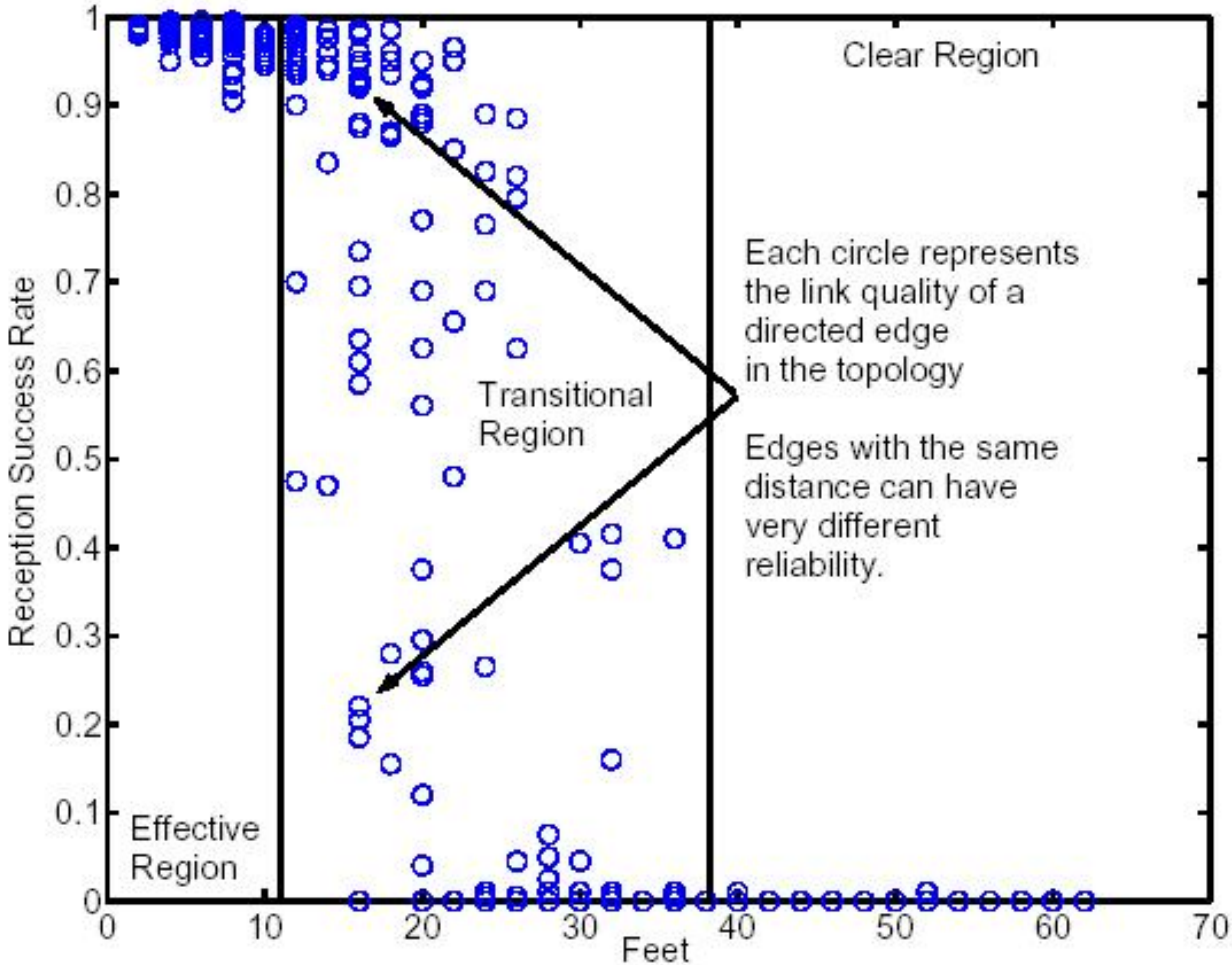


*Cerpa et. al. 03

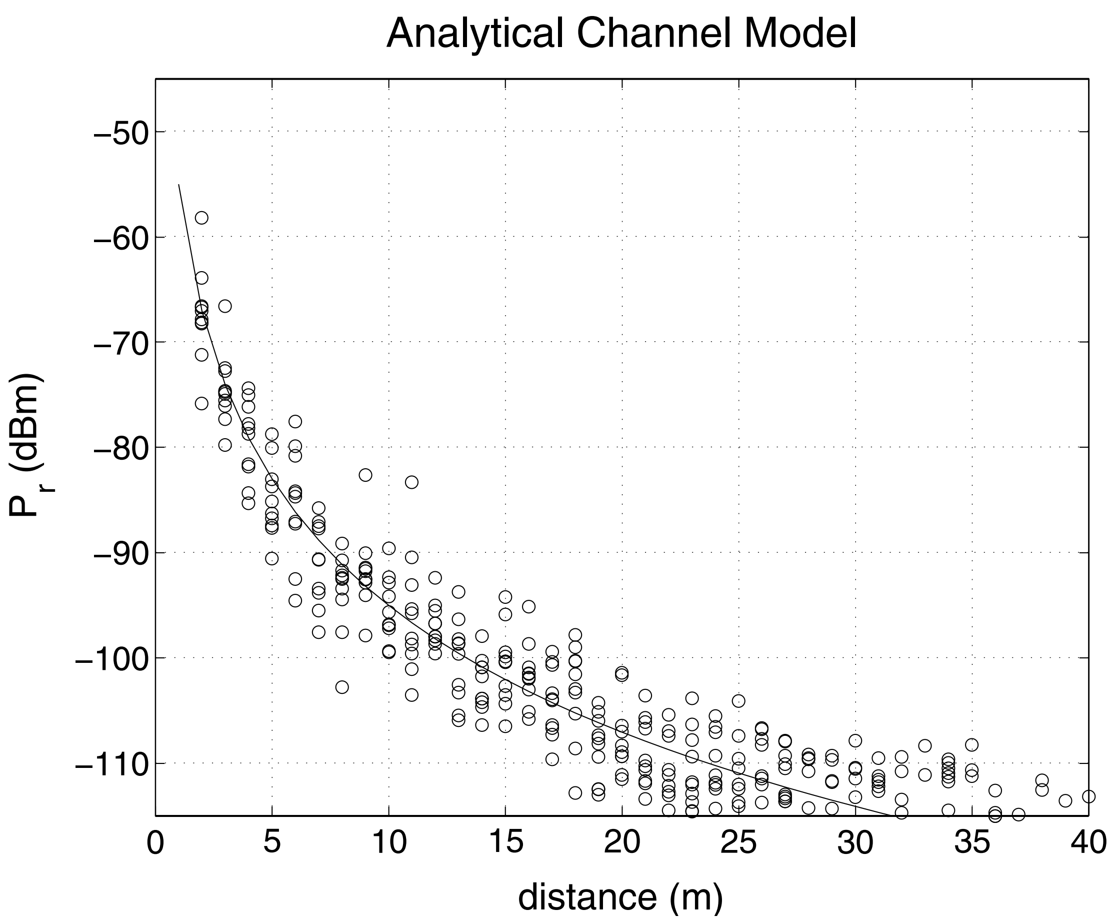
