Tho Le-Ngoc, Winter 2008

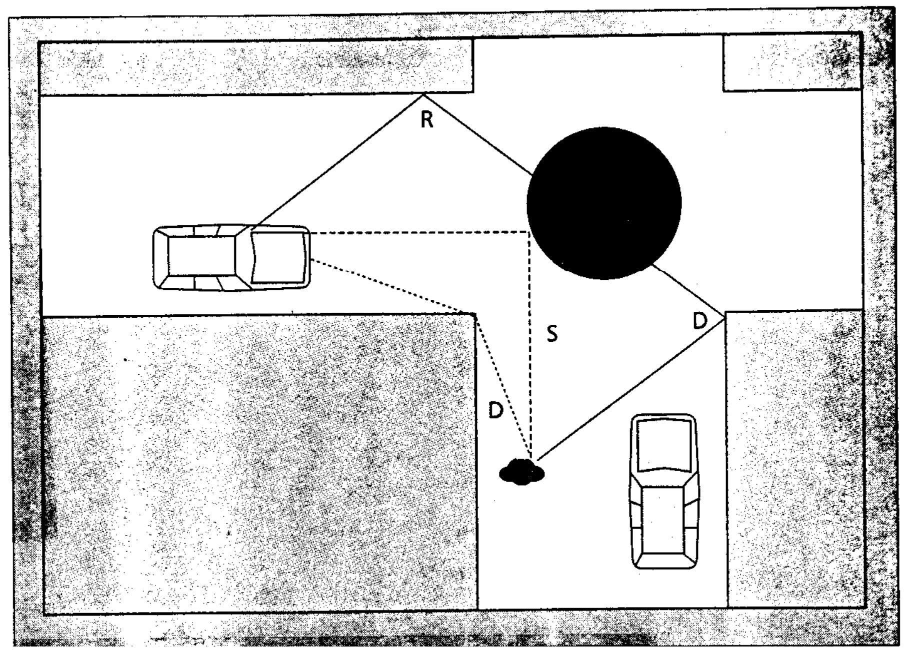
MOBILE COMMUNICATIONS CHANNELS:

BEHAVIOUR & CHARACTERIZATION

MULTIPATH PROPAGATION

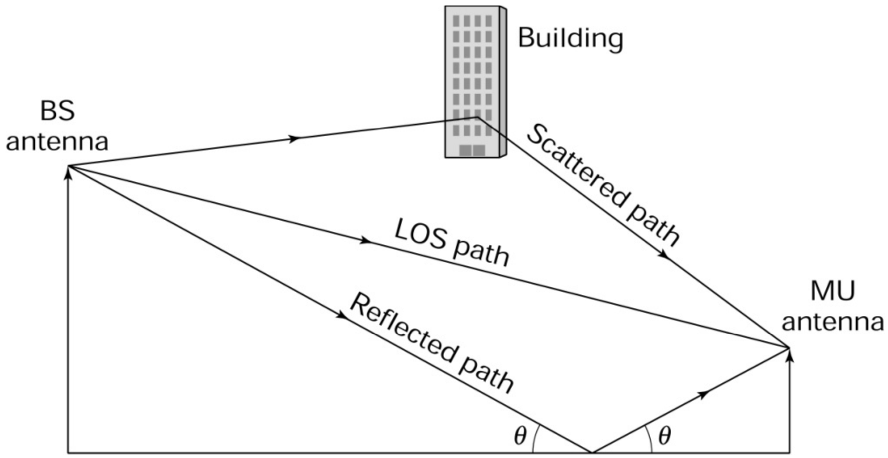
Three basic propagation mechanisms:

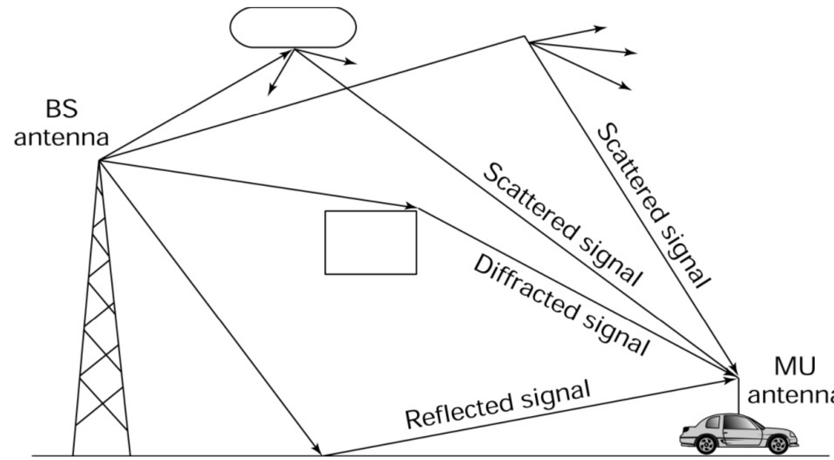
- **Reflection** (R) occurs when a propagation radio wave impinges upon an obstruction with dimensions very large compared to the wavelength of the radio wave.
- **Diffraction** (D) occurs when the radio path between the transmitter and receiver is obstructed by an impenetrable body. Based on Huggen's principle, secondary waves are formed behind the obstructing body even though there is no LOS between the transmitter and receiver.
- **Scattering** (S) occurs when the radio channel contains objects with dimensions that are on the order of the wavelength or less of the propagating wave.

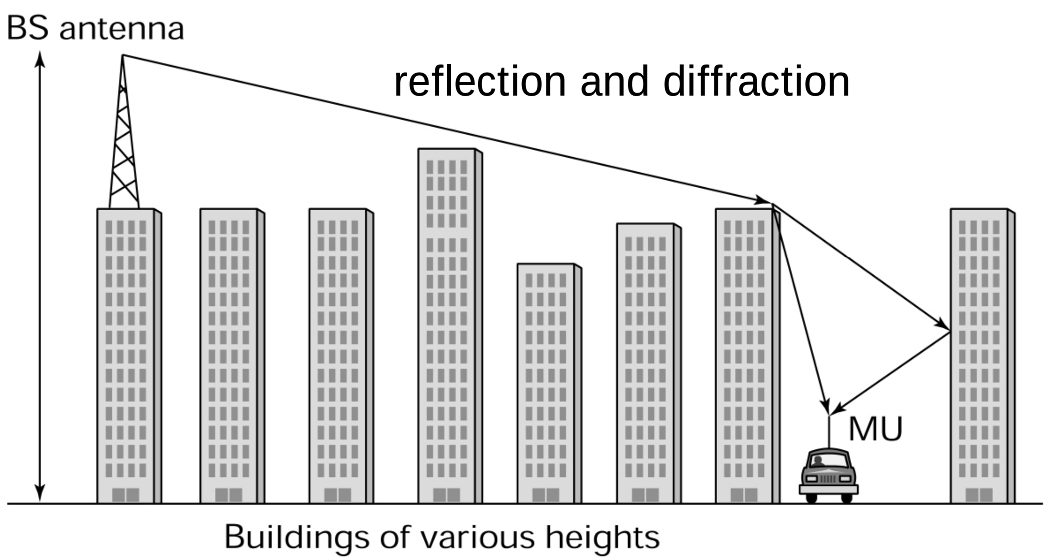


Scattering, which follows the same physical principles as diffraction, causes energy from a transmitter to be reradiated in many different directions. It is the most difficult mechanism to predict.

