Mobile Radio Systems: The Mobile Radio Channel

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Chapter Outline

- Physical mechanisms
- Elements of propagation models
  - Large scale modeling (for coverage area)
    - Path loss
    - Shadowing
  - Small scale modeling - fading
    (for local area of several wavelengths)

Propagation effects – model components (1)

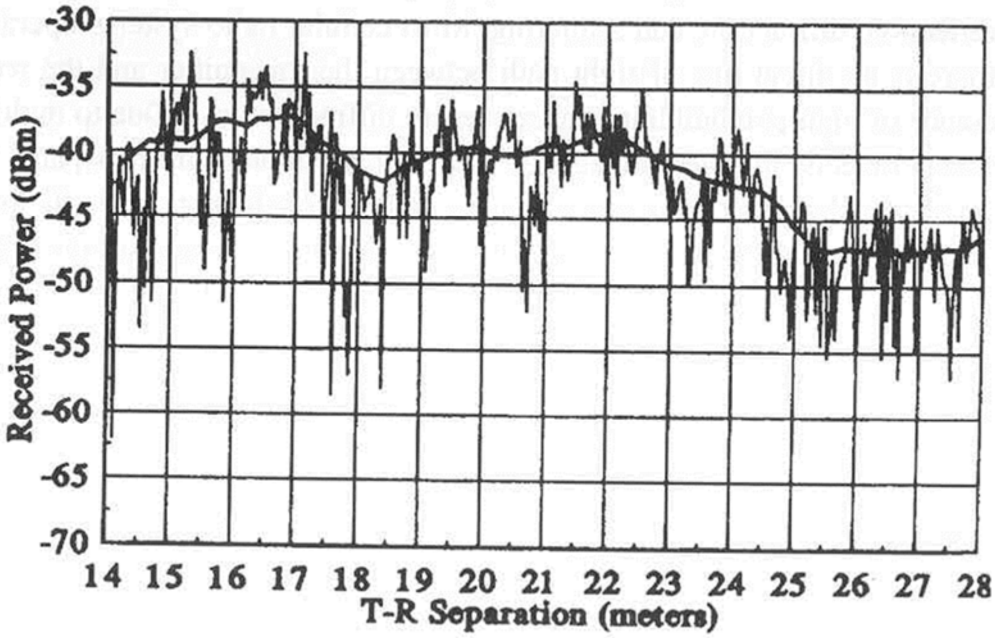
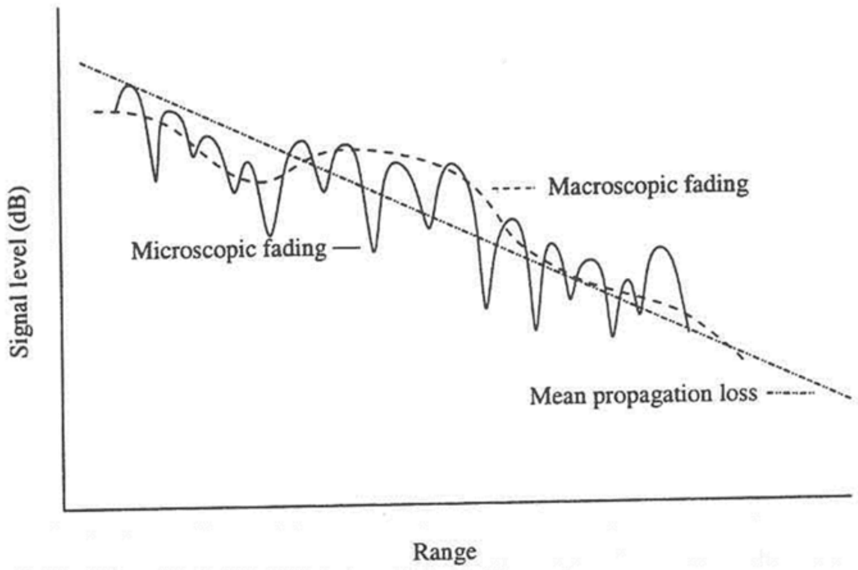