Impact of antenna height

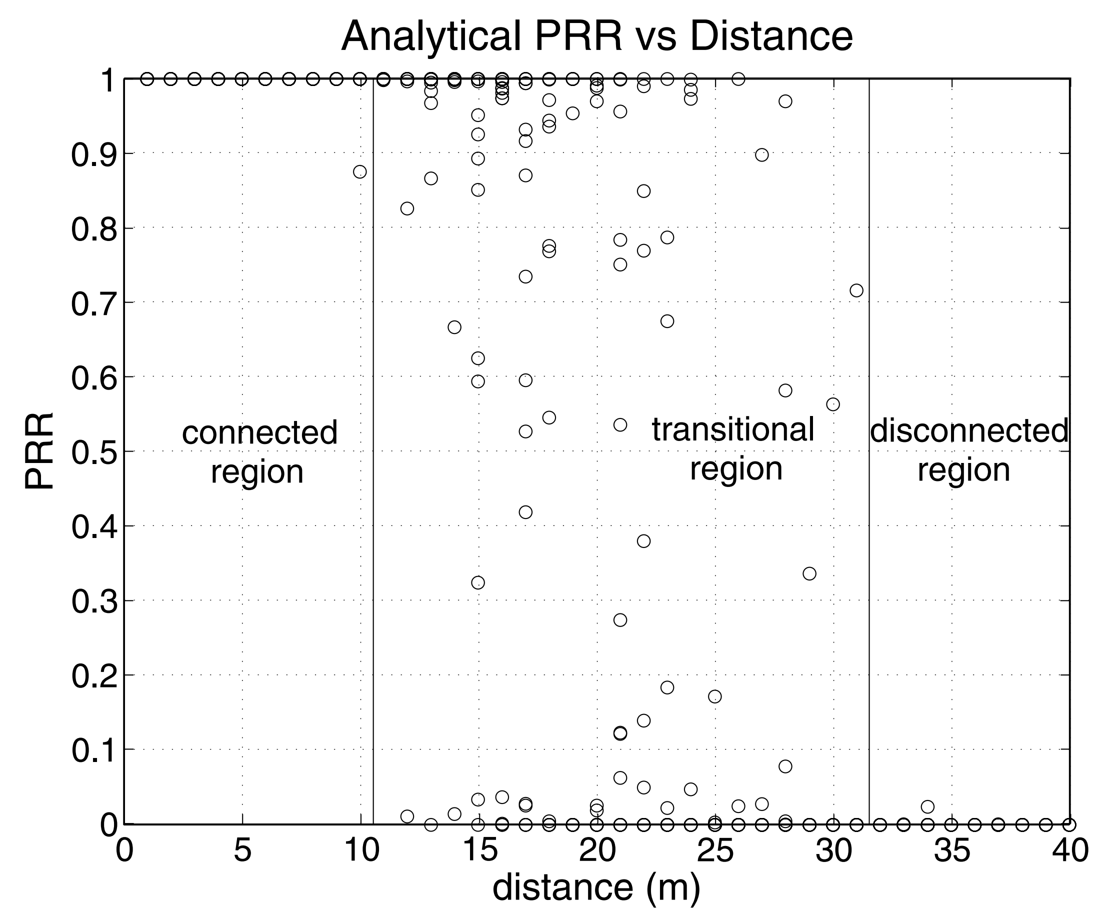


Transitional region (*aka grey region*)