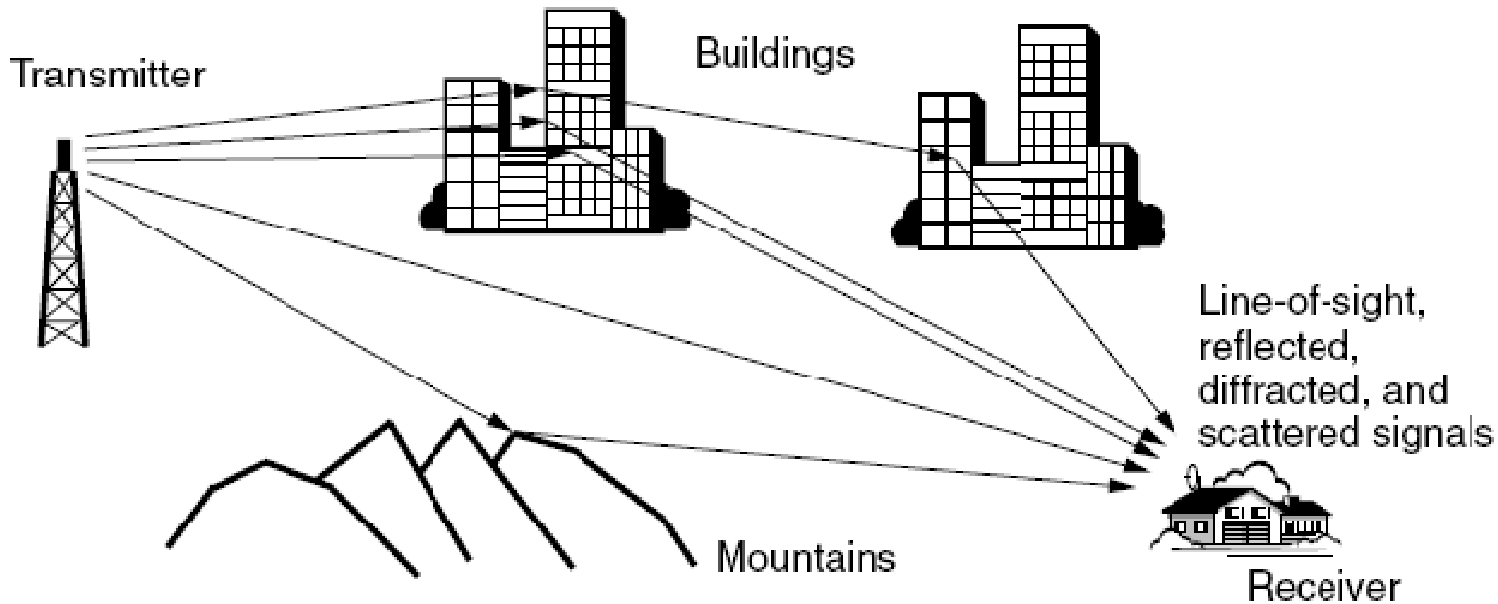
Multipath Propagation in Mobile Environment



