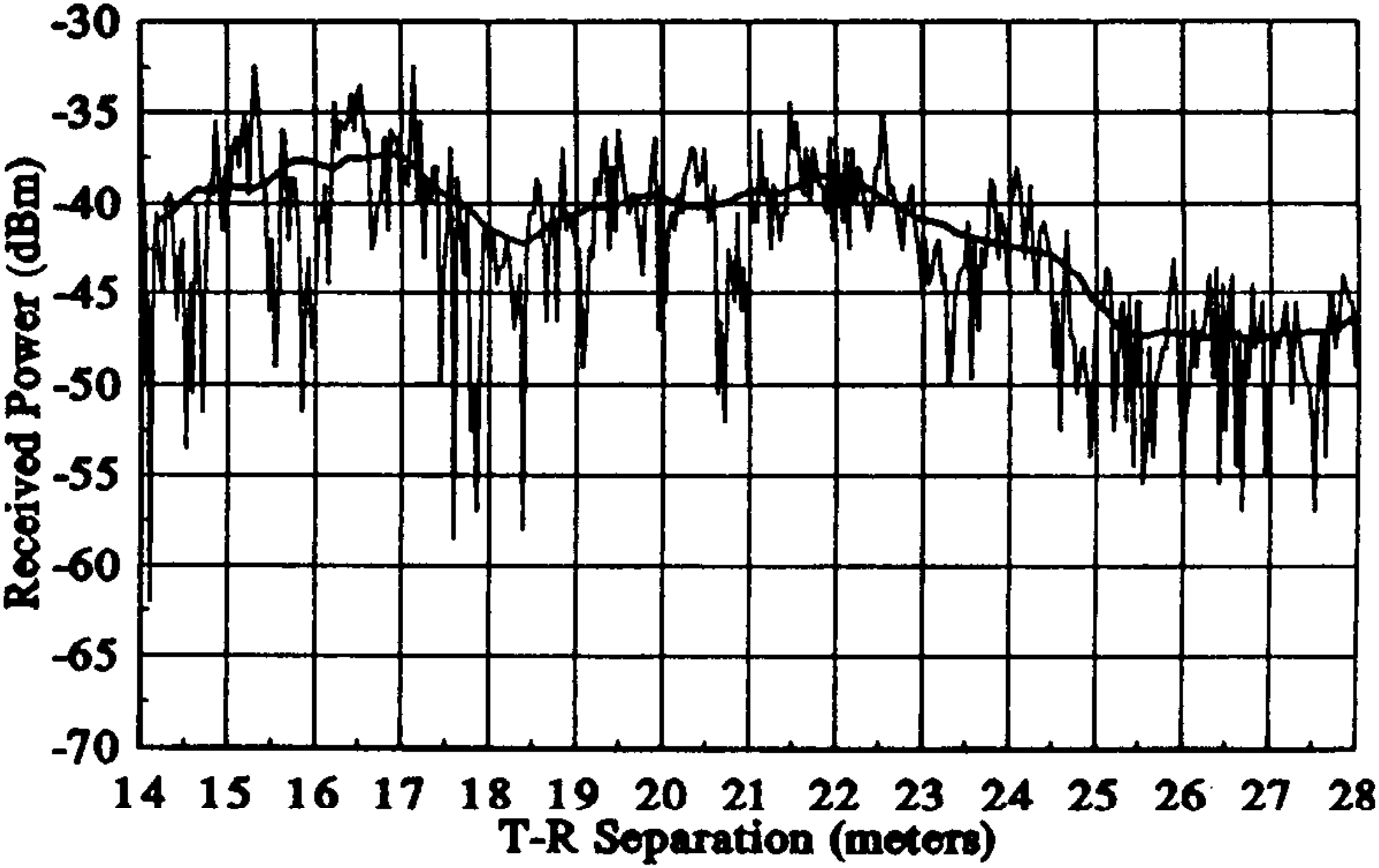
Unit 2

Mobile radio propagation

Department of Electronics and Communication Engineering

Large-scale small-scale propagation



Models are Specialized

- Refraction, diffraction and scattering
- Different scales
  - Large scale (averaged over meters)
  - Small scale (order of wavelength)
- Different environmental characteristics
  - Outdoor, indoor, land, sea, space, etc.
- Different application areas
  - macrocell (2km), microcell(500m), picocell
- Chapter 2
- Some figures in the slides from Rappaport book

Radio Propagation Mechanisms

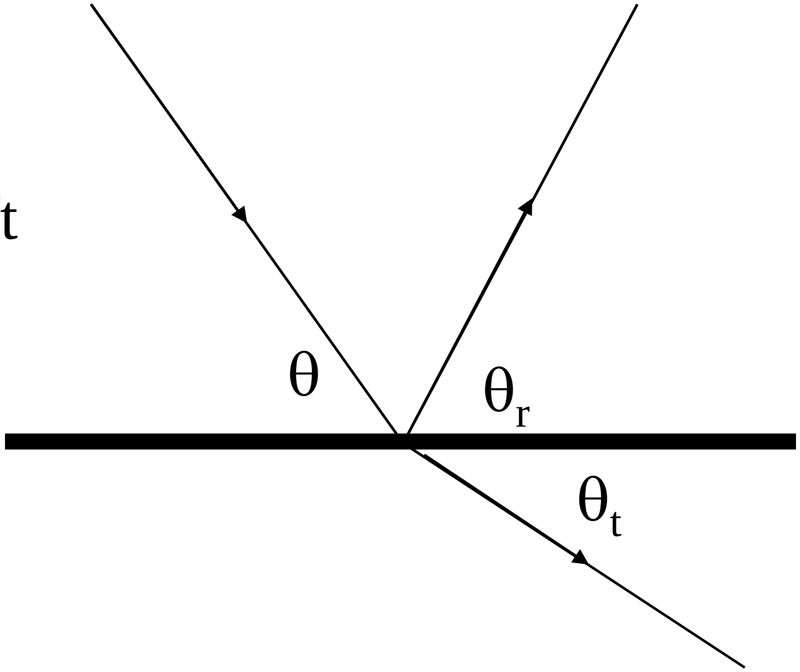
- Refraction
  - Conductors & Dielectric materials (refraction)
  - Propagation wave impinges on an object which is large as compared to wavelength

    - e.g., the surface of the Earth, buildings, walls, etc.
- Diffraction
  - Fresnel zones
  - Radio path between transmitter and receiver obstructed by surface with sharp irregular edges
  - Waves bend around the obstacle, even when LOS (line of sight) does not exist
- Scattering
  - Objects smaller than the wavelength of the propagation wave

    - e.g. foliage, street signs, lamp posts
  - "Clutter" is small relative to wavelength

Refraction

- Perfect conductors reflect with no attenuation
  - Like light to the mirror
- Dielectrics reflect a fraction of incident energy
  - "Grazing angles" reflect max*
  - Steep angles transmit max*
  - Like light to the water
- Reflection induces 180° phase shift
  - Why? See yourself in the mirror



Classical 2-ray ground bounce model

- One line of sight and one ground bound

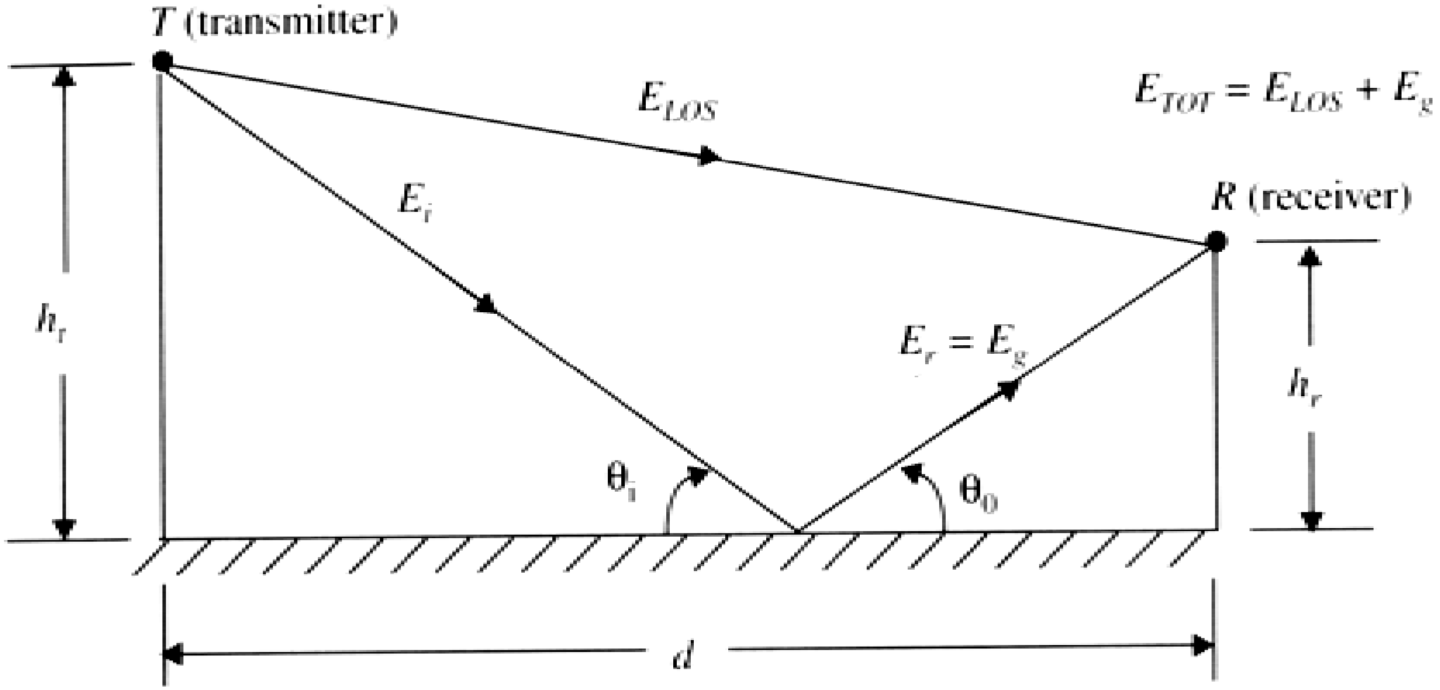


Figure 4.7 Two-ray ground reflection model.