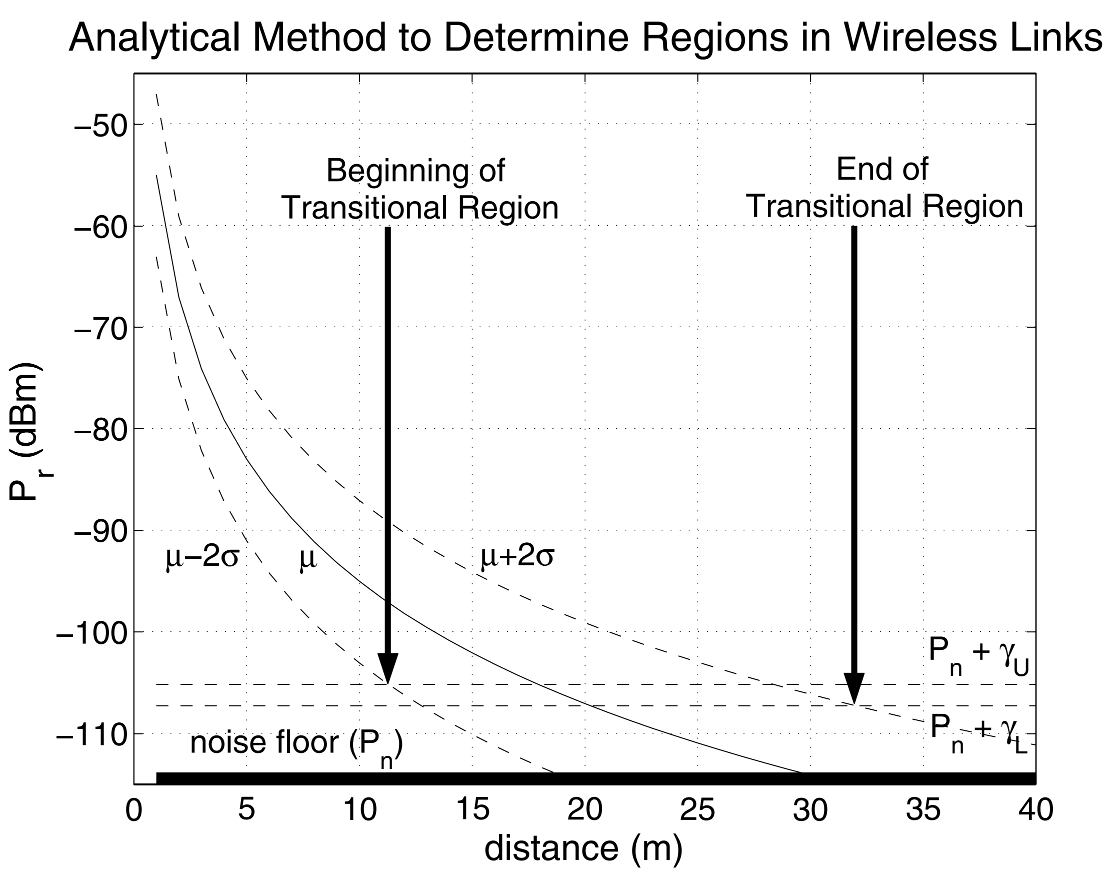


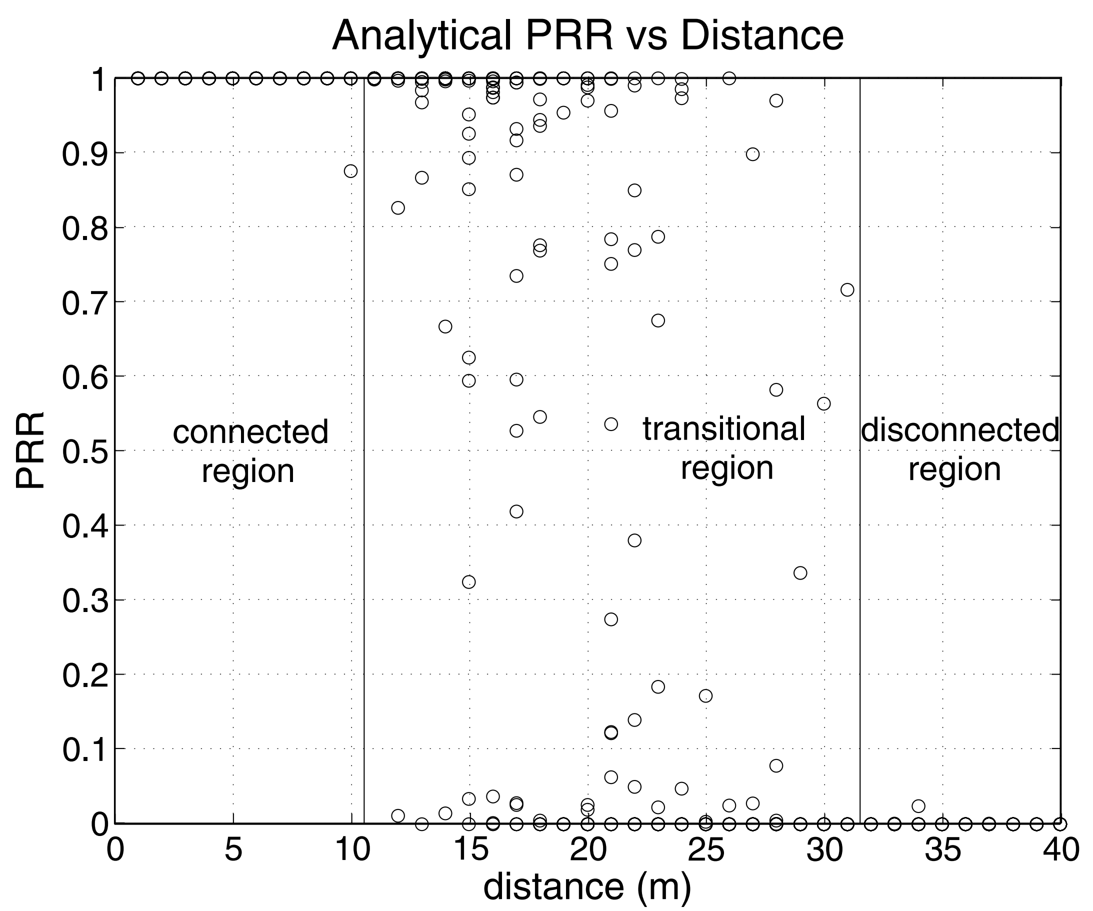
Transitional region





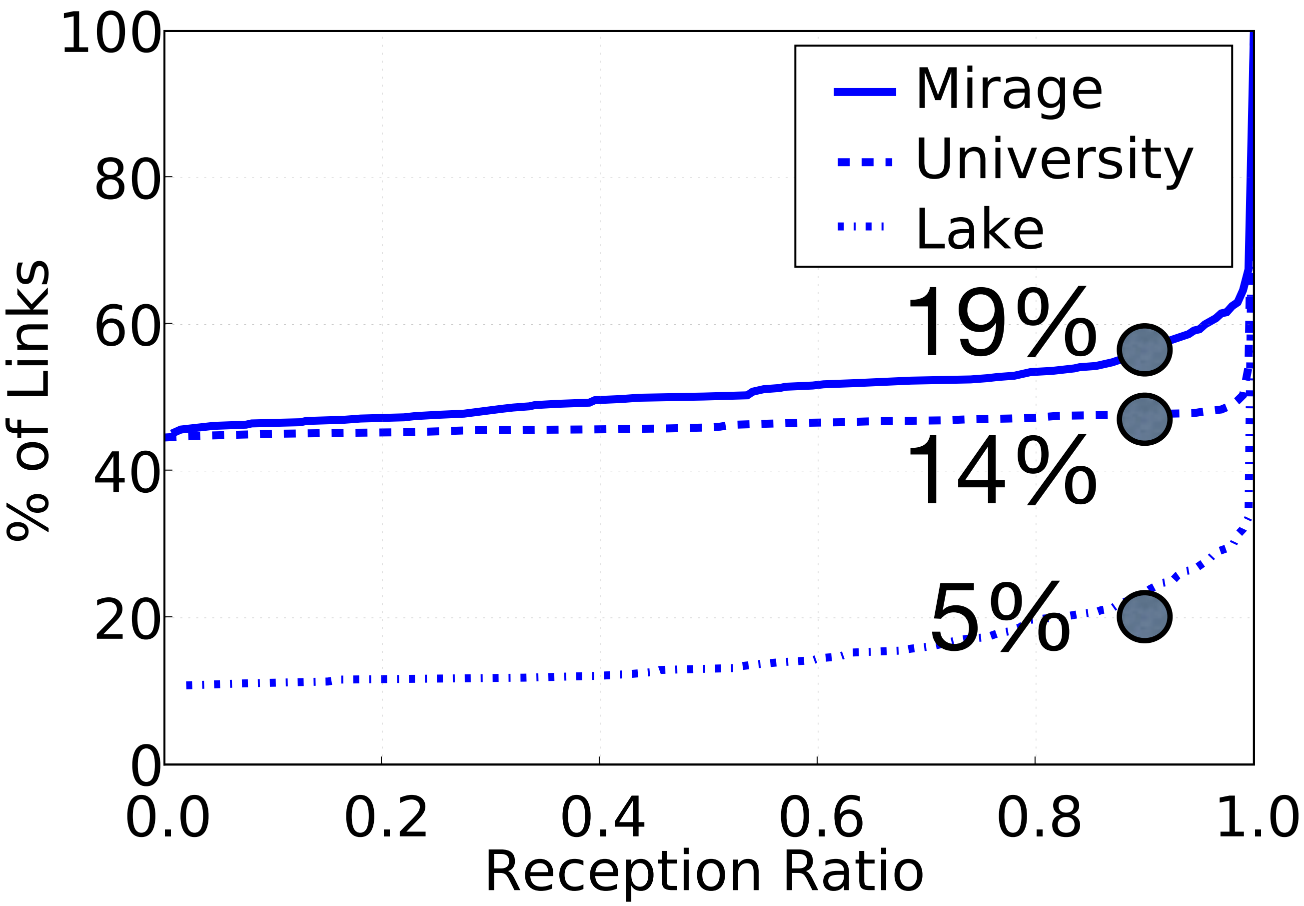