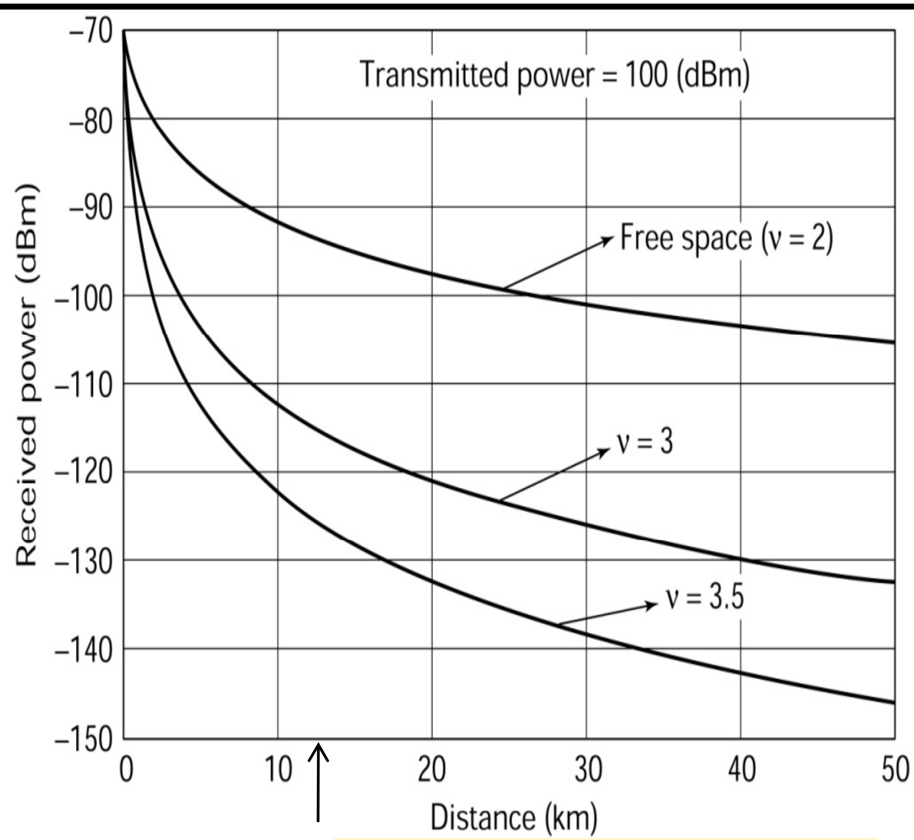




Multipath propagation environment.



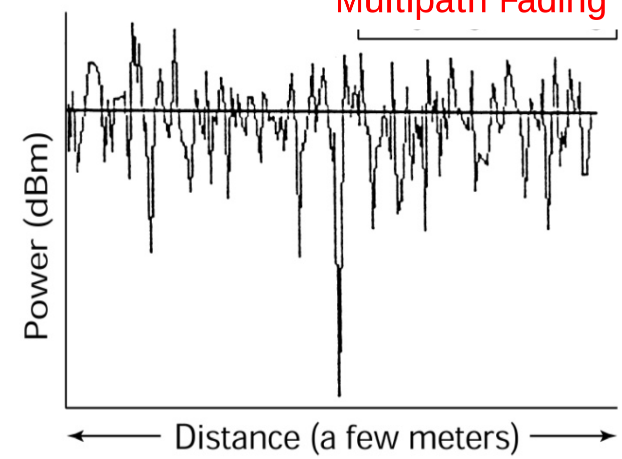
POWER LOSSES



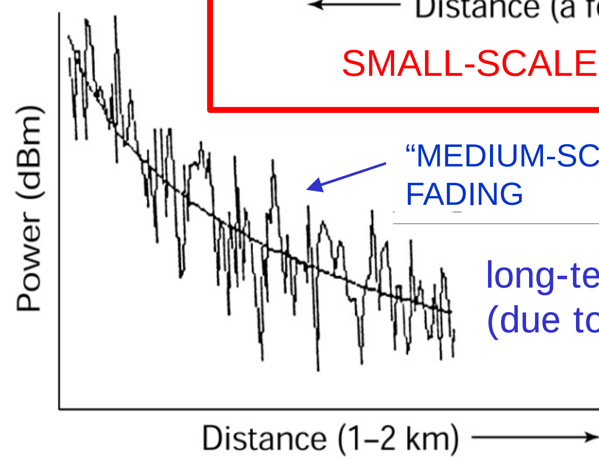
LARGE-SCALE FADING

VERY LONG-TERM PATH LOSS
(includes *average* shadowing)
in dB= $A+10\nu\log_{10}(\text{distance})$

short-term
Multipath Fading

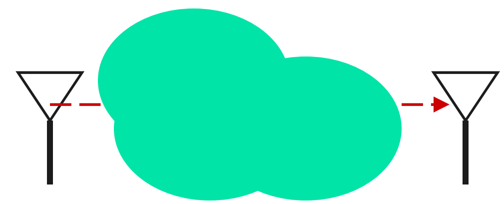


SMALL-SCALE FADING



"MEDIUM-SCALE"
FADING

long-term shadowing
(due to obstructions)



Shadowing

- attenuation from obstructions: random due to the number and types of obstructions are random, e.g., mobile/terminal travels into a propagation shadow behind a building or a hill or other obstacle much larger than the wavelength of the transmitted signal, and the associated received signal level is attenuated significantly.
- typically follows a log-normal distribution, i.e., power in dB value is Gaussian

$$\varepsilon_{dB} \sim N(0, \sigma_\varepsilon^2) \qquad f_{\epsilon(\mathrm{dB})}(x) = \frac{1}{\sqrt{2\pi}\sigma_\epsilon}\exp(-\frac{x^2}{2\sigma_\epsilon^2}).$$