Method of image

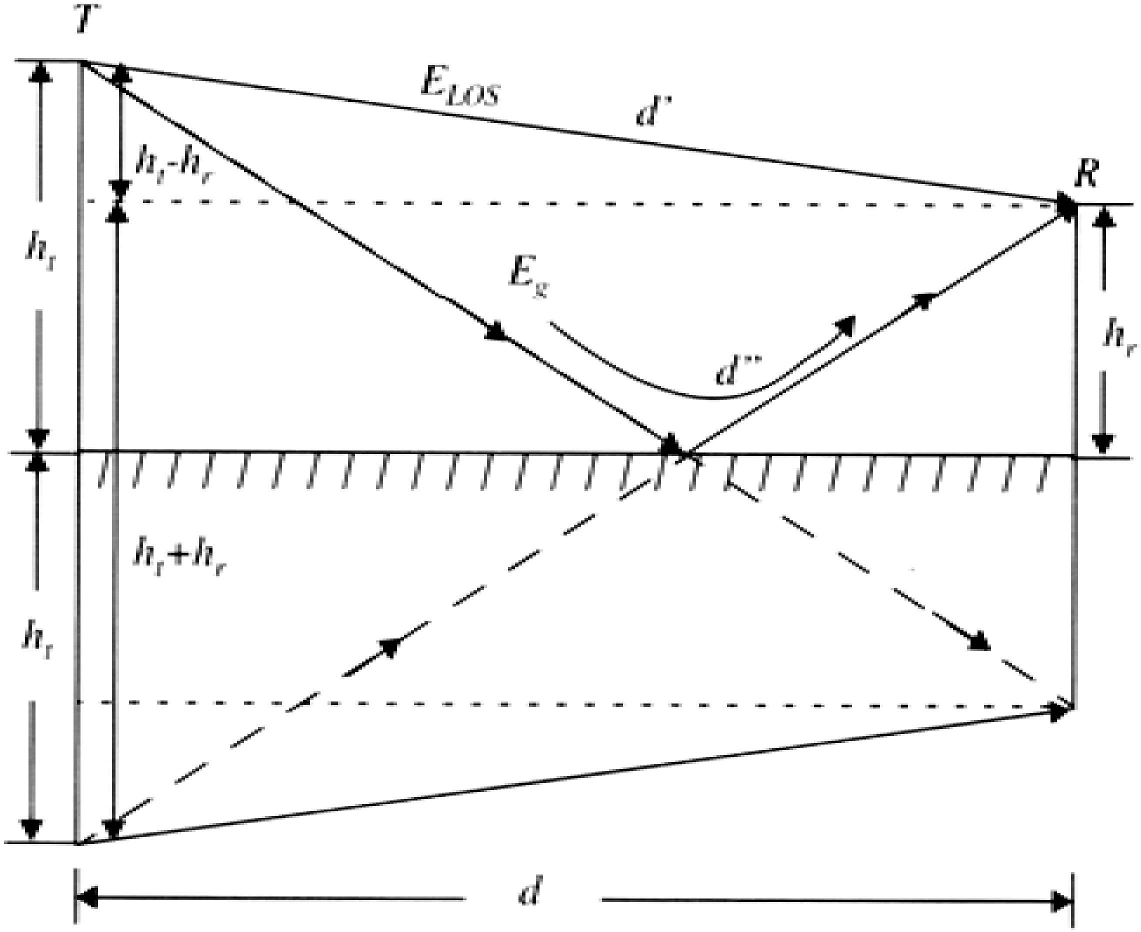


Figure 4.8 The method of images is used to find the path difference between the line-of-sight and the ground reflected paths.

Vector addition of 2 rays

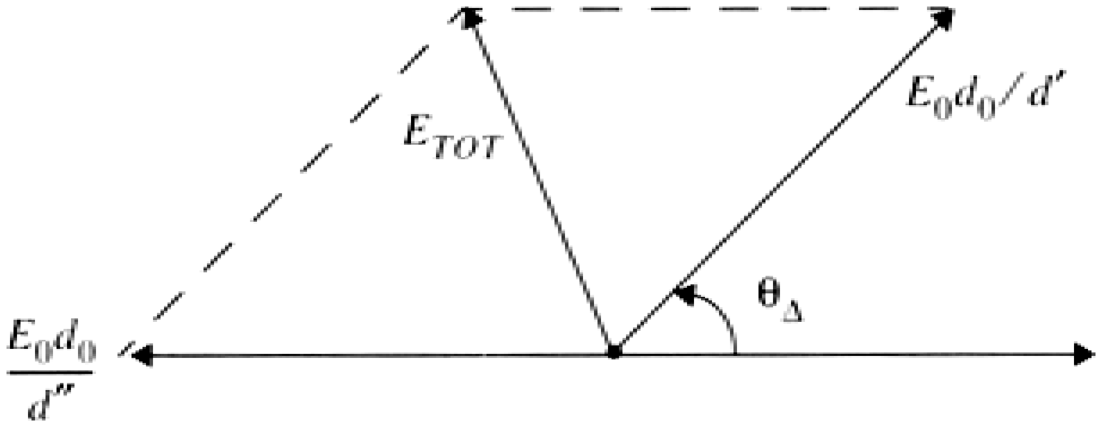
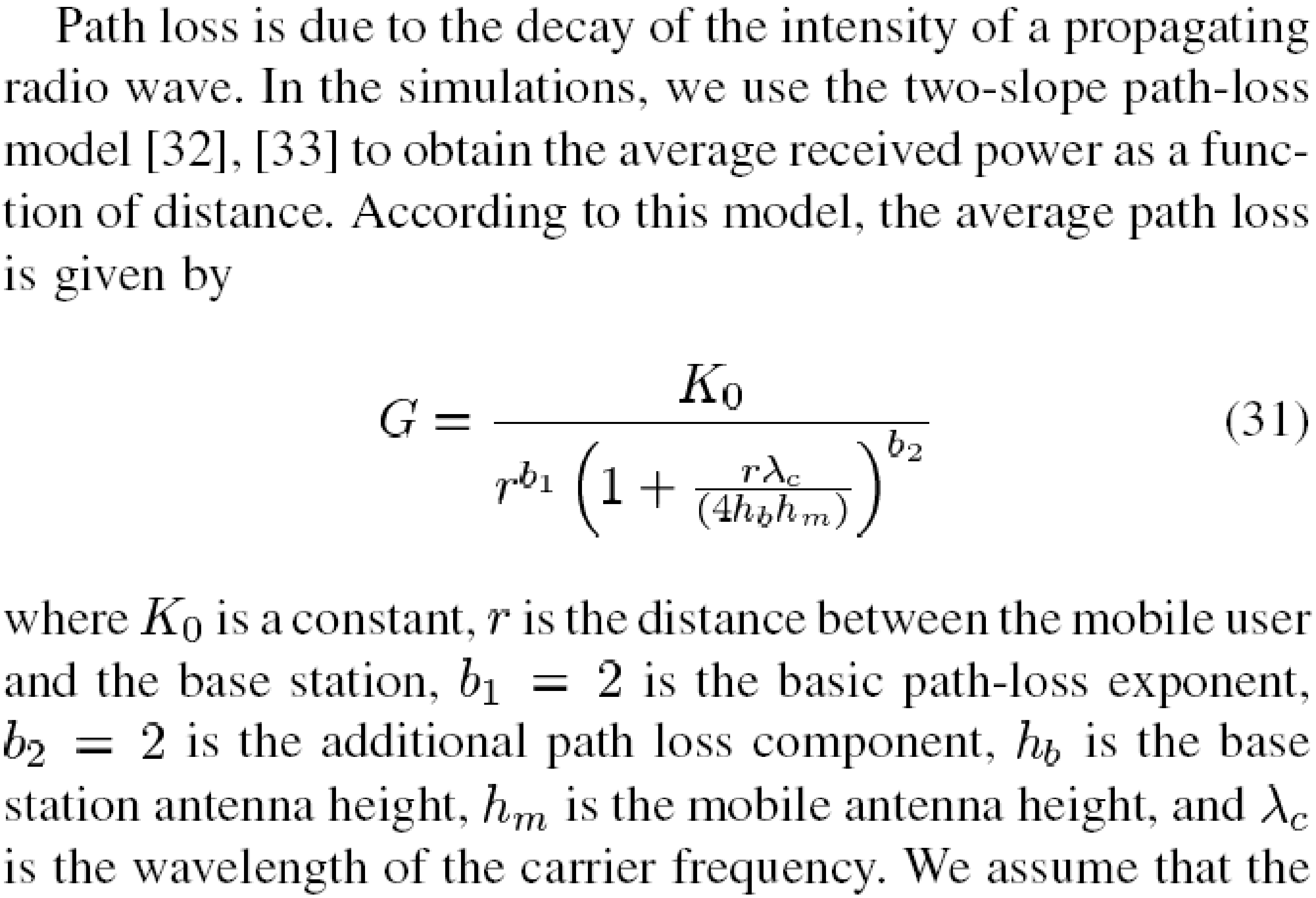


Figure 4.9 Phasor diagram showing the electric field components of the line-of-sight, ground reflected, and total received E-fields, derived from Equation (4.45).

Simplified model

- Far field simplified model
- Example 2.2

$$P_r = P_t G_t G_r \frac{h_t^2 h_r^2}{d^4}$$



Path loss is due to the decay of the intensity of a propagating radio wave. In the simulations, we use the two-slope path-loss model [32], [33] to obtain the average received power as a function of distance. According to this model, the average path loss is given by

$$G = \frac{K_0}{r^{b_1}\left(1 + \frac{r\lambda_c}{(4h_b h_m)}\right)^{b_2}} \qquad (31)$$

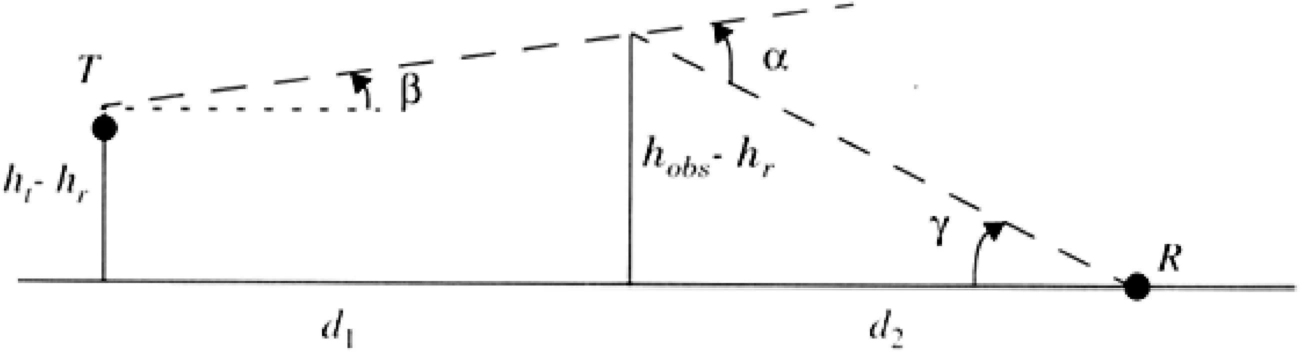
where K_0 is a constant, r is the distance between the mobile user and the base station, $b_1 = 2$ is the basic path-loss exponent, $b_2 = 2$ is the additional path loss component, h_b is the base station antenna height, h_m is the mobile antenna height, and λ_c is the wavelength of the carrier frequency. We assume that the

Diffraction

- Diffraction occurs when waves hit the edge of an obstacle
  - "Secondary" waves propagated into the shadowed region
  - Water wave example
  - Diffraction is caused by the propagation of secondary wavelets into a shadowed region.
  - Excess path length results in a phase shift
  - The field strength of a diffracted wave in the shadowed region is the vector sum of the electric field components of all the secondary wavelets in the space around the obstacle.
  - Huygen's principle: all points on a wavefront can be considered as point sources for the production of secondary wavelets, and that these wavelets combine to produce a new wavefront in the direction of propagation.