Transitional region

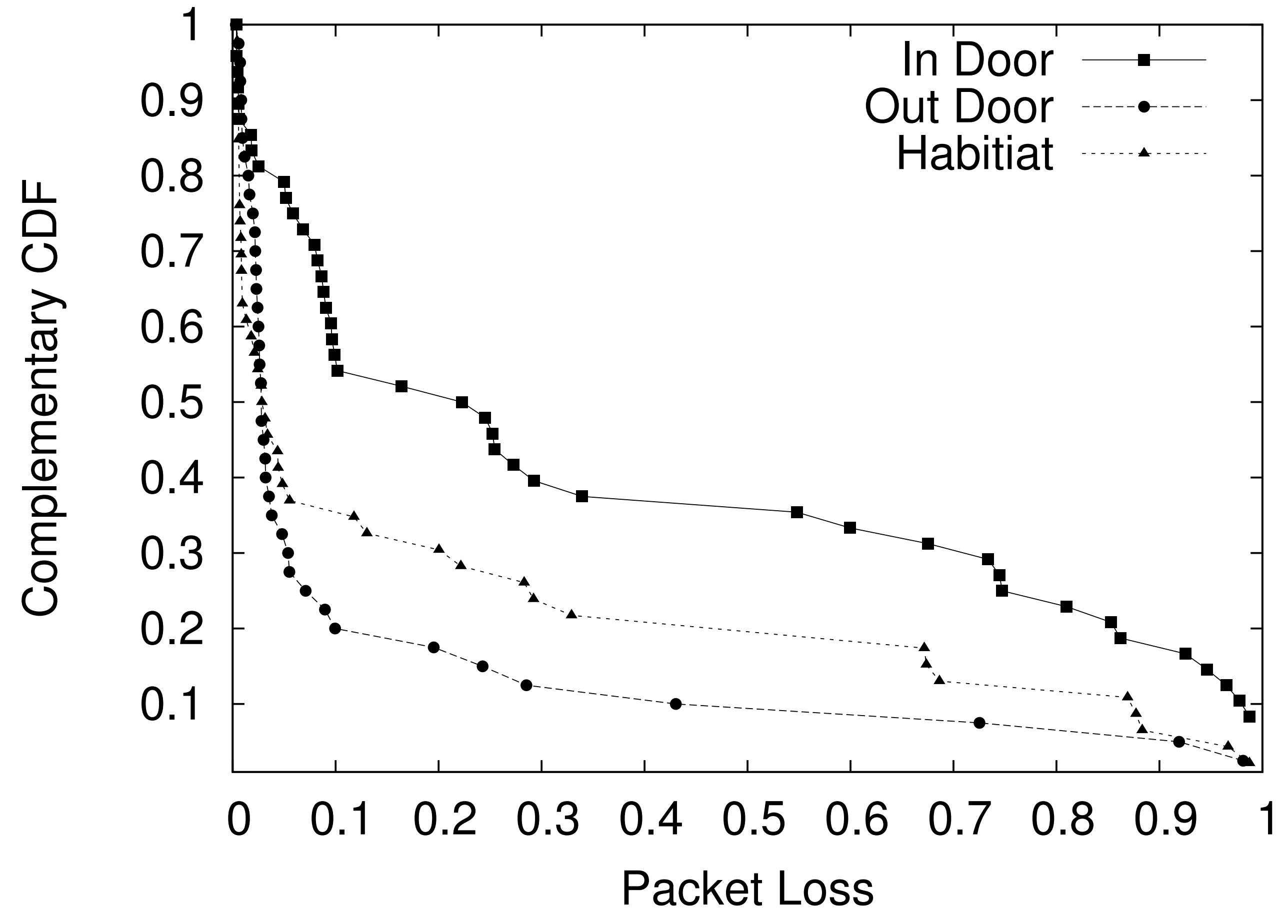


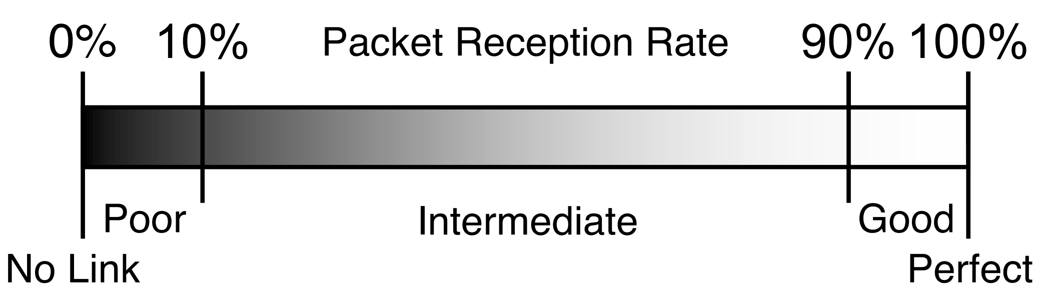


- **Length of the transitional region increases with**
  - increases in shadowing => impact of multi-path
  - decreases in path loss coefficient