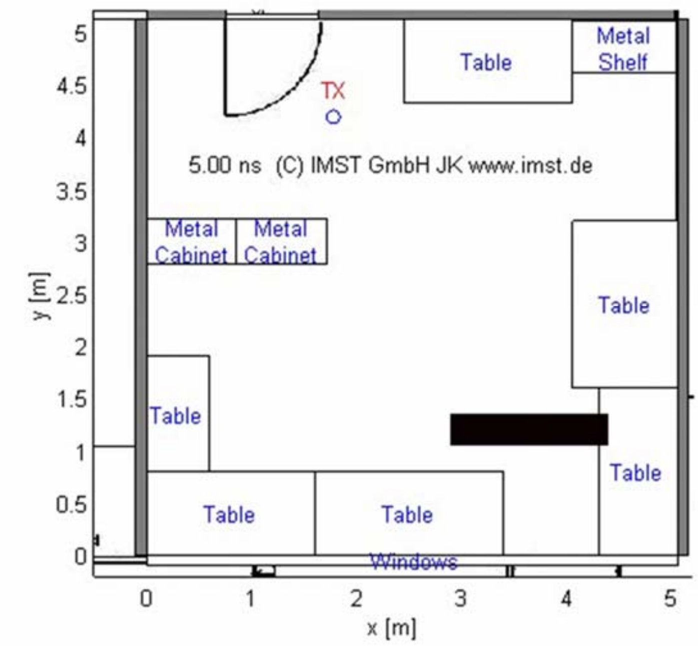
Figure 4.1 Small-scale and large-scale fading.

Propagation effects – model components (2)

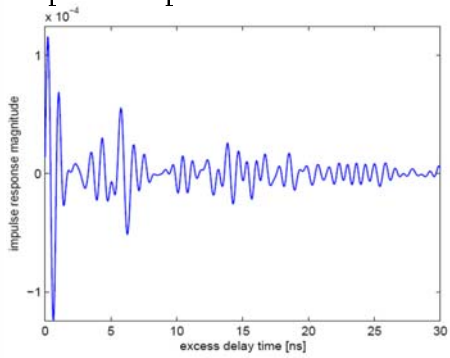


Wireless Channel

- Experiment: Transmit an ultra-short pulse
  - Line-of-sight link



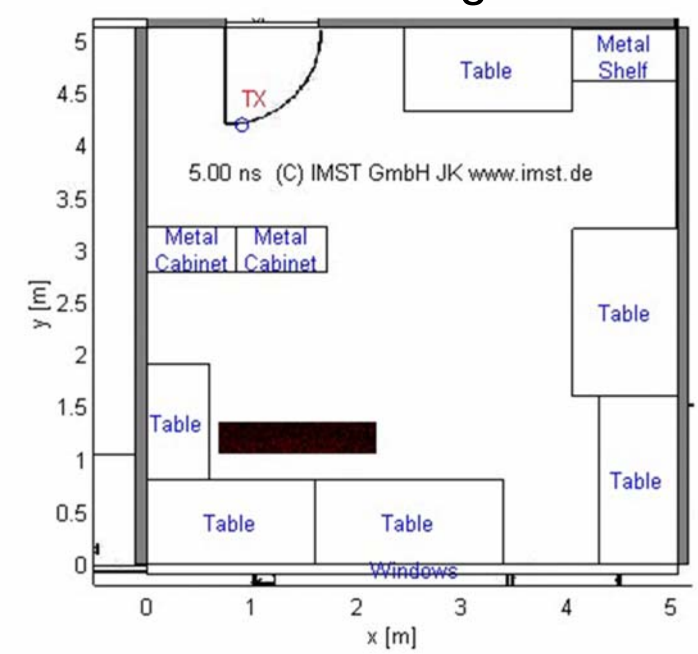
Impulse response:



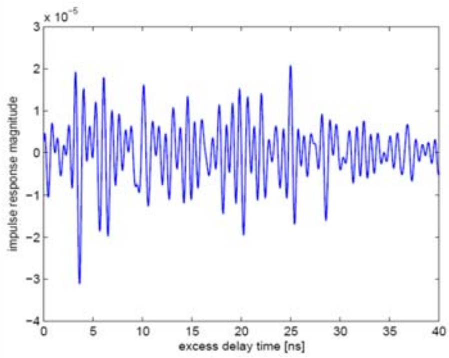
(Thanks to Jürgen Kunisch, IMST)

Wireless Channel

- Experiment: Transmit an ultra-short pulse
  - Non-line-of-sight link



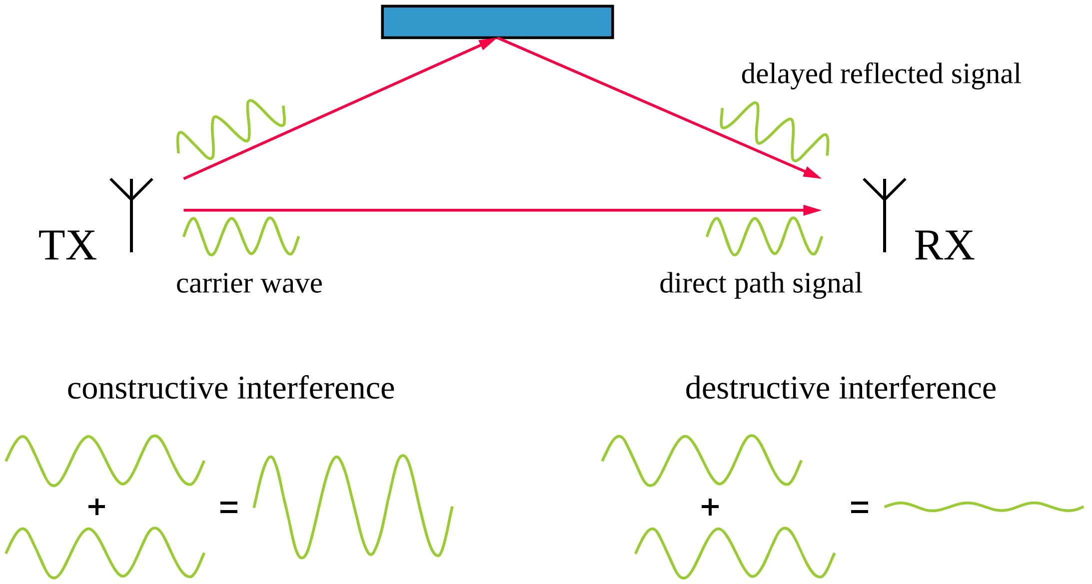
Impulse response:



(Thanks to Jürgen Kunisch, IMST)

Channel Effect on a Signal

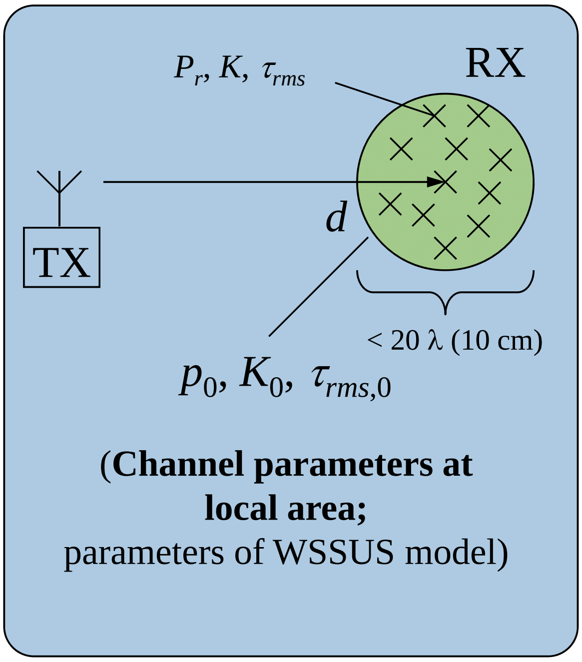
- Conventional **narrowband** transmission