Diffraction geometry

- Fresnel-Kirchoff distraction parameters,



(c) Equivalent knife-edge geometry where the smallest height (in this case h_r) is subtracted from all other heights.

Fresnel Screens

- Fresnel zones relate phase shifts to the positions of obstacles
- A rule of thumb used for line-of-sight microwave links 55% of the first Fresnel zone is kept clear.

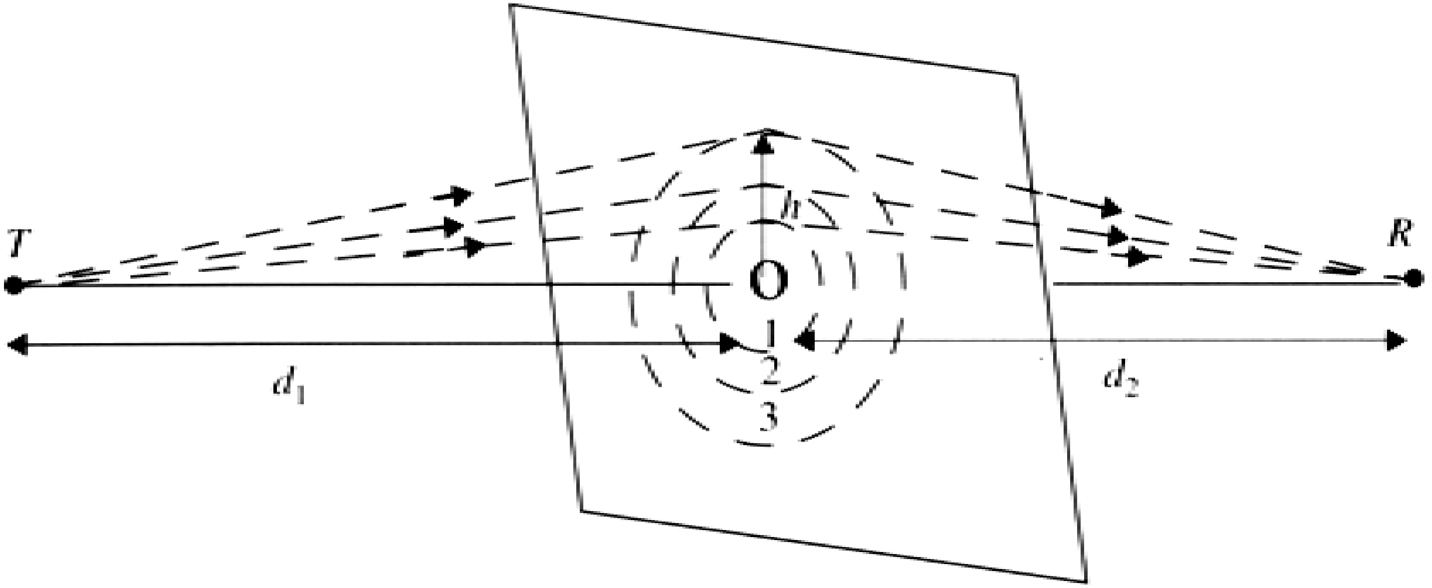
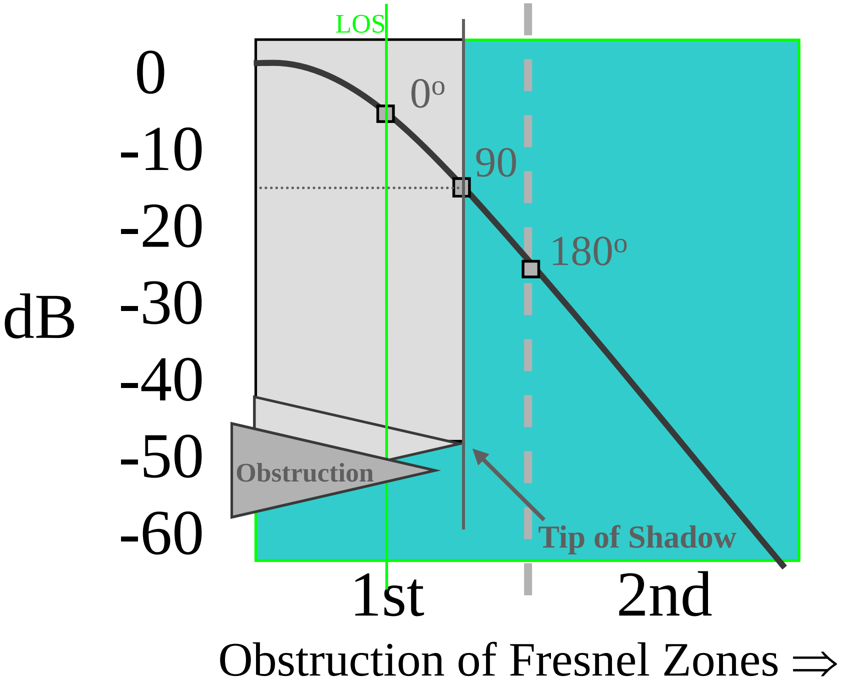


Figure 4.11 Concentric circles which define the boundaries of successive Fresnel zones.

Fresnel Zones

- Bounded by elliptical loci of constant delay
- Alternate zones differ in phase by 180°
  - Line of sight (LOS) corresponds to 1st zone
  - If LOS is partially blocked, 2nd zone can destructively interfere (diffraction loss)
- How much power is propagated this way?
  - 1st FZ: 5 to 25 dB below free space prop.



Knife-edge diffraction loss

- Gain

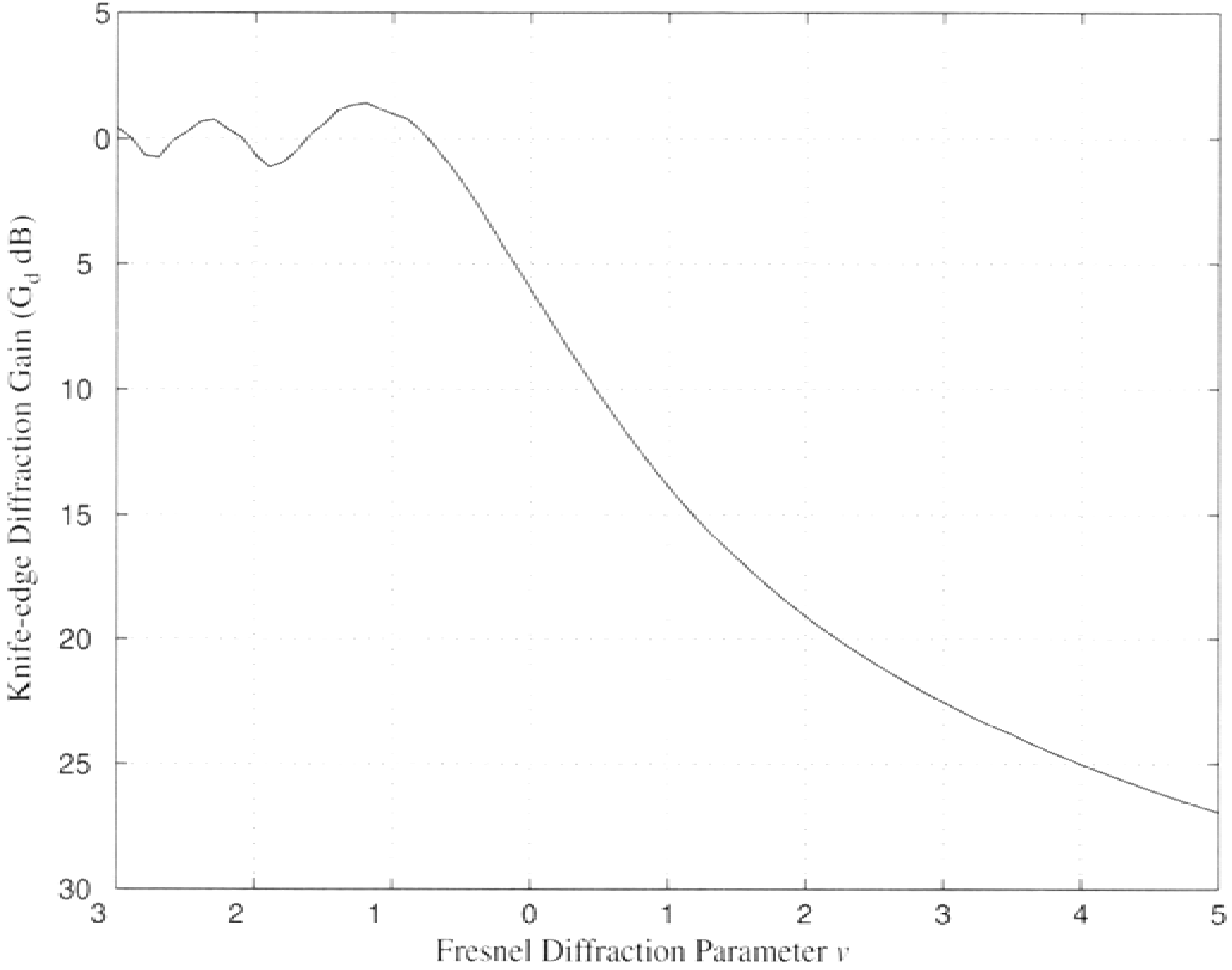


Figure 4.14 Knife-edge diffraction gain as a function of Fresnel diffraction parameter v.

