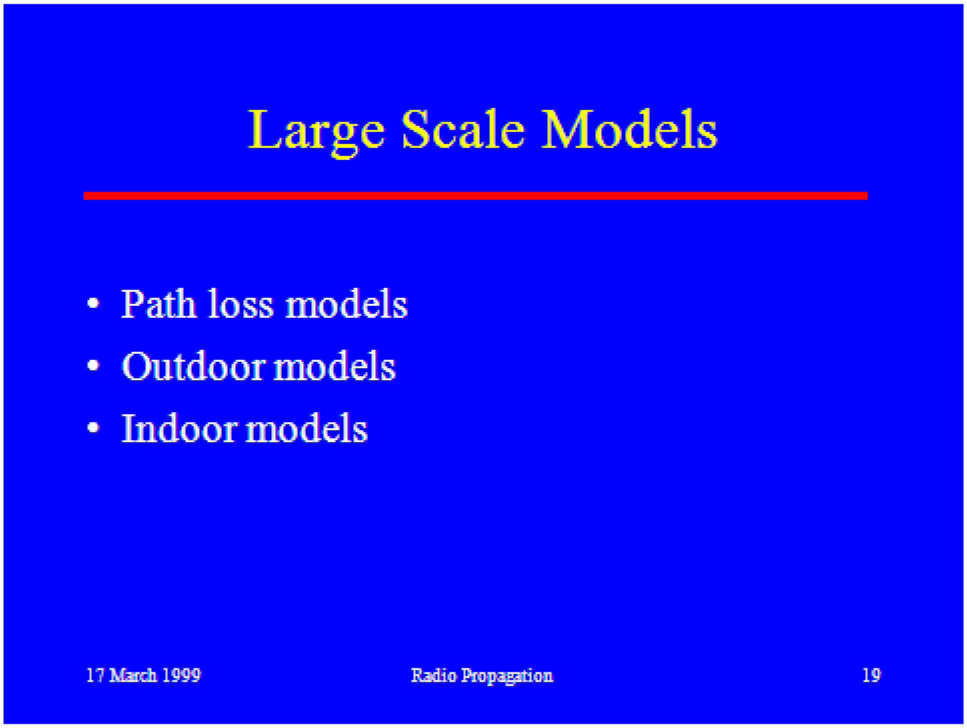
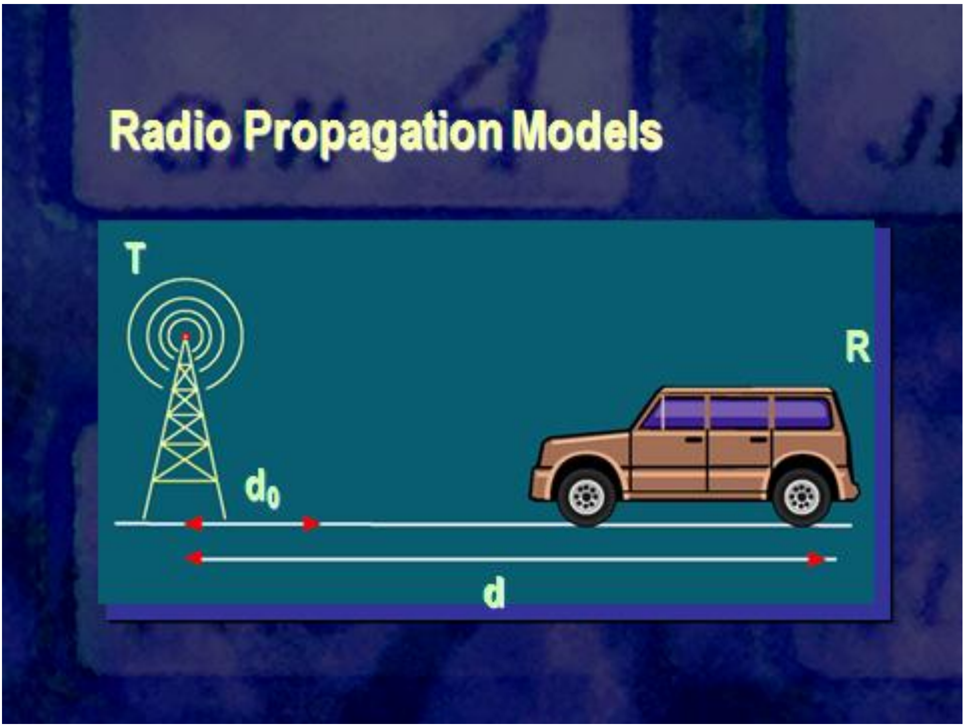