Prevalence of good, bad, and intermediary links

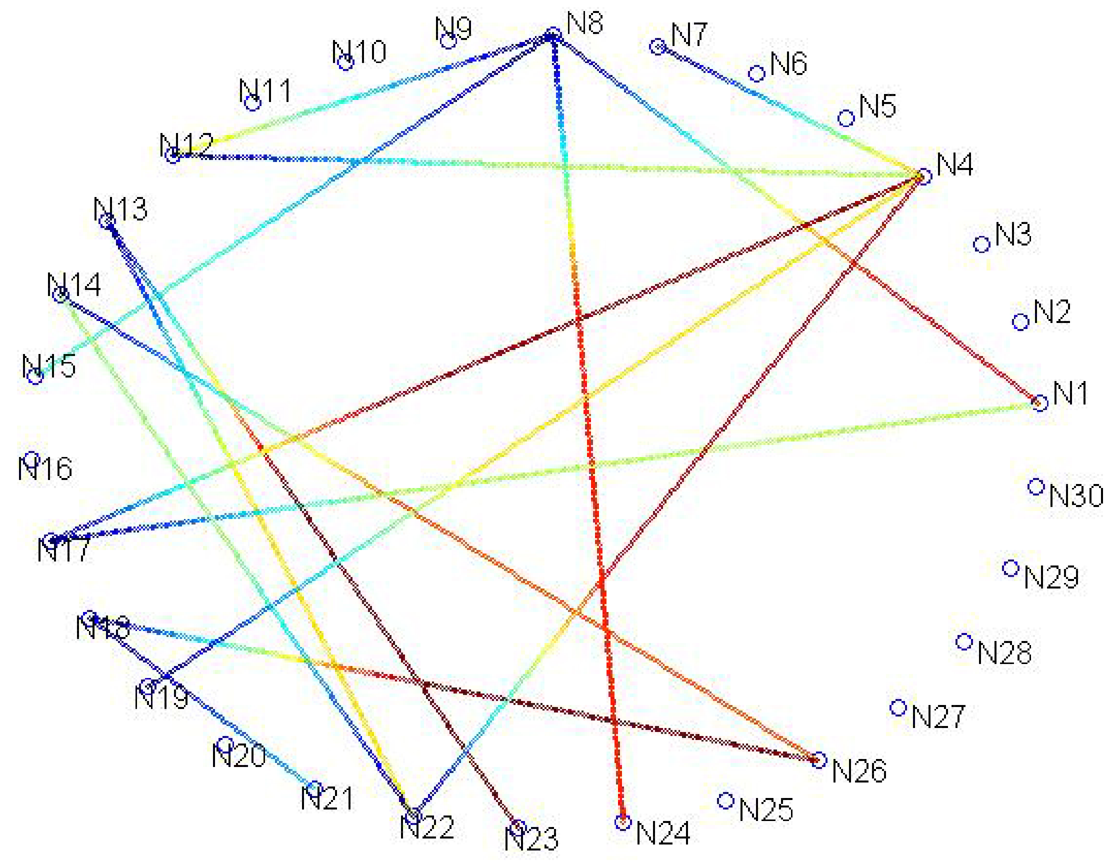






- **A significant fraction of links fall within the transitional region**
  - these links are important for protocols but hard to utilize