Scattering

- Rough surfaces
  - Lamp posts and trees, scatter all directions
  - Critical height for bumps is f(λ,incident angle),
  - Smooth if its minimum to maximum protuberance h is less than critical height.
  - Scattering loss factor modeled with Gaussian distribution,
- Nearby metal objects (street signs, etc.)
  - Usually modeled statistically
- Large distant objects
  - Analytical model: Radar Cross Section (RCS)
  - Bistatic radar equation,

Impulse Response Model of a Time Variant Multipath Channel

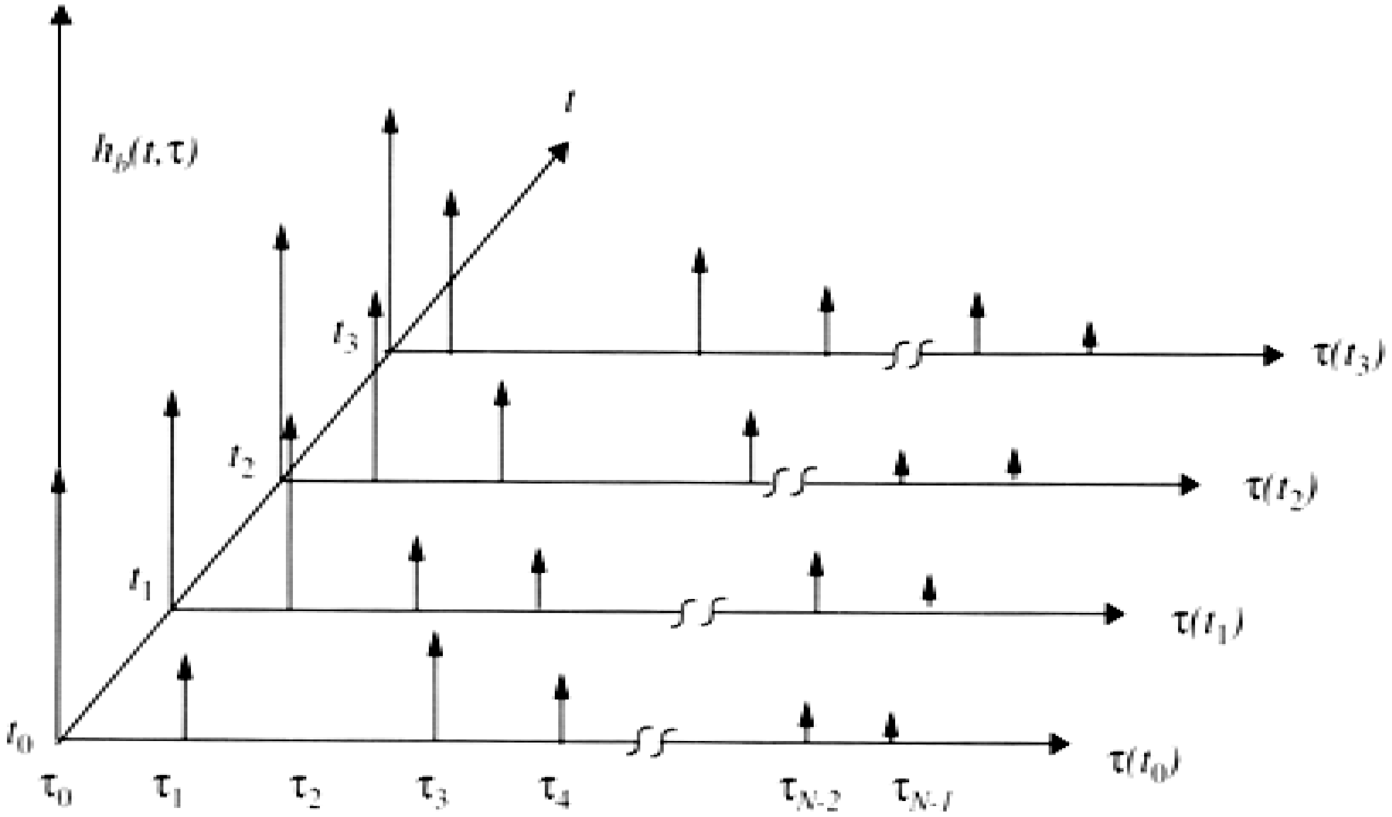


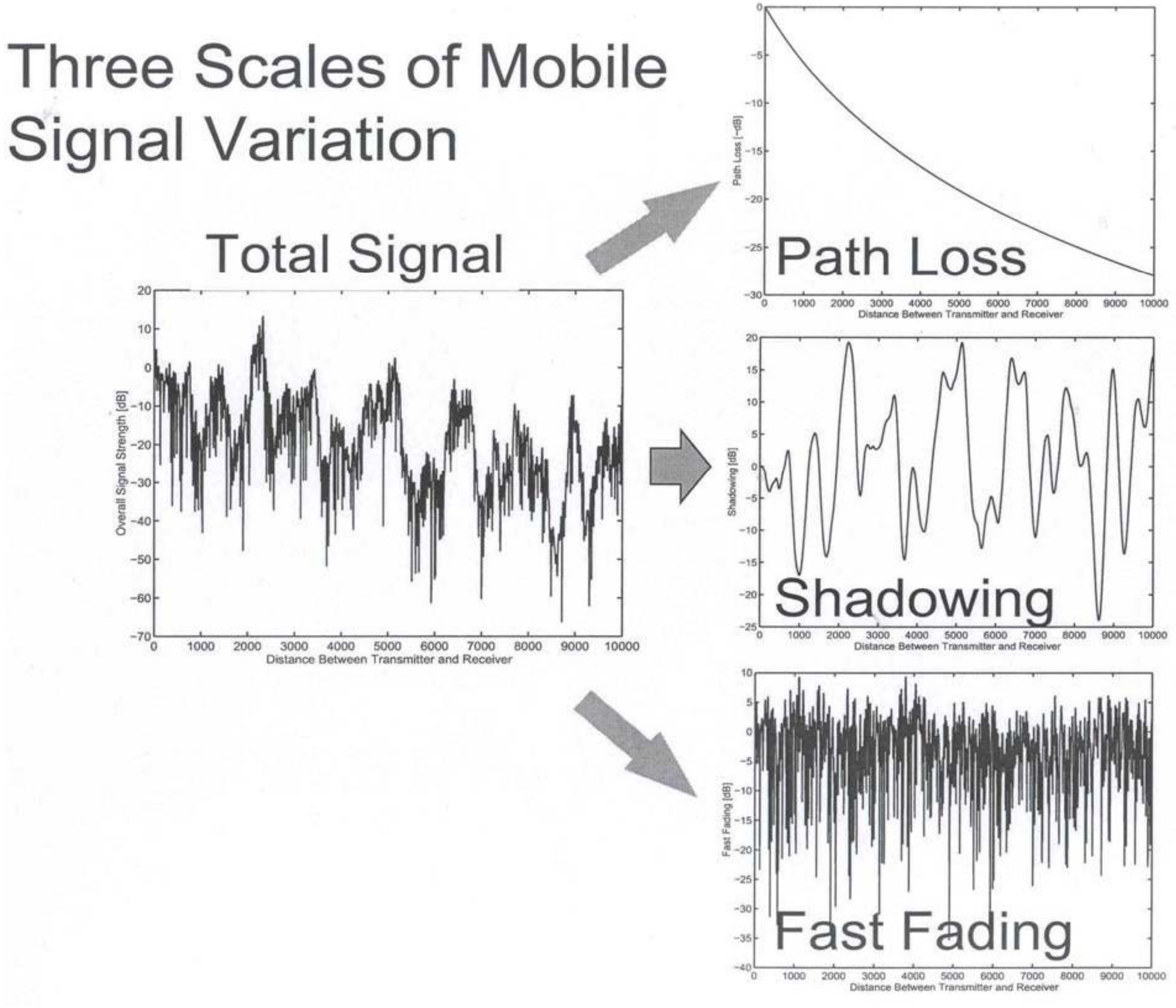
Figure 5.4 An example of the time varying discrete-time impulse response model for a multipath radio channel. Discrete models are useful in simulation where modulation data must be convolved with the channel impulse response [Tra02].

Transition

- Stochastic large scale models:
  - Log-distance path loss model
  - log-normal shadowing
- Outdoor propagation models
- Indoor propagation models

Three scales of path model

- Figure 2.1



Propagation Models

- Large scale models predict behavior averaged over distances >> λ
  - Function of distance & significant environmental features, roughly frequency independent
  - Breaks down as distance decreases
  - Useful for modeling the range of a radio system and rough capacity planning,
  - Experimental rather than the theoretical for previous three models
  - **Path loss models**, Outdoor models, Indoor models
- Small scale (fading) models describe signal variability on a scale of λ
  - Multipath effects (phase cancellation) dominate, path attenuation considered constant
  - Frequency and bandwidth dependent
  - Focus is on modeling “Fading”: rapid change in signal over a short distance or length of time.

Free space propagation model

- Assumes far-field (Fraunhofer region)
  - d >> D and d >> λ , where
    - ◆ *D is the largest linear dimension of antenna*
    - ◆ *λ is the carrier wavelength*
- No interference, no obstructions
- Effective isotropic radiated power
- Effective radiated power
- Path loss
- Fraunhofer region/far field
- In log scale
- Equation (2.9)
- Example 2.1

$$PL(d) = PL(d_0) + \beta \left[\frac{d}{d_0} \right]_{dB}$$

Free Space Path Loss

- Path Loss is a measure of attenuation based only on the distance to the transmitter
- Free space model only valid in far-field;
  - Path loss models typically define a "close-in" point d_0 and reference other points from there:

$$P_r(d) = P_r(d_0)\left(\frac{d_0}{d}\right)^2$$

$$PL(d) = [P_r(d)]_{dB} = PL(d_0) + 2\left[\frac{d}{d_0}\right]_{dB}$$

- Log-distance generalizes path loss to account for other environmental factors
  - Choose a d_0 in the far field.
  - Measure $PL(d_0)$ or calculate Free Space Path Loss.
  - Take measurements and derive β empirically.