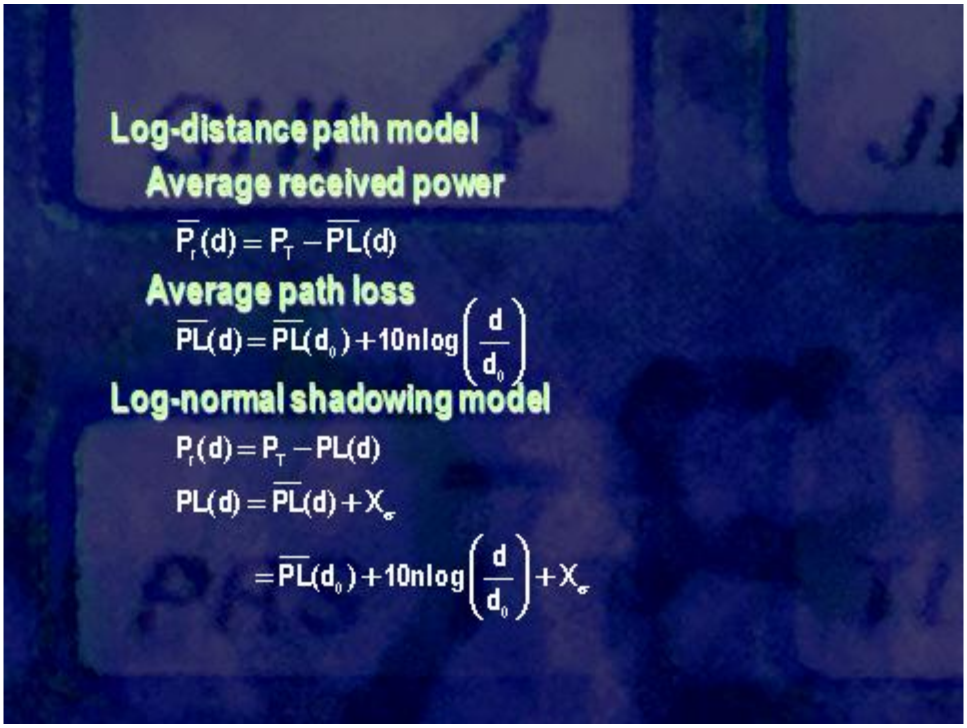
Large Scale Models

- Path loss models
- Outdoor models
- Indoor models

Practical Radio Propagation Models



Radio Propagation Models



Log-distance path model

Average received power

$$\overline{P}_r(d) = P_T - \overline{PL}(d)$$

Average path loss

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

Log-normal shadowing model

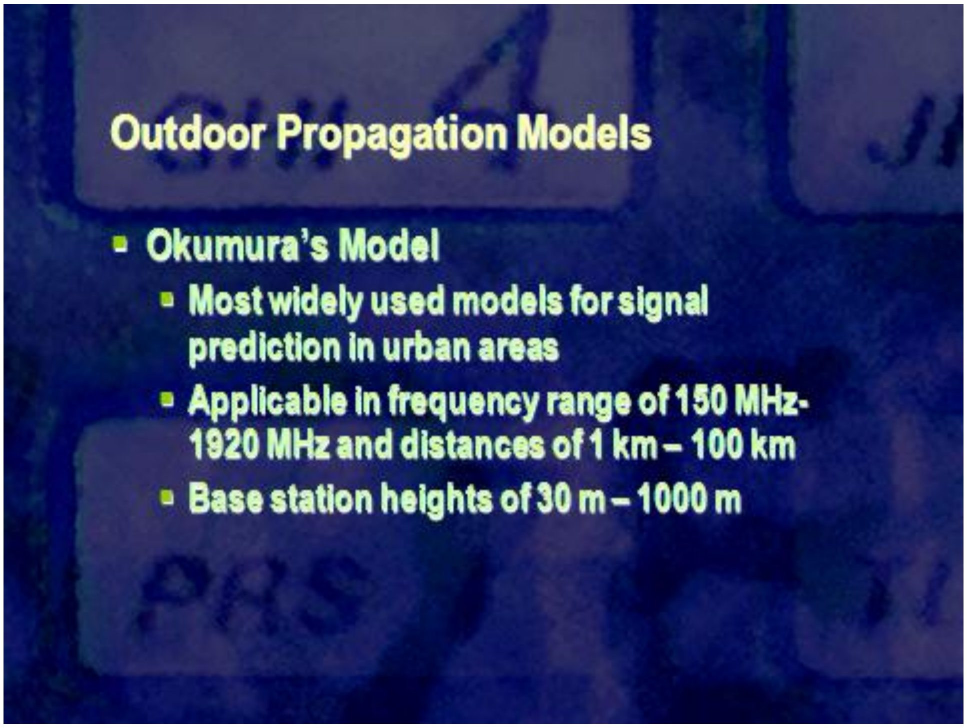
$$P_r(d) = P_T - PL(d)$$

$$PL(d) = \overline{PL}(d) + X_\sigma$$