Channel Model Components

Layer 3 - Small-scale fading

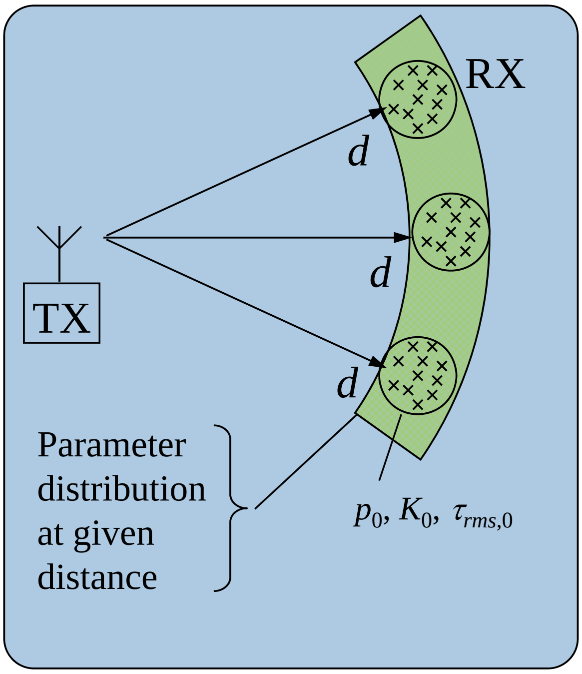
- Multipath interference
  - rapid variations of signal strength (Rayleigh, Rice)
  - Time dispersion (frequency selectivity)
- WSSUS channel model
  (2nd order statistics)



Channel Model Components

Layer 2 - Large-scale fading (shadowing)

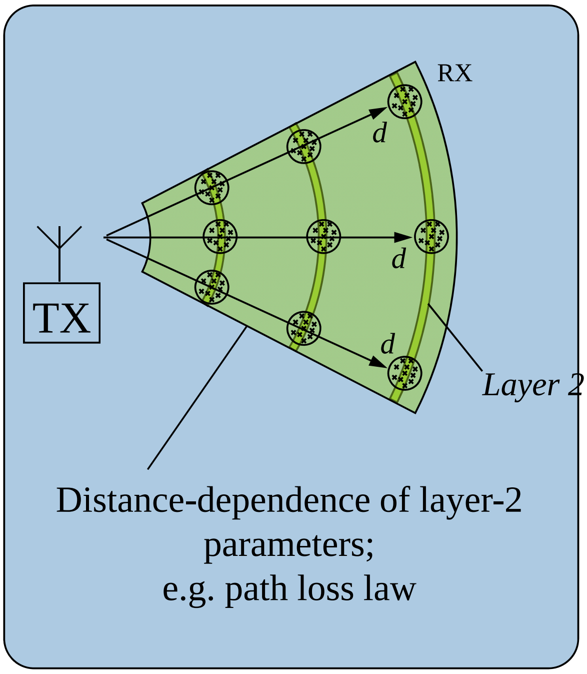
- Variability of p_0, K_0, $\tau_{rms,0}$
- Modeling by random distributions



Channel Model Components

Layer 1 – Large-scale model (distance dependence)

- E.g. path loss law



Course material

- A. F. Molisch: *Wireless Communications*, Wiley, 2005
- T. S. Rappaport: *Wireless Communications – Principles and Practice*, 2nd ed., 2002, Prentice Hall
- J. D. Parsons: *The Mobile Radio Propagation Channel*, 2nd ed., 2000, Wiley
- A. Paulraj, R. Nabar, and D. Gore: *Introduction to Space-Time Wireless Communications*, 2003, Cambridge

- Figures and material from these sources

Physical mechanisms

- Reflection
  - Objects much larger than wavelength (walls, buildings, earth surface, etc.)
- Diffraction
  - Bending of waves around obstacles (sharp edges!)
- Scattering
  - Objects much smaller than wavelength; rough surfaces

Large Scale Models

- Distance dependence
- **Free space** model – Friis equation
  - Received power at distance *d*:

$$P_r(d) = \frac{P_t G_t G_r \lambda^2}{(4\pi)^2 d^2 L} = P_r(d_0) \left(\frac{d_0}{d}\right)^2$$