$$PL(d) = PL(d_0) + \beta\left[\frac{d}{d_0}\right]_{dB}$$

Typical large-scale path loss

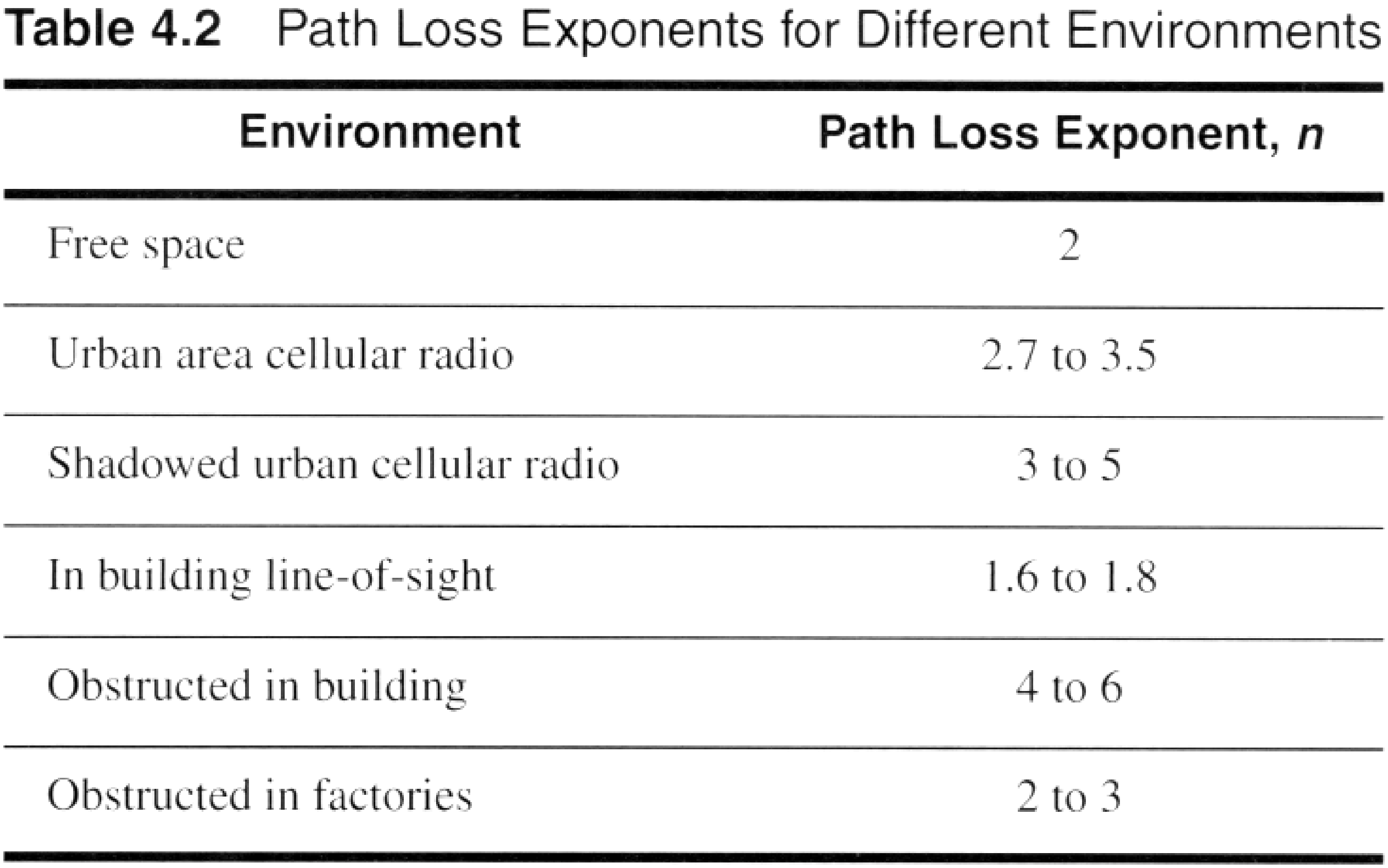


Table 4.2 Path Loss Exponents for Different Environments

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 Model

- Shadowing occurs when objects block LOS between transmitter and receiver
- A simple statistical model can account for unpredictable "shadowing"
    - – PL(d)(dB)=PL(d)+X0,
    - – Add a 0-mean Gaussian RV to Log-Distance PL
    - – Variance σ is usually from 3 to 12.
    - – Reason for Gaussian

Measured large-scale path loss

- Determine n and σ by mean and variance
- Basic of Gaussian Distribution

Example 2.3

Example 2.4

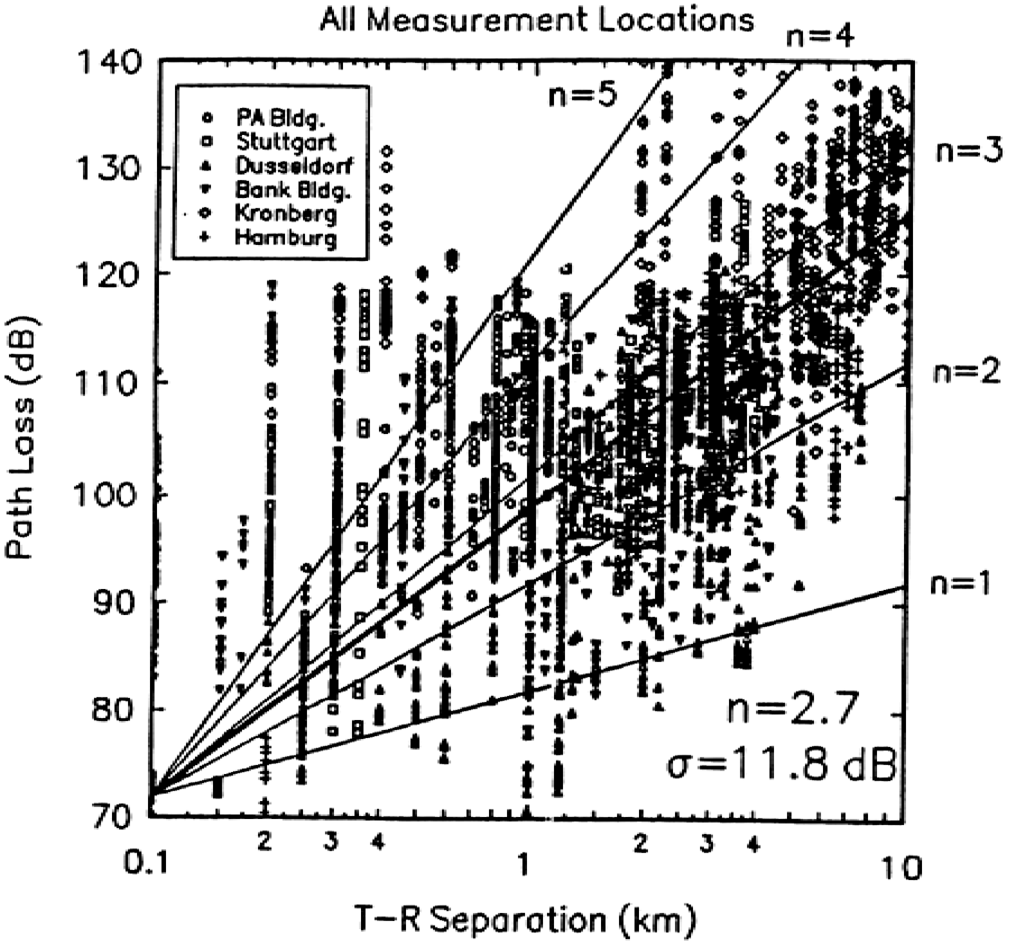


Figure 4.17 Scatter plot of measured data and corresponding MMSE path loss model for many cities in Germany. For this data, $n = 2.7$ and $\sigma = 11.8$ dB [from [Sei91] © IEEE].

Okumura Model

- It is one of the most widely used models for signal prediction in urban areas, and it is applicable for frequencies in the range 150 MHz to 1920 MHz
- Based totally on measurements (not analytical calculations)
- Applicable in the range: 150MHz to ~ 2000MHz, 1km to 100km T-R separation, Antenna heights of 30m to 100m

$$L_{50}(dB) = L_F + A_{mu}(f,d) - G(h_{re}) - G(h_{te}) - G_{AREA}$$

Where

L_{50} is the median path loss (50%)

L_F is the free space path loss

$A_{mu}(f,d)$ is the median attenuation relative to free space

$G(h_{re}), G(h_{te})$ are antenna height gain factors

G_{AREA} is the gain due to the type of environment

Okumura Model

- The major disadvantage with the model is its low response to rapid changes in terrain, therefore the model is fairly good in urban areas, but not as good in rural areas.
- Common standard deviations between predicted and measured path loss values are around 10 to 14 dB.
- G(hre)：

$$G(h_{te}) = 20\log\left(\frac{h_{te}}{200}\right) \qquad 1000\,\mathrm{m} > h_{te} > 30\,\mathrm{m}$$

$$G(h_{re}) = 10\log\left(\frac{h_{re}}{3}\right) \qquad h_{re} \le 3\,\mathrm{m}$$

$$G(h_{re}) = 20\log\left(\frac{h_{re}}{3}\right) \qquad 10\,\mathrm{m} > h_{re} > 3\,\mathrm{m}$$

Okumura and Hata's model

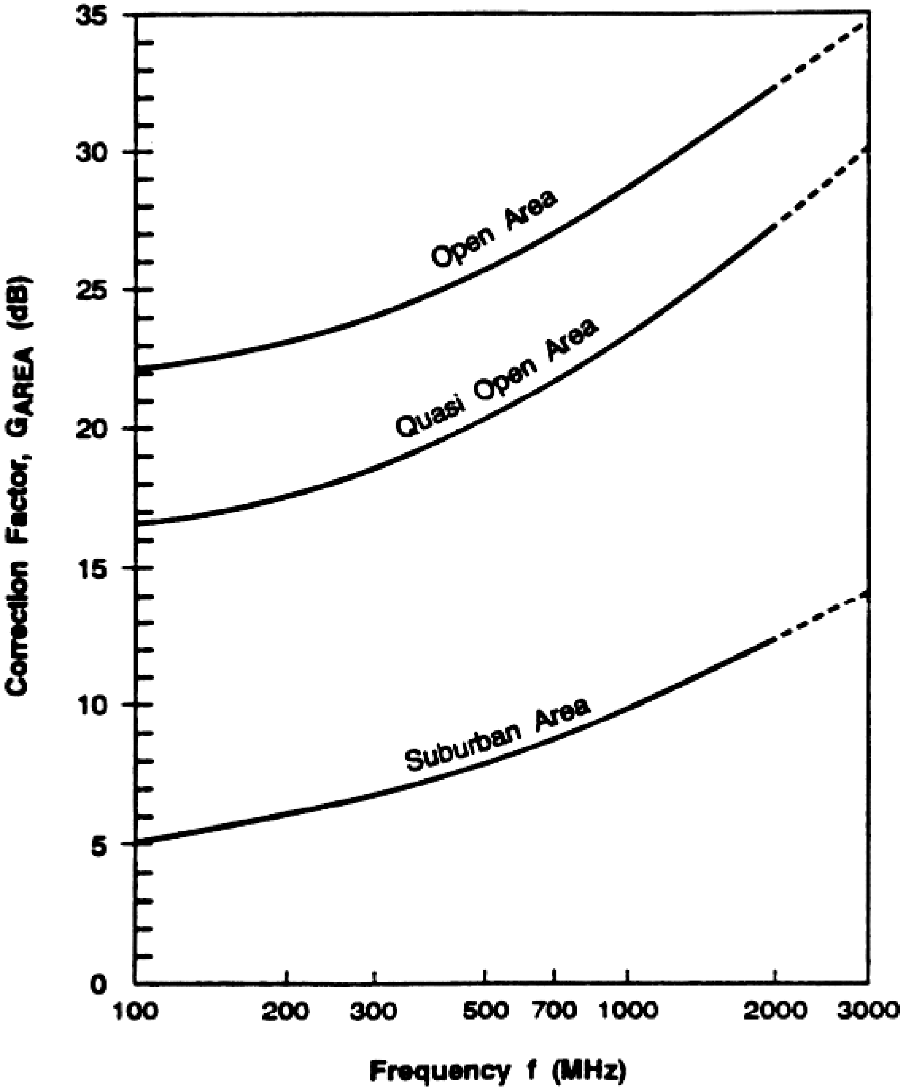


Figure 4.24 Correction factor, G_{AREA}, for different types of terrain [from [Oku68] © IEEE].