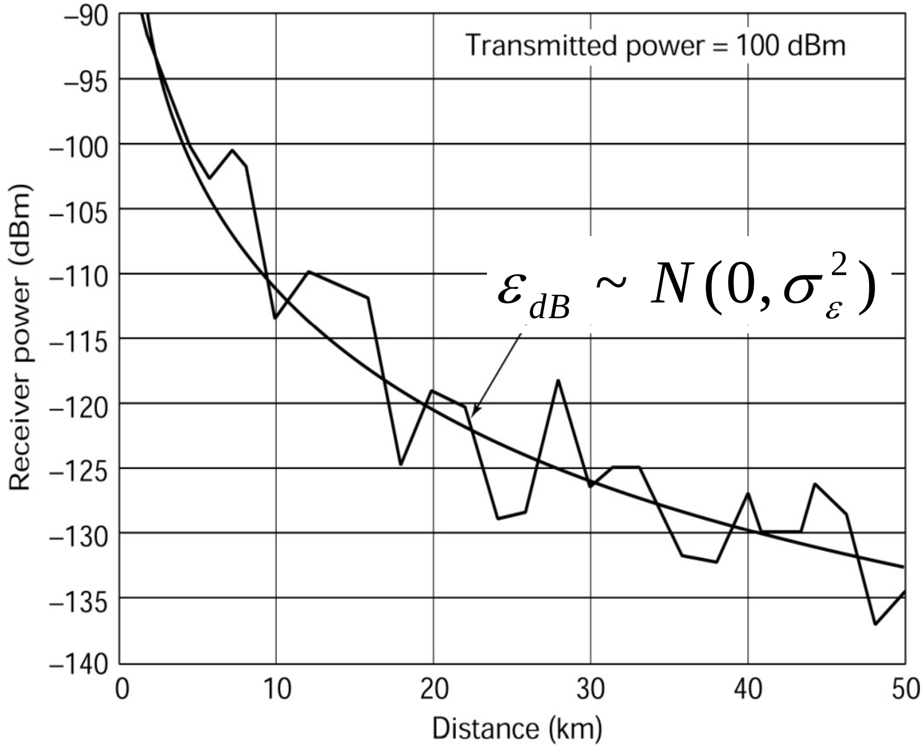
  - zero mean since actual mean was included in the path loss),
  - $4<\sigma_\varepsilon<12$ (empirical)
- decorrelated over some distance called *decorrelation distance*

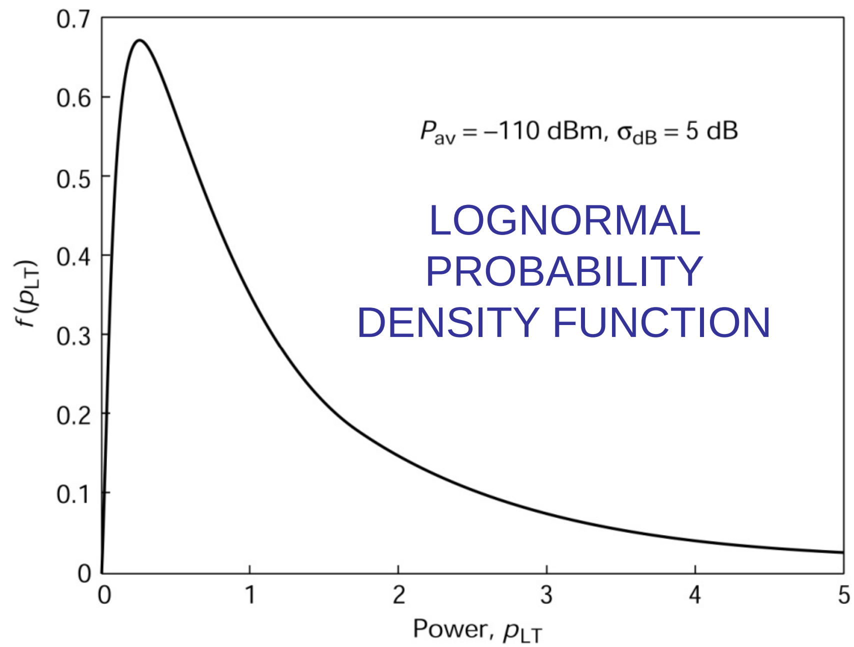
• $\epsilon_{(\mathrm{dB})}$ follows the Gaussian (normal) distribution $\Longrightarrow$ ϵ in linear scale is said to follow a log-normal distribution with pdf given by

$$f_\epsilon(y) = \frac{20/\ln 10}{\sqrt{2\pi}y\sigma_\epsilon}\exp[-\frac{(20\log_{10} y)^2}{2\sigma_\epsilon^2}].$$