  - Path loss exponent is 2
  - Valid in the **far field** of the antenna:

$$d_f \gg \lambda \quad \text{and} \quad d_f \gg D$$

Free-space model (2)

- In dB:

$$P_r(d)\ [dB] = 10 \log P_r(d_0) + 20 \log \left(\frac{d_0}{d}\right)$$

  - Linear on log-log scale (power vs. distance)
- Path-loss:

$$PL(d)\ [dB] = 10 \log \frac{P_t}{P_r} = PL(d_0) + 20 \log \left(\frac{d}{d_0}\right)$$

$$P_r(d)\ [dBm] = P_t\ [dBm] - PL(d)\ [dB]$$

Log-distance path loss model

- Empirical models:
  - Curve (parameters) fitted to measurements
- Individual measurements deviate
- Defines **mean** path loss vs. distance

$$\overline{PL}(d) \propto \left(\frac{d}{d_0}\right)^n$$

$$\overline{PL}(d)\ [dB] = \overline{PL}(d_0) + 10n \log\left(\frac{d}{d_0}\right)$$

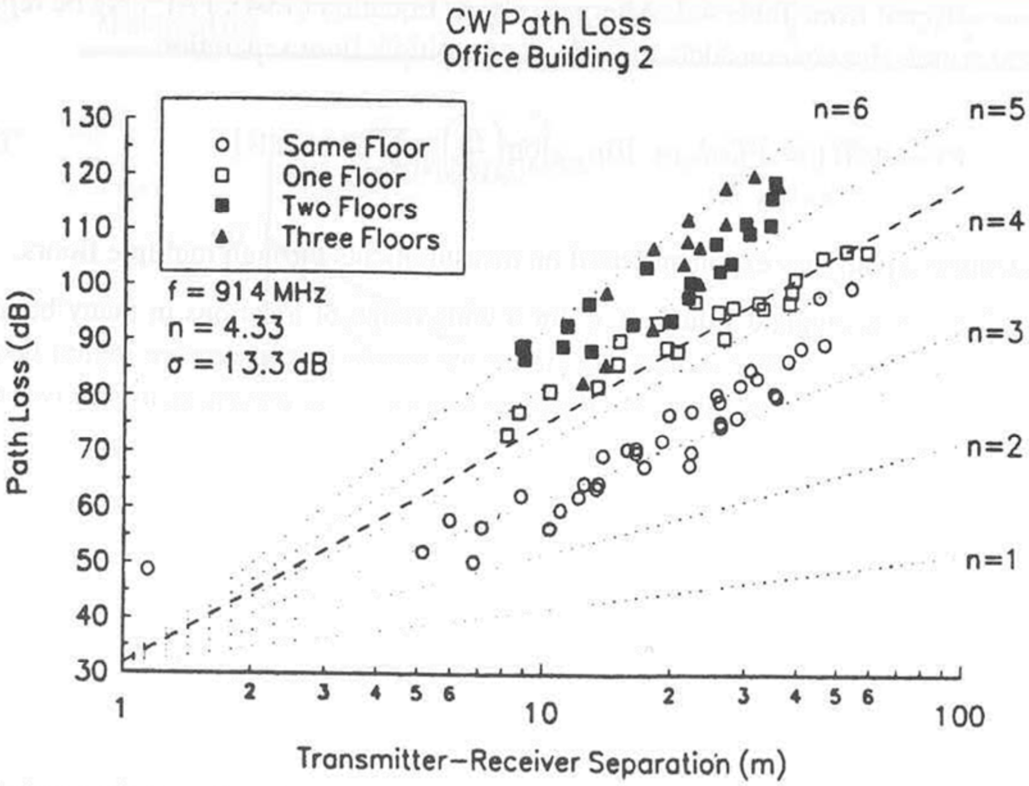


Figure 4.29 Scatter plot of path loss as a function of distance in Office Building 2 [from [Sei92b] © IEEE].