Hata Model

- Empirical formulation of the graphical data in the Okamura model. Valid 150MHz to 1500MHz, Used for cellular systems
- The following classification was used by Hata:
  - Urban area $L_{dB} = A + B \log d - E$
  - Suburban area $L_{dB} = A + B \log d - C$
  - Open area $L_{dB} = A + B \log d - D$

$$A = 69.55 + 26.16 \log f - 13.82 h_b$$

$$B = 44.9 - 6.55 \log h_b$$

$$C = 2(\log(f/28))^2 + 5.4$$

$$D = 4.78 \log(f/28)^2 + 18.33 \log f + 40.94$$

$$E = 3.2(\log(11.75 h_m))^2 - 4.97 \quad \text{for large cities, } f \geq 300 MHz$$

$$E = 8.29(\log(1.54 h_m))^2 - 1.1 \quad \text{for large cities, } f < 300 MHz$$

$$E = (1.11 \log f - 0.7) h_m - (1.56 \log f - 0.8) \quad \text{for medium to small cities}$$

PCS Extension of Hata Model

- **COST-231 Hata Model, European standard**
- Higher frequencies: up to 2GHz
- Smaller cell sizes
- Lower antenna heights

$$L_{dB} = F + B\log d - E + G$$

$$F = 46.3 + 33.9\log f - 13.82\log h_b \qquad \text{f >1500MHz}$$

$$G = \begin{matrix} 3 & \text{Metropolitan centers} \\ 0 & \text{Medium sized city and suburban areas} \end{matrix}$$

Indoor Propagation Models

- The distances covered are much smaller
- The variability of the environment is much greater
- Key variables: layout of the building, construction materials, building type, where the antenna mounted, …etc.
- In general, indoor channels may be classified either as LOS or OBS with varying degree of clutter
- The losses between floors of a building are determined by the external dimensions and materials of the building, as well as the type of construction used to create the floors and the external surroundings.
- Floor attenuation factor (FAF)

Partition losses between floors

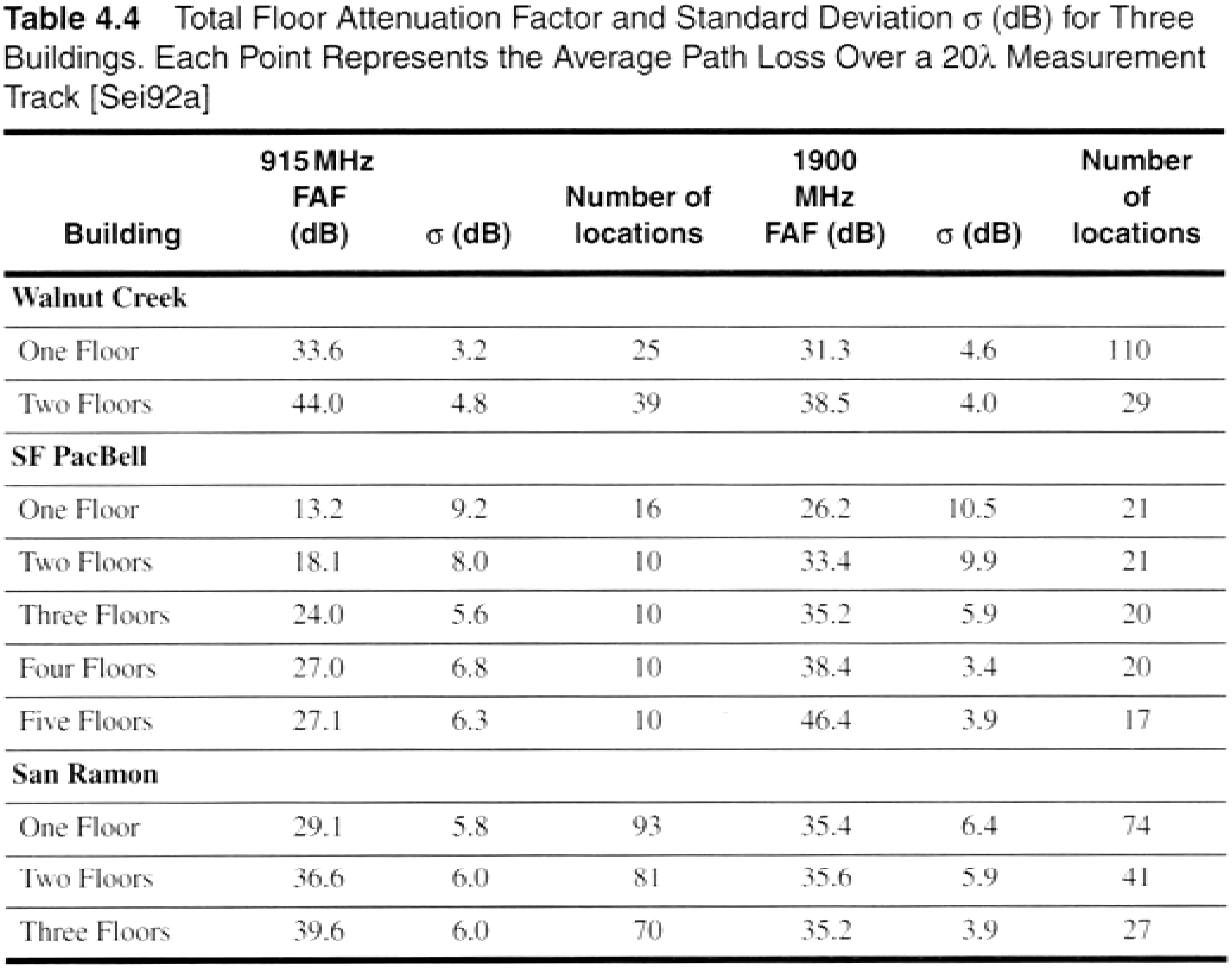


Table 4.4 Total Floor Attenuation Factor and Standard Deviation σ (dB) for Three Buildings. Each Point Represents the Average Path Loss Over a 20λ Measurement Track [Sei92a]

Building	915 MHz FAF (dB)	σ (dB)	Number of locations	1900 MHz FAF (dB)	σ (dB)	Number of locations
Walnut Creek						
One Floor	33.6	3.2	25	31.3	4.6	110
Two Floors	44.0	4.8	39	38.5	4.0	29
SF PacBell						
One Floor	13.2	9.2	16	26.2	10.5	21
Two Floors	18.1	8.0	10	33.4	9.9	21
Three Floors	24.0	5.6	10	35.2	5.9	20
Four Floors	27.0	6.8	10	38.4	3.4	20
Five Floors	27.1	6.3	10	46.4	3.9	17
San Ramon						
One Floor	29.1	5.8	93	35.4	6.4	74
Two Floors	36.6	6.0	81	35.6	5.9	41
Three Floors	39.6	6.0	70	35.2	3.9	27

Partition losses between floors

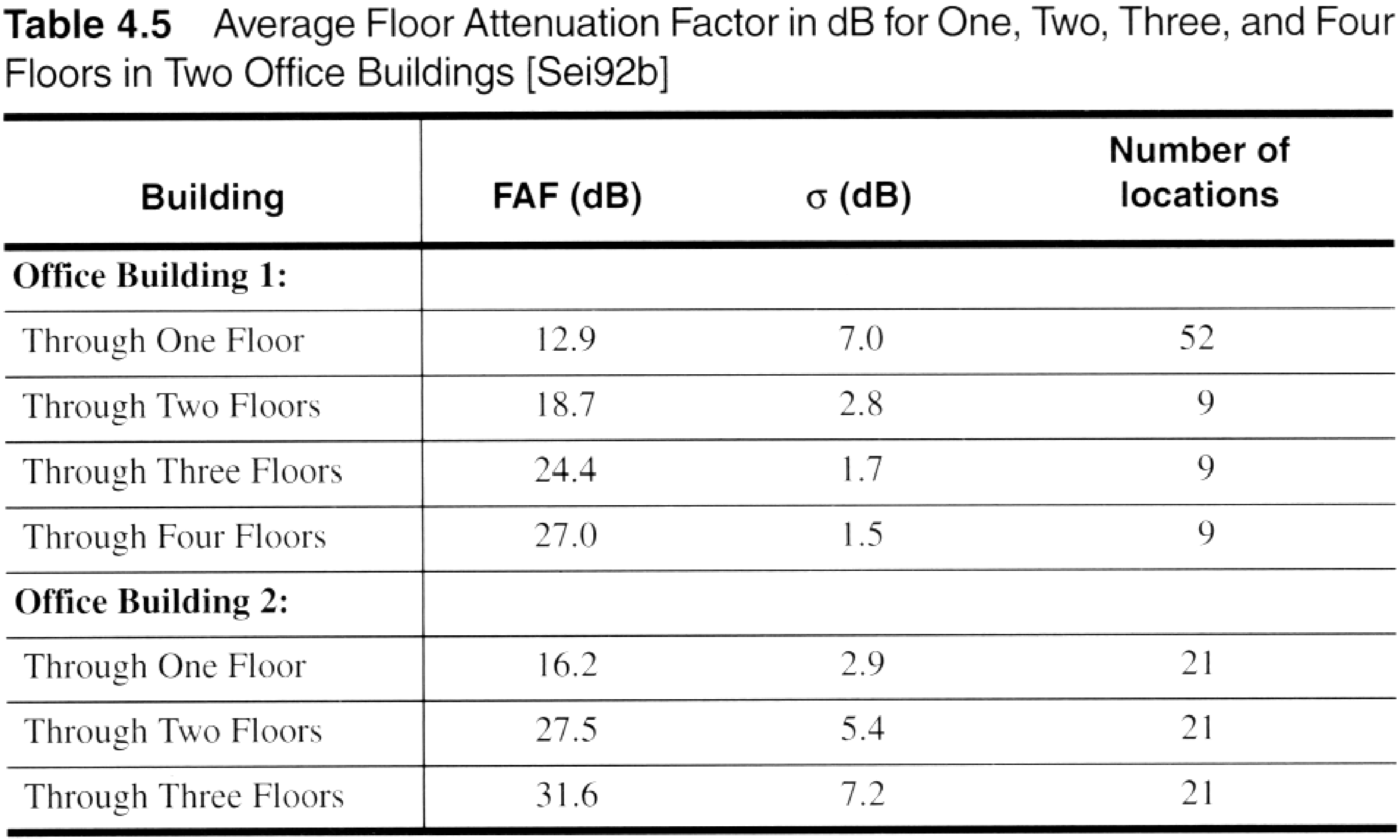


Table 4.5 Average Floor Attenuation Factor in dB for One, Two, Three, and Four Floors in Two Office Buildings [Sei92b]

Building	FAF (dB)	σ (dB)	Number of locations
Office Building 1:			
Through One Floor	12.9	7.0	52
Through Two Floors	18.7	2.8	9
Through Three Floors	24.4	1.7	9
Through Four Floors	27.0	1.5	9
Office Building 2:			
Through One Floor	16.2	2.9	21
Through Two Floors	27.5	5.4	21
Through Three Floors	31.6	7.2	21

Log-distance Path Loss Model

- The exponent n depends on the surroundings and building type
  - X_σ is the variable in dB having a standard deviation σ.