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

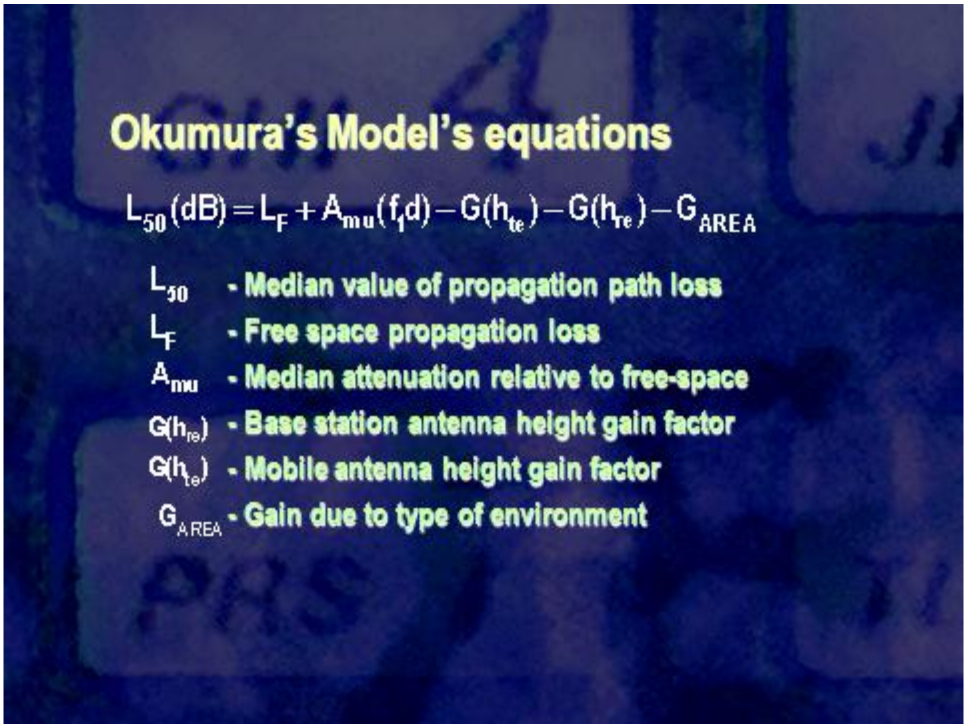
Examples of Outdoor Models

- Longley-Rice Model
- Durkin's Model
- Okumura's Model
- Hata Model
- PCS extension to Hata Model



Outdoor Propagation Models

- Okumura's Model
  - Most widely used models for signal prediction in urban areas
  - Applicable in frequency range of 150 MHz-1920 MHz and distances of 1 km – 100 km
  - Base station heights of 30 m – 1000 m