Path loss exponents

Table 4.2 Path Loss Exponents for Different Environments

Environment	Path Loss Exponent, *n*
Free space	2
Urban area cellular radio	2.7 to 3.5
Shadowed urban cellular radio	3 to 5
In building line-of-sight	1.6 to 1.8
Obstructed in building	4 to 6
Obstructed in factories	2 to 3

Log-normal shadowing

- Defines variations around mean

$$PL\,[dB] = \overline{PL}(d) + X_\sigma = \overline{PL}(d_0) + 10n\log\left(\frac{d}{d_0}\right) + X_\sigma$$

- X_σ [dB] is zero-mean Gaussian
  - with standard deviation σ [dB]
- PDF:

$$f_{X_\sigma}(x) = \frac{1}{\sqrt{2\pi}\sigma}\exp\left(-\frac{x^2}{2\sigma^2}\right)$$

Application of this equation

- Compute probability that PL < threshold

$$P(P_r(d) > \gamma) = Q\left(\frac{\gamma - \overline{P_r}(d)}{\sigma}\right)$$

  - can be used to compute % coverage in cell area with signal > γ (see figure 4.18)
  - (all parameters in [dB])

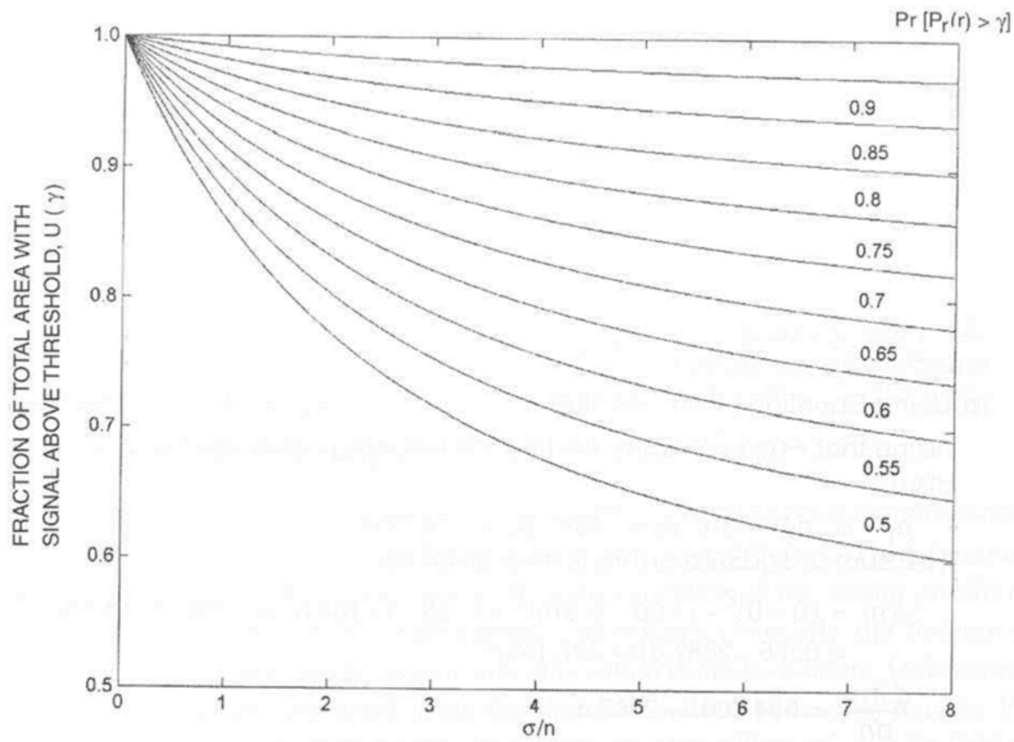


Figure 4.18 Family of curves relating fraction of total area with signal above threshold, $U(\gamma)$ as a function of probability of signal above threshold on the cell boundary.