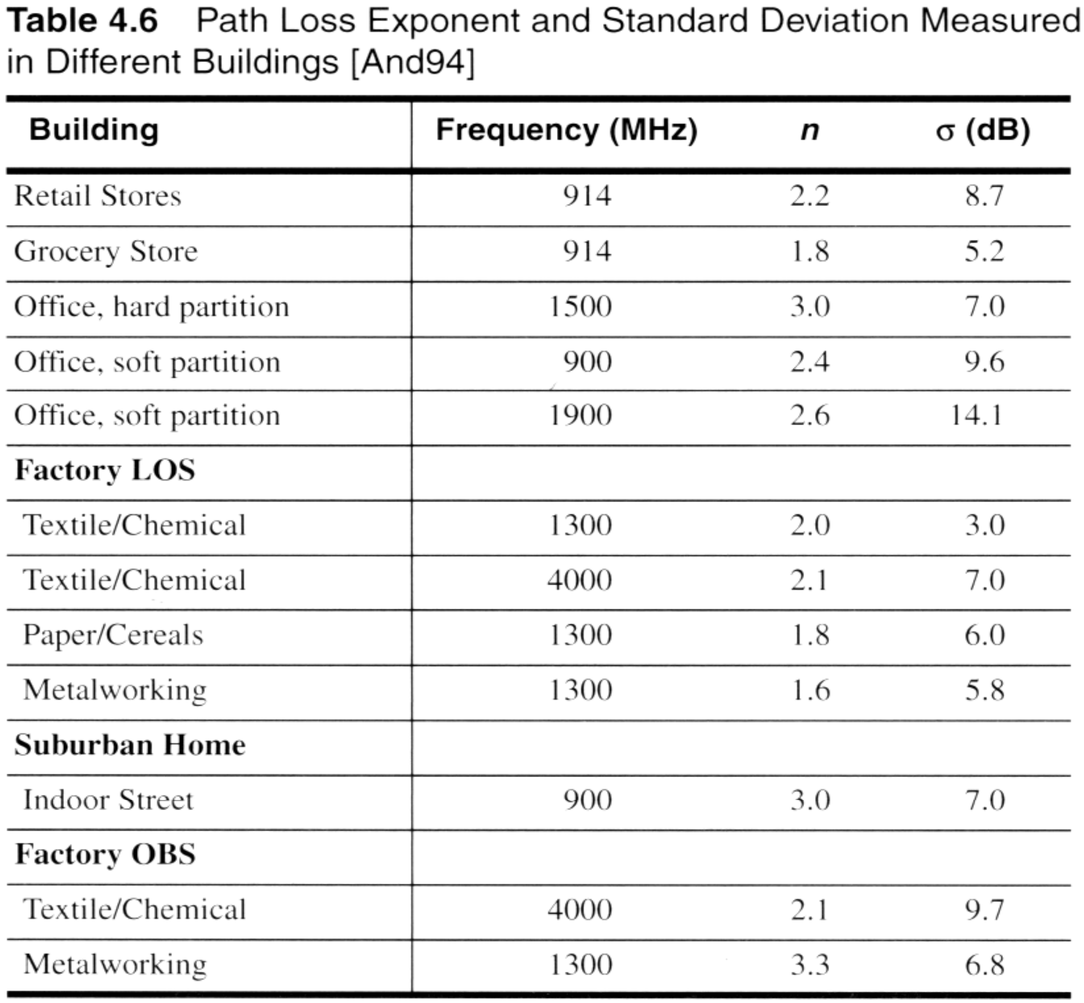


Table 4.6 Path Loss Exponent and Standard Deviation Measured in Different Buildings [And94]

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

$$PL(d) = PL(d_0) + 10n\log(d/d_0) + X_\sigma$$

Ericsson Multiple Breakpoint Model

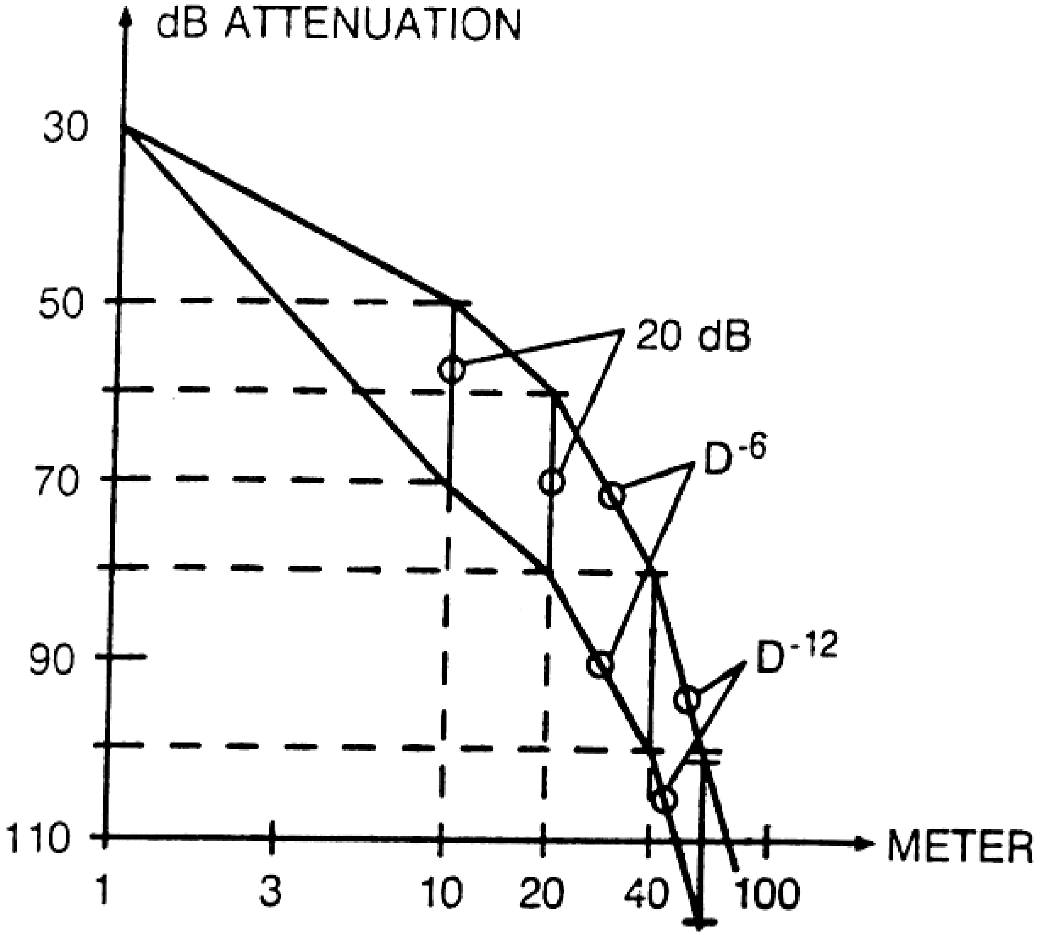


Figure 4.27 Ericsson in-building path loss model [from [Ake88] © IEEE].

Attenuation Factor Model

- FAF represents a floor attenuation factor for a specified number of building floors.
- PAF represents the partition attenuation factor for a specific obstruction encountered by a ray drawn between the transmitter and receiver in 3-D
- α is the attenuation constant for the channel with units of dB per meter.

$$PL(d) = PL(d_0) + 10 n_{SF} \log(d/d_0) + FAF + \sum PAF$$

$$PL(d) = PL(d_0) + 10 n_{MF} \log(d/d_0) + \sum PAF$$

$$PL(d) = PL(d_0) + 10 \log(d/d_0) + \alpha d + FAF + \sum PAF$$

Measured indoor path loss

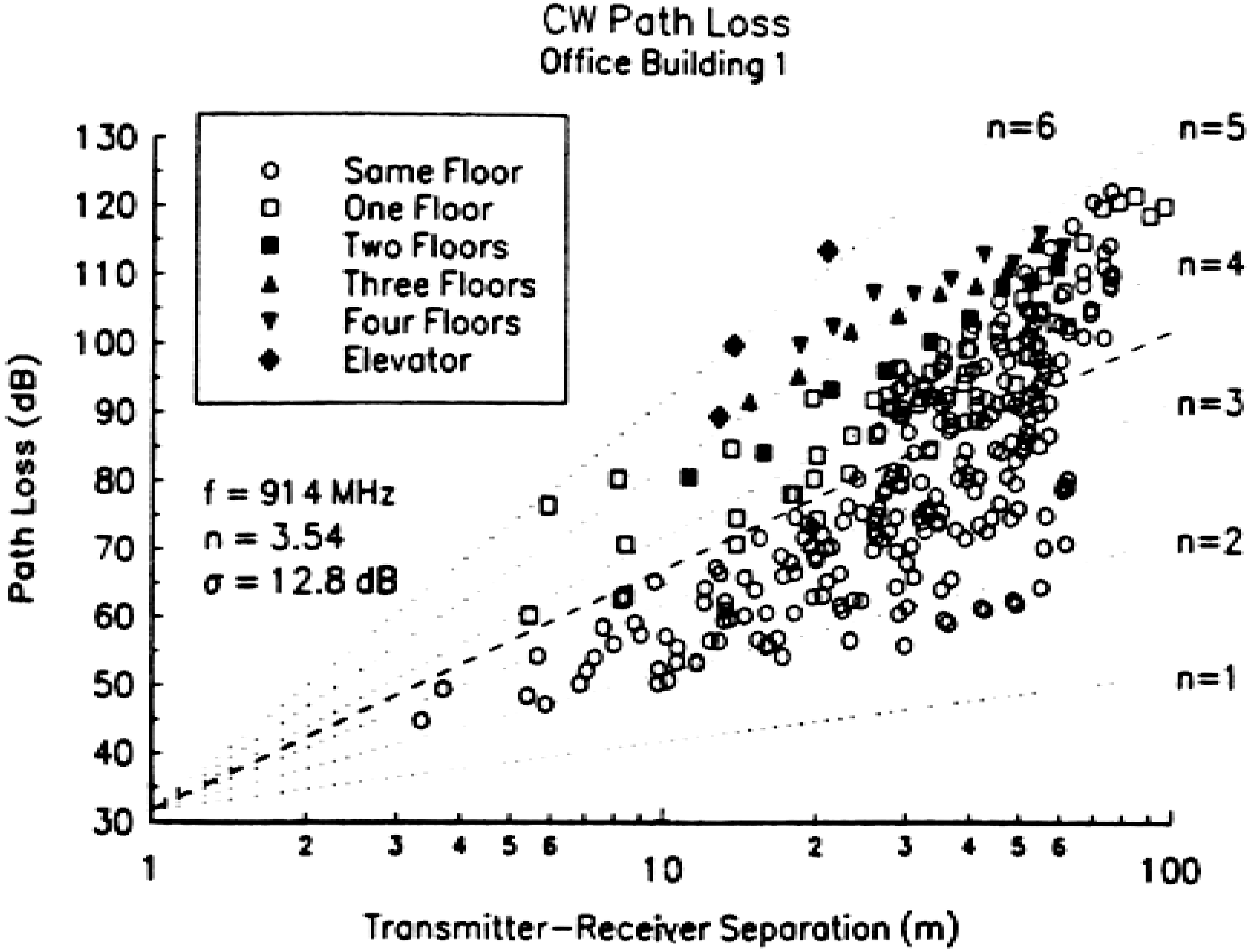


Figure 4.28 Scatter plot of path loss as a function of distance in Office Building 1 [from [Sei92b] © IEEE].