Okumura's Model's equations

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

L_{50} - Median value of propagation path loss

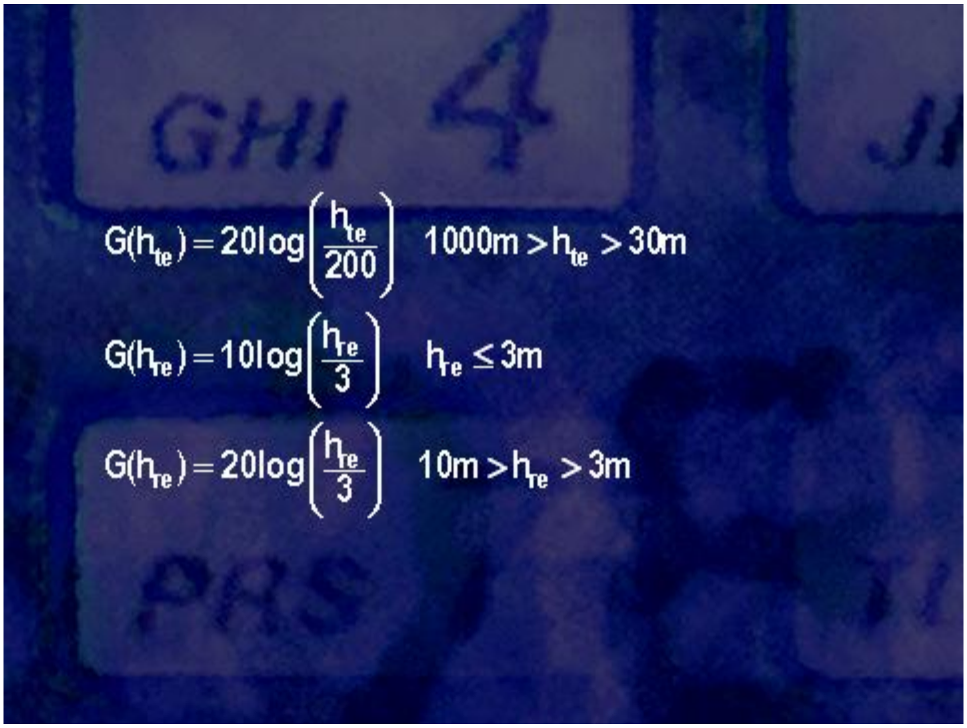
L_F - Free space propagation loss

A_{mu} - Median attenuation relative to free-space

$G(h_{re})$ - Base station antenna height gain factor