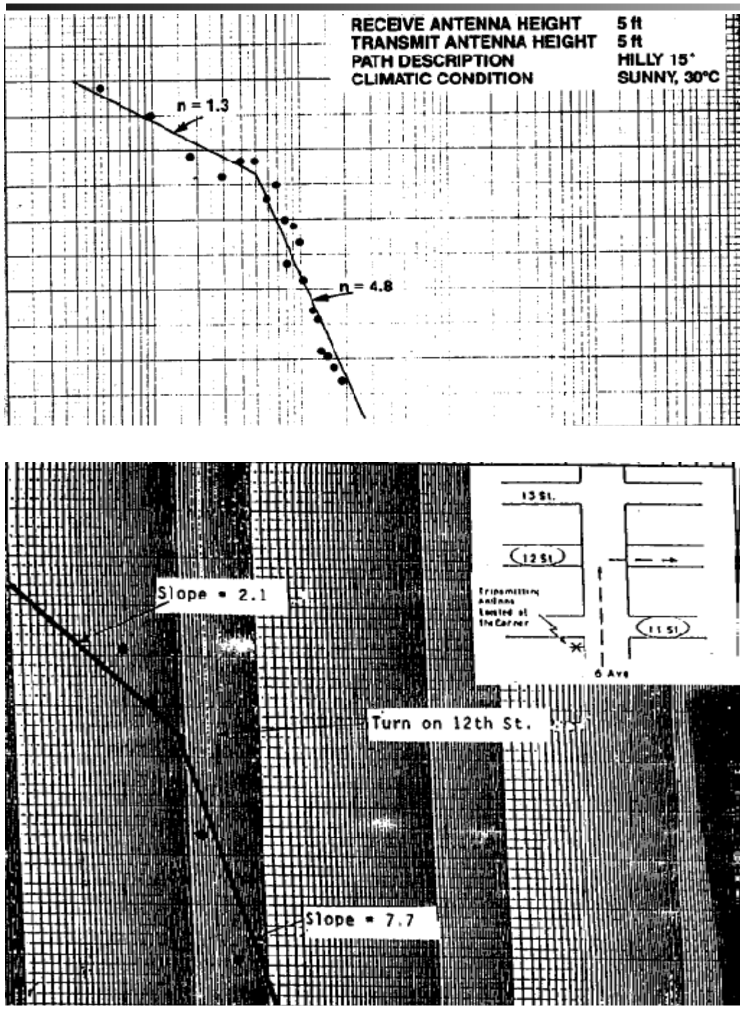
• σ_ϵ: 8 dB for an outdoor cellular system and 5 dB for an indoor environment.

Received power under path-loss & shadowing





Path-Loss Modeling Techniques



Examples of measured Path-Loss

- **Free-space 2-path loss model:** (too simple) Ground reflection approximately cancels LOS path above a critical distance. Hence, loss Proportional to d^2 (small d) or d^4 ($d>d_c$), Independent of l (f)
- **Maxwell's equations** (impractically complex)
- **Ray-tracing models:** (similar but simpler to Maxwell)
- requires site-specific information (e.g., detailed geometry and dielectric properties) to model all signal components (Reflections, Scattering, Diffraction)
- **Empirical Models:** (good for high-level analysis) environment-specific, with simplified power falloff models. $P_r=P_tK[d_0/d]^{\gamma}$, $2\le\gamma\le8$.
  - Captures main characteristics of path loss
  - Used when path loss dominated by reflections.
  - Most important parameter is the path loss exponent γ, determined empirically.