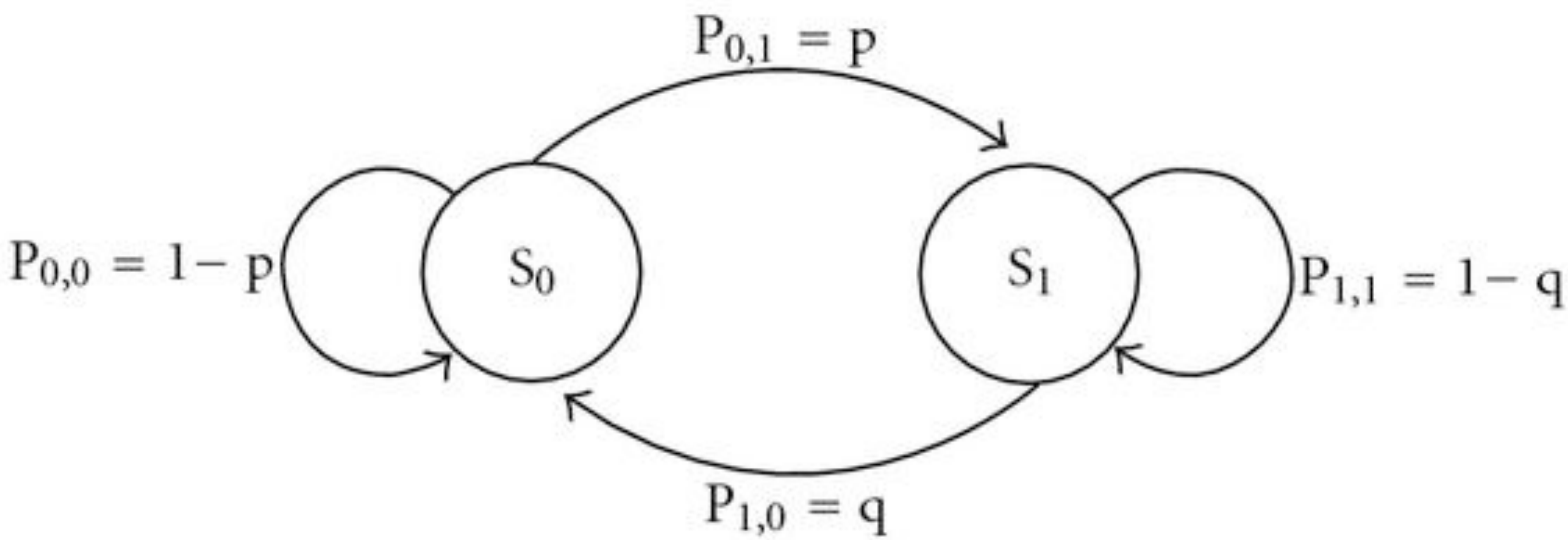
Link symmetry



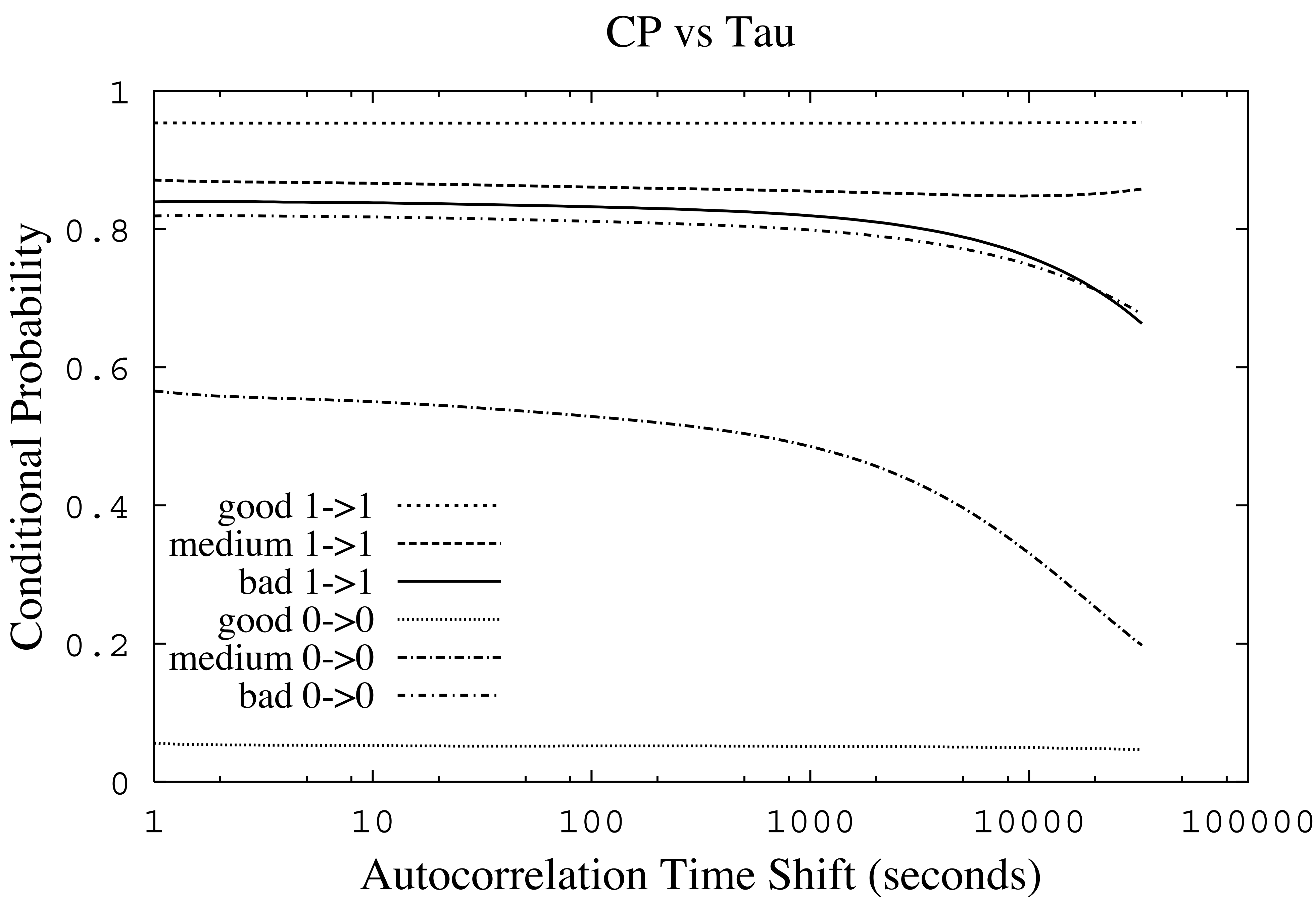
- **Links are often asymmetric**
  - protocols that assume path symmetry will not work well
  - (e.g., path reversal)

Temporal variability

- **Observation: errors in packet transmissions tend to be clustered**
  - i.e., they are not independent
- **Gillbert-Elliot channel: a simple channel model**



Temporal properties of links



Temporal properties of links

- **Good and bad links are temporally stable**
- **Intermediary links have significant fluctuations**

Next class

- **Low-power MACs**