$G(h_{te})$ - Mobile antenna height gain factor

G_{AREA} - Gain due to type of environment



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

$$G(h_{re}) = 10\log\left(\frac{h_{re}}{3}\right) \quad h_{re} \leq 3m$$

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

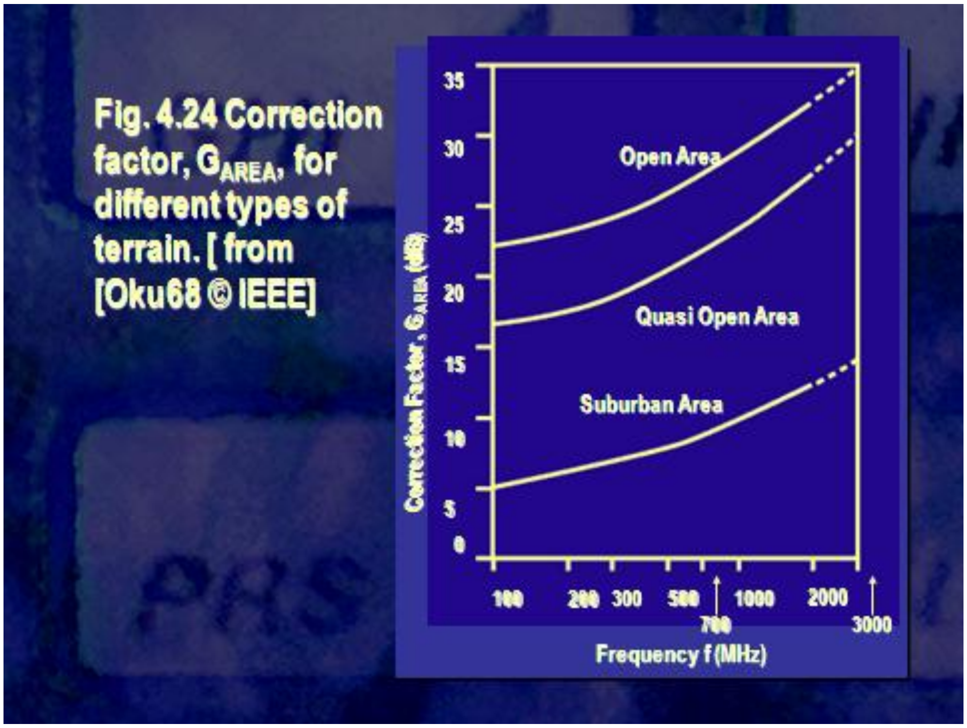
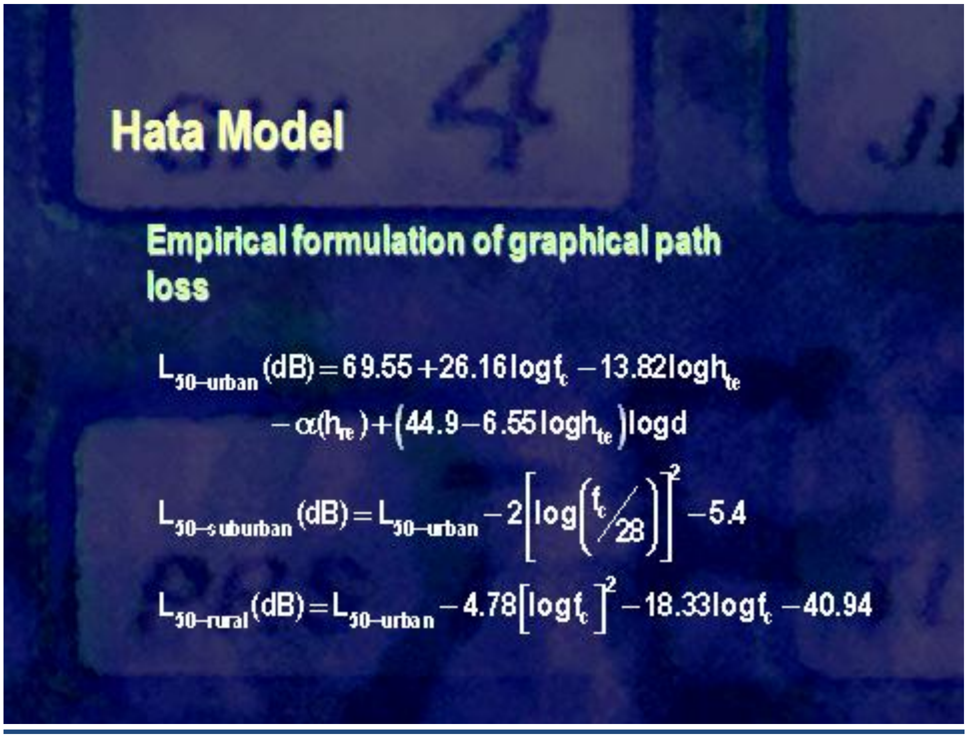