Large-scale Path Loss and Shadowing Models

- Recall: fixed LOS free-space loss: $L_{FS,\ dB} = 92.44 + 20\log_{10}(f_{GHz}) + 20\log_{10}(d_{km})$
- general Path Loss and Shadowing:
  $L_p(d,f) = L_o + 10\kappa\log_{10}(d/d_o) + 10n\log_{10}(f/f_o) + \varepsilon_{dB}$ $\qquad \varepsilon_{dB} \sim N(0, \sigma_\varepsilon^2)$
- L_o obtained from measurements at d_0 (=1km, macrocell, 100m, microcell outdoor, 10mpicocell indoor)
- κ: path-loss exponent usually=$2 \le \kappa \le 8$, n: frequency-loss exponent, are MMSE estimates based on data
- Shadowing variance is estimated variance of measured data relative to straight-line path-loss

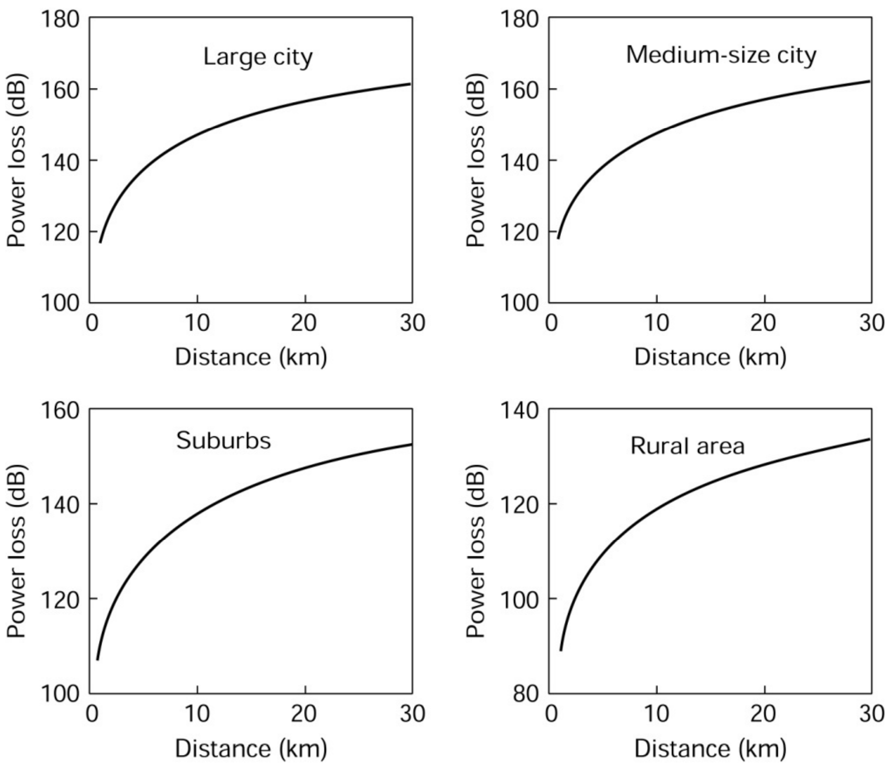
Environment	Path Loss Exponent, κ
free space	2
urban cellular radio	2.7 to 3.5
shadowed urban cellular radio	3 to 5
in building with line of sight	1.6 to 1.8
obstructed in building	4 to 6

Examples of other Models:

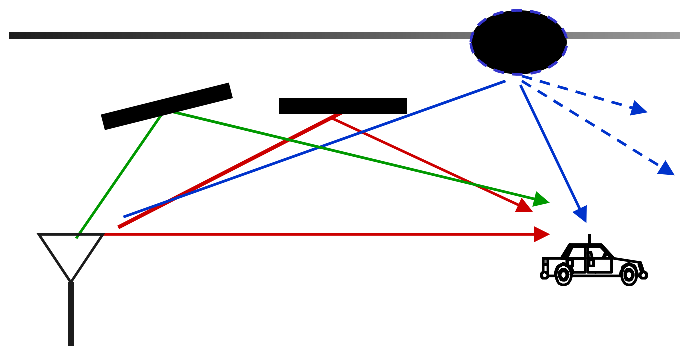
Empirical Models:

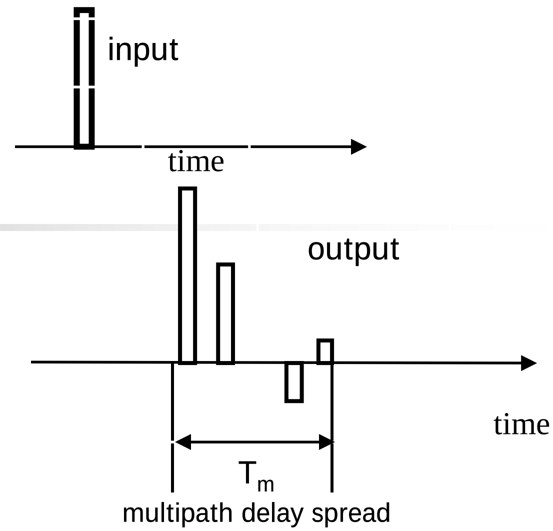
- Okumura model
  - Empirically based (site/freq specific)
  - Awkward (uses graphs)
- Hata model
  - Analytical approximation to Okumura model
- Cost 136 Model:
  - Extends Hata model to higher frequency (2 GHz)
- Walfish/Bertoni:
  - Cost 136 extension to include diffraction from rooftops
- Okumura-Hara, Lee

Examples of Path Loss based on the Hata model with f = 900 MHz, antenna height: BS: 150 m, MS:1.5m.

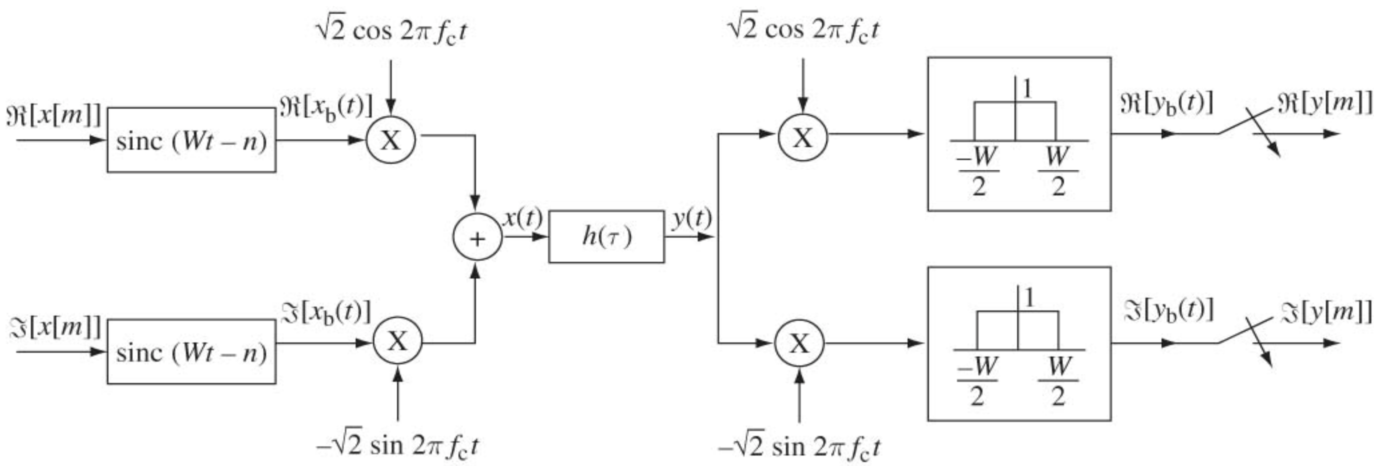


Multipath Modeling





- Channel consists of a random number of path components, each with random amplitude, phase, Doppler shift, delay, changing with time. Multipath fading due to constructive and destructive interference of the transmitted waves.
- W: signal bandwidth, sampling rate: 1/W
- Transmission at passband [f_c-W/2, f_c+W/2] and processing at baseband [-W/2,+W/2].



REFERENCES

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- J. Mark, W. Zhuang, Wireless Communications and Networking, Prentice-Hall, 2003
- P.M. Shankar, Introduction to Wireless Systems, John Wiley & Sons, 2002
- and materials from various sources