Example 4.9

Four received power measurements were taken at distances of 100 m, 200 m, 1 km, and 3 km from a transmitter. These measured values are given in the following table. It is assumed that the path loss for these measurements follows the model in Equation (4.69.a), where d_0 = 100 m: (a) find the minimum mean square error (MMSE) estimate for the path loss exponent, n; (b) calculate the standard deviation about the mean value; (c) estimate the received power at d = 2 km using the resulting model; (d) predict the likelihood that the received signal level at 2 km will be greater than -60 dBm; and (e) predict the percentage of area within a 2 km radius cell that receives signals greater than –60 dBm, given the result in (d).

Distance from Transmitter	Received Power
100 m	0 dBm
200 m	–20 dBm
1000 m	–35 dBm
3000 m	–70 dBm

Outdoor propagation models

- Models for median path loss vs.:
  - distance; antenna heights; frequency
  - considering environment / terrain features
- Examples
  - Okomura
  - Hata
  - COST 231 (European Cooperative for Scientific and Technical research)

e.g. Hata Model

- for urban areas

$$L_{50}(urban)\ [dB] = 69.55 + 26.16 \log f_c - 13.82 \log h_{re} - a(h_{re}) + (44.9 - 6.55 \log h_{te}) \log d$$

  - $a(h_{re})$ … correction factor for effective mobile antenna height
  - e.g. for small to medium city:

$$a(h_{re})\ [dB] = (1.1 \log f_c - 0.7) h_{re} - (1.56 \log f_c - 0.8)$$

Indoor models

- essentially same:
  - Log-distance path loss model with
  - log-normal shadowing

$$PL\ [dB] = \overline{PL}(d) + X_\sigma = \overline{PL}(d_0) + 10 n \log\left(\frac{d}{d_0}\right) + X_\sigma$$

  - different parameters (see table 4.6)

Indoor model parameters

Table 4.6 Path Loss Exponent and Standard Deviation Measured in Different Buildings [And94]

Building	Frequency (MHz)	*n*	σ (dB)
Retail Stores	914	2.2	8.7
Grocery Store	914	1.8	5.2
Office, hard partition	1500	3.0	7.0
Office, soft partition	900	2.4	9.6
Office, soft partition	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 Street	900	3.0	7.0
Factory OBS			
Textile/Chemical	4000	2.1	9.7
Metalworking	1300	3.3	6.8

Fitting of model parameters

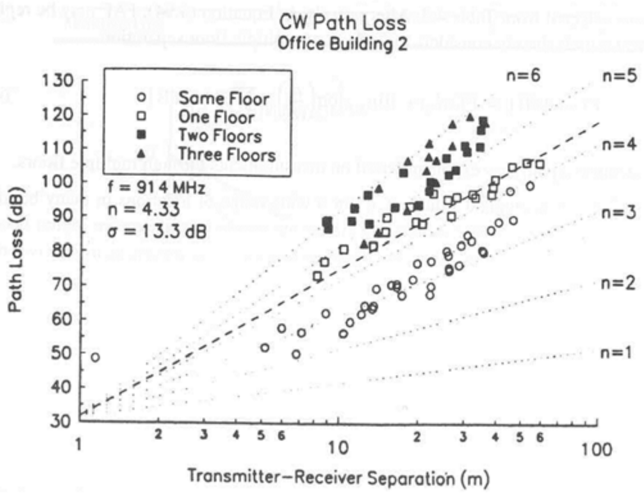


Table 4.7 Path Loss Exponent and Standard Deviation for Various Types of Buildings [Sei92b]

	n	σ (dB)	Number of locations
All Buildings:			
All locations	3.14	16.3	634
Same Floor	2.76	12.9	501
Through One Floor	4.19	5.1	73
Through Two Floors	5.04	6.5	30
Through Three Floors	5.22	6.7	30
Grocery Store	1.81	5.2	89
Retail Store	2.18	8.7	137
Office Building 1:			
Entire Building	3.54	12.8	320
Same Floor	3.27	11.2	238
West Wing 5th Floor	2.68	8.1	104
Central Wing 5th Floor	4.01	4.3	118
West Wing 4th Floor	3.18	4.4	120
Office Building 2:			
Entire Building	4.33	13.3	100
Same Floor	3.25	5.2	37

Small scale fading

- Interference of multipath components