Fig. 4.24 Correction factor, G_{AREA}, for different types of terrain. [from [Oku68 © IEEE]

Hata Model

- An extension of OKUMURA model
- Empirical formula Valid for all situations
- Predictions are very much close to the original OKUMURA model
- Well suited for large cell environments
- Modification of the formula for 2 GHZ (PCS) environment



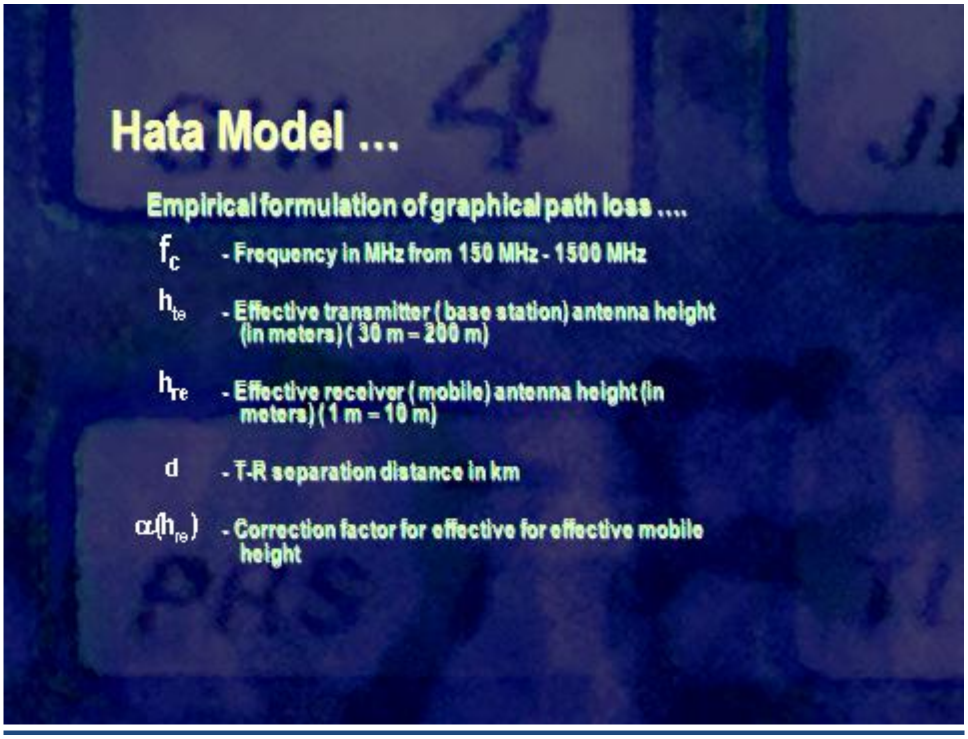
Hata Model

Empirical formulation of graphical path loss

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

$$L_{50-suburban}(dB) = L_{50-urban} - 2\left[\log\left(f_c/28\right)\right]^2 - 5.4$$

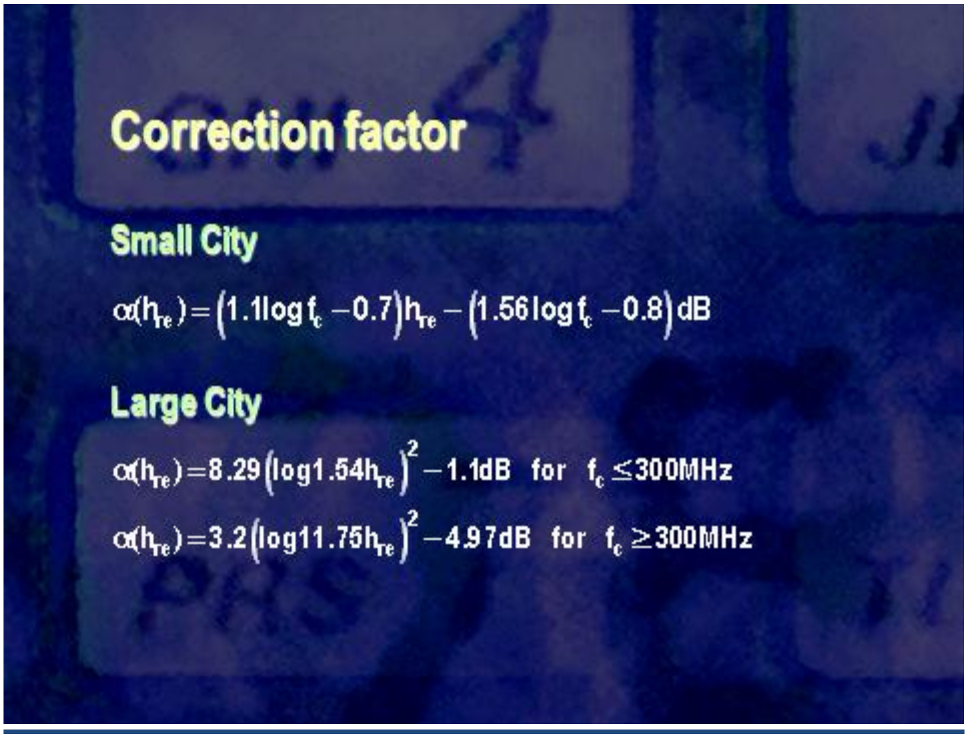
$$L_{50-rural}(dB) = L_{50-urban} - 4.78\left[\log f_c\right]^2 - 18.33\log f_c - 40.94$$



Hata Model ...

Empirical formulation of graphical path loss ....

f_c	- Frequency in MHz from 150 MHz - 1500 MHz
h_{te}	- Effective transmitter (base station) antenna height (in meters) (30 m - 200 m)
h_{re}	- Effective receiver (mobile) antenna height (in meters) (1 m - 10 m)
d	- T-R separation distance in km
$\alpha(h_{re})$	- Correction factor for effective for effective mobile height