Measured indoor path loss

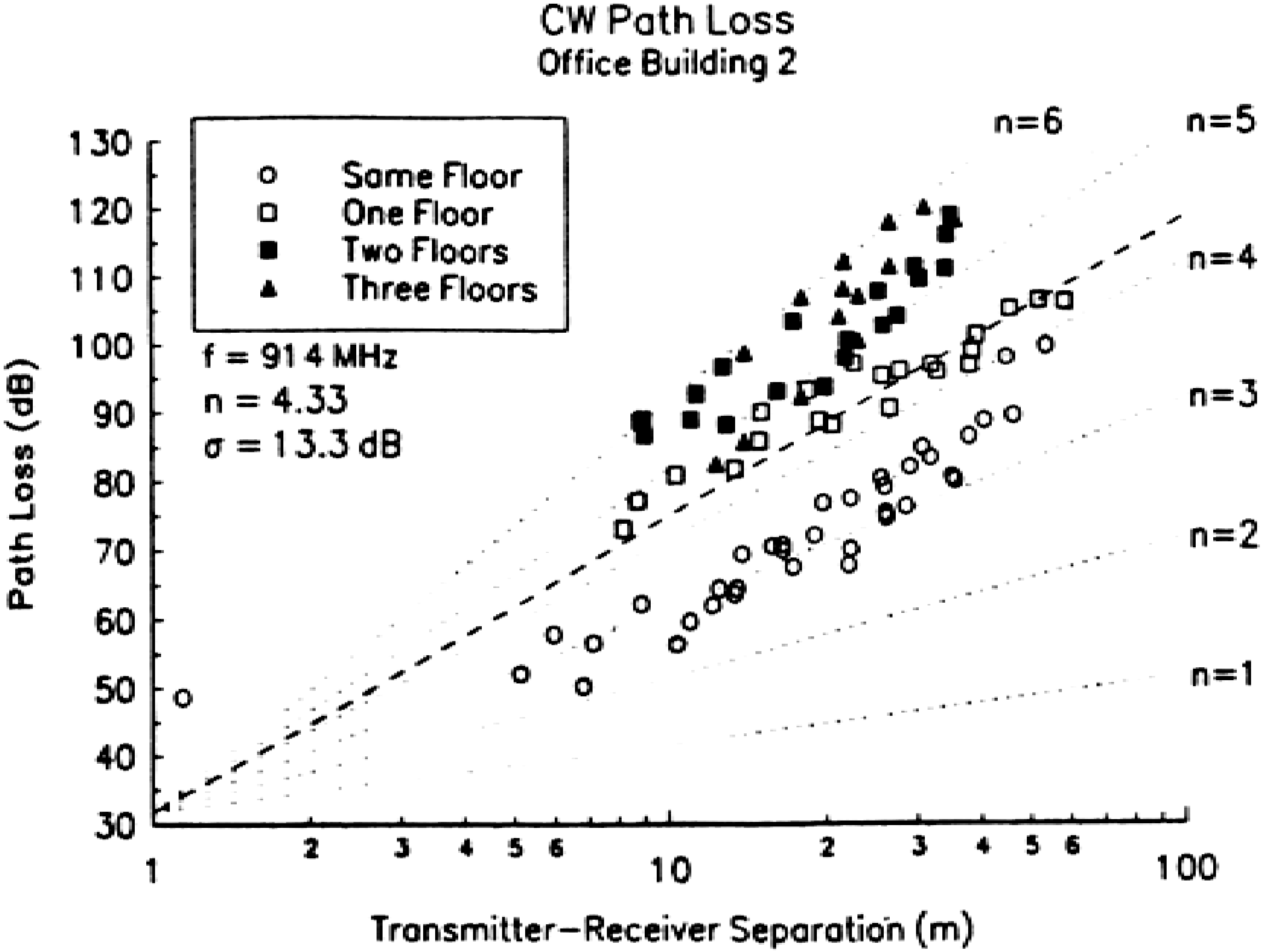


Figure 4.29 Scatter plot of path loss as a function of distance in Office Building 2 [from [Sei92b] © IEEE].

Measured indoor path loss

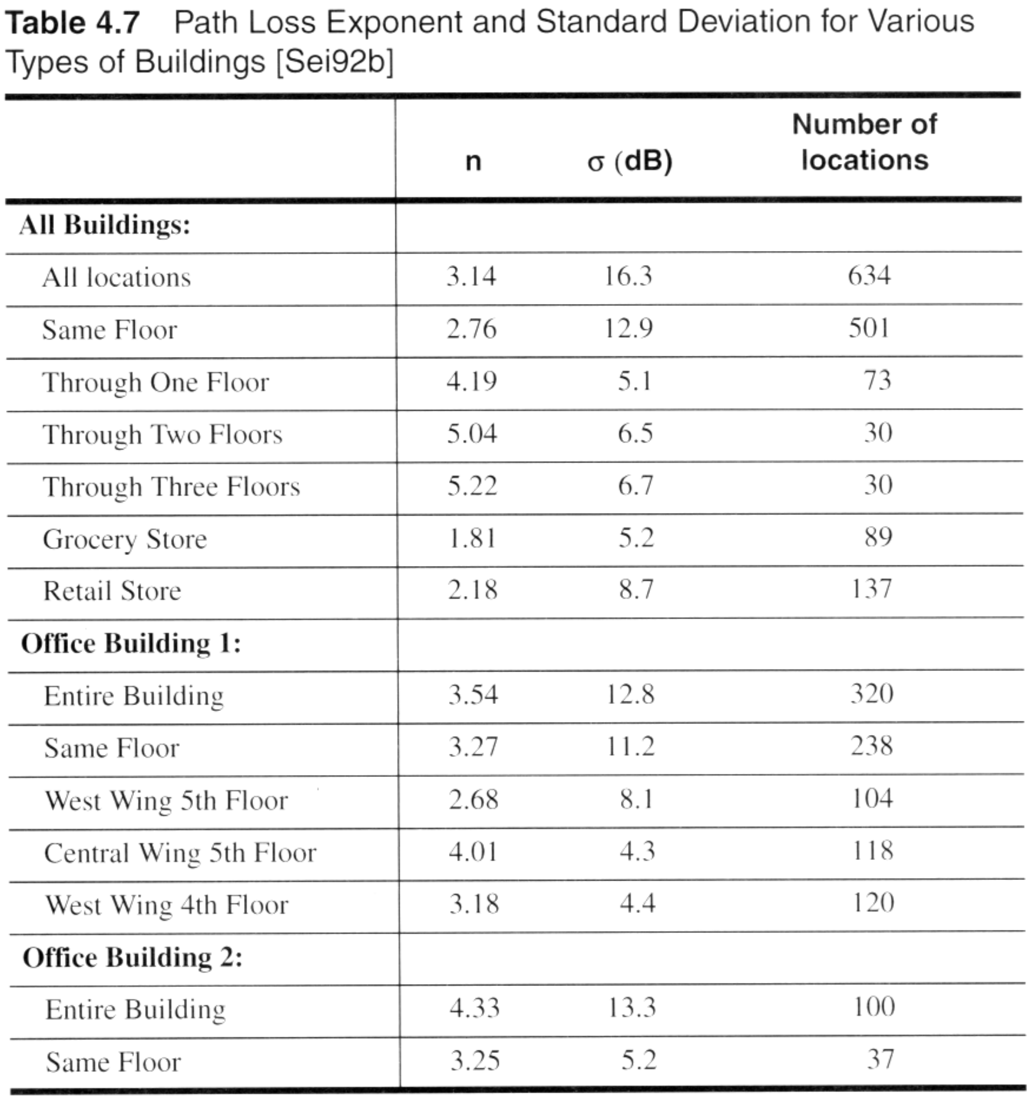


Table 4.7 Path Loss Exponent and Standard Deviation for Various Types of Buildings [Sei92b]

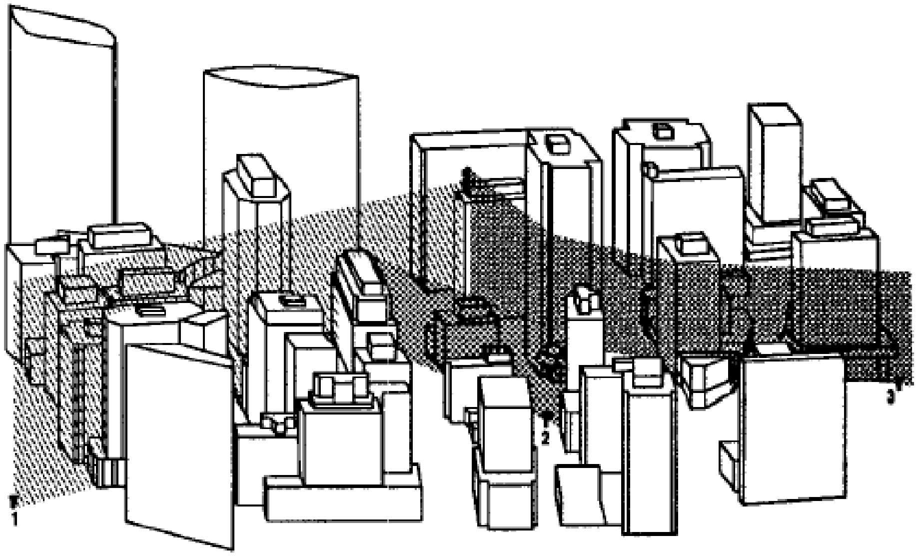
	n	σ (dB)	Number of locations
All Buildings:			
All locations	3.14	16.3	634
Same Floor	2.76	12.9	501
Through One Floor	4.19	5.1	73
Through Two Floors	5.04	6.5	30
Through Three Floors	5.22	6.7	30
Grocery Store	1.81	5.2	89
Retail Store	2.18	8.7	137
Office Building 1:			
Entire Building	3.54	12.8	320
Same 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

Signal Penetration into Buildings

- RF penetration has been found to be a function of frequency as well as height within the building. Signal strength received inside a building increases with height, and penetration loss decreases with increasing frequency.
- Walker's work shows that building penetration loss decrease at a rate of 1.9 dB per floor from the ground level up to the 15th floor and then began increasing above the 15th floor. The increase in penetration loss at higher floors was attributed to shadowing effects of adjacent buildings.
- Some devices to conduct the signals into the buildings

Ray Tracing and Site Specific Modeling

- Site specific propagation model and graphical information system. Ray tracing. Deterministic model.
- Data base for buildings, trees, etc.
- SitePlanner



Cell Coverage Area

- Example 2.6 and 2.7