Correction factor

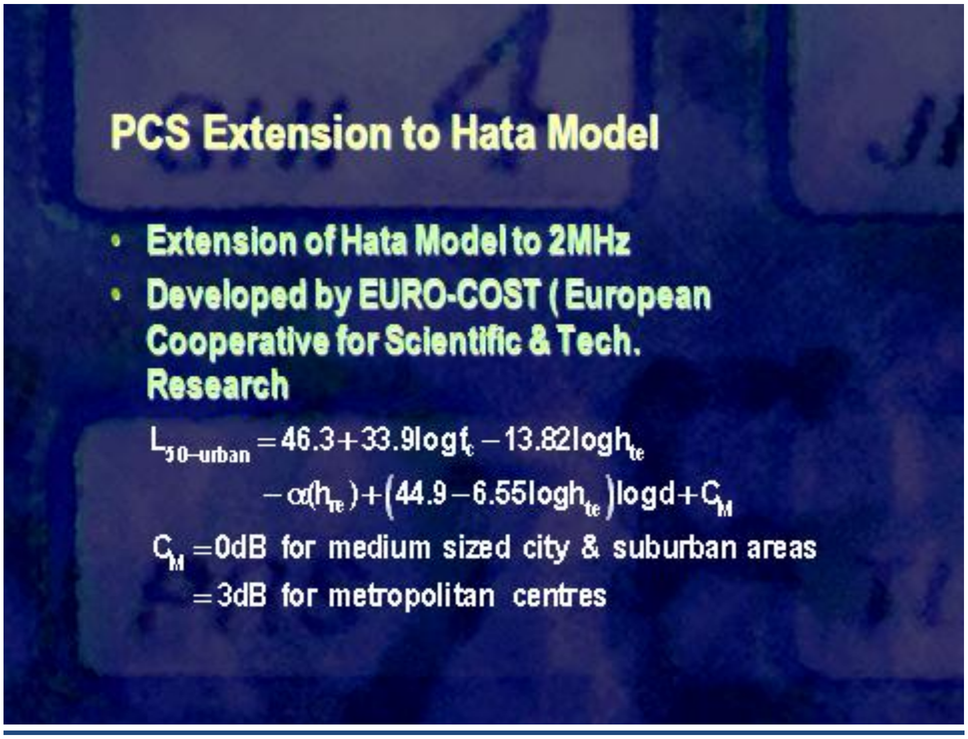
Small City

$$\alpha(h_{re}) = \left(1.1\log f_c - 0.7\right)h_{re} - \left(1.56\log f_c - 0.8\right)\text{dB}$$

Large City

$$\alpha(h_{re}) = 8.29\left(\log 1.54h_{re}\right)^2 - 1.1\text{dB} \quad \text{for} \quad f_c \leq 300\text{MHz}$$

$$\alpha(h_{re}) = 3.2\left(\log 11.75h_{re}\right)^2 - 4.97\text{dB} \quad \text{for} \quad f_c \geq 300\text{MHz}$$



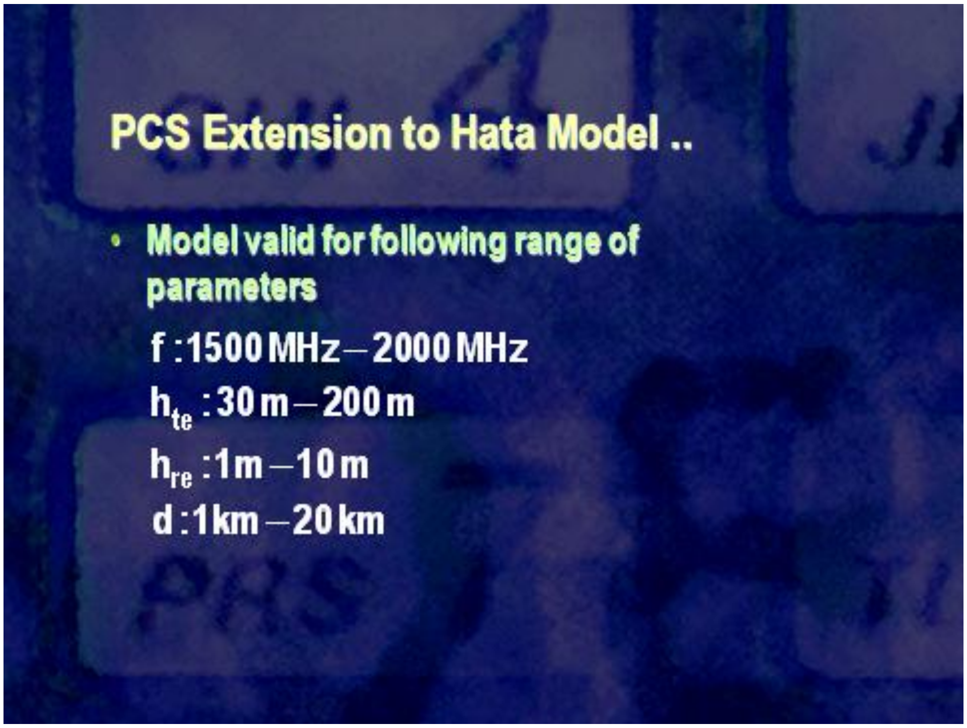
PCS Extension to Hata Model

- Extension of Hata Model to 2MHz
- Developed by EURO-COST (European Cooperative for Scientific & Tech. Research

$$L_{50-urban} = 46.3 + 33.9\log f_c - 13.82\log h_{te} - \alpha(h_{re}) + \left(44.9 - 6.55\log h_{te}\right)\log d + C_M$$

C_M = 0dB for medium sized city & suburban areas

= 3dB for metropolitan centres



PCS Extension to Hata Model ..

- Model valid for following range of parameters

f : 1500 MHz – 2000 MHz

h_{te} : 30 m – 200 m

h_{re} : 1 m – 10 m

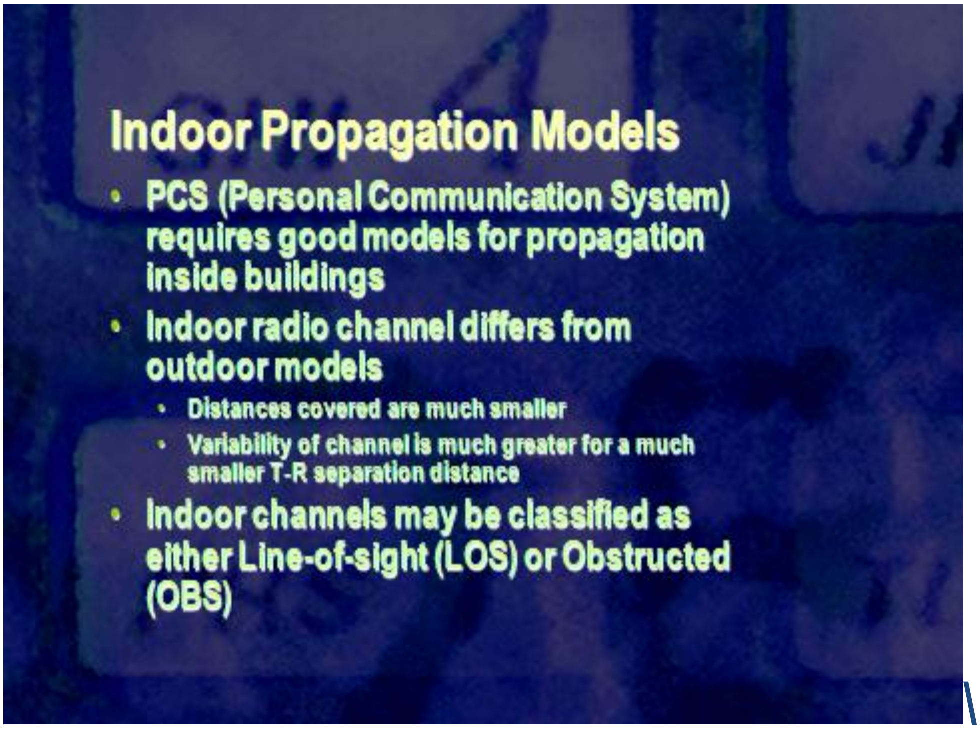
d : 1 km – 20 km

Hata Path Loss Model

- **Hata Model used extensively in cellular communications.**
- **Empirical Model based on Okumura.**
  - Better estimates the path loss experienced as compared to Free Space.
  - Valid with range 1-20km, base height 30-200m
- **Formula to compute the path loss:**
  - $L_H = 69.55 + 26.16\log_{10}f_c - 13.82\log_{10}h_b - a(h_m) + (44.9 - 6.55\log_{10}h_b)\log_{10}R$
    - h_b is the base station antenna height in meters.
    - h_m is the mobile antenna height also measured in meters.
    - R is the distance from the cell site to the mobile in km.
    - f_c is the transmit frequency in MHz.
    - $a(h_m)$ is an adjustment factor for the type of environment and the hieght of the mobile.
      - $a(h_m) = 0$ for urban environments with a mobile height of 1.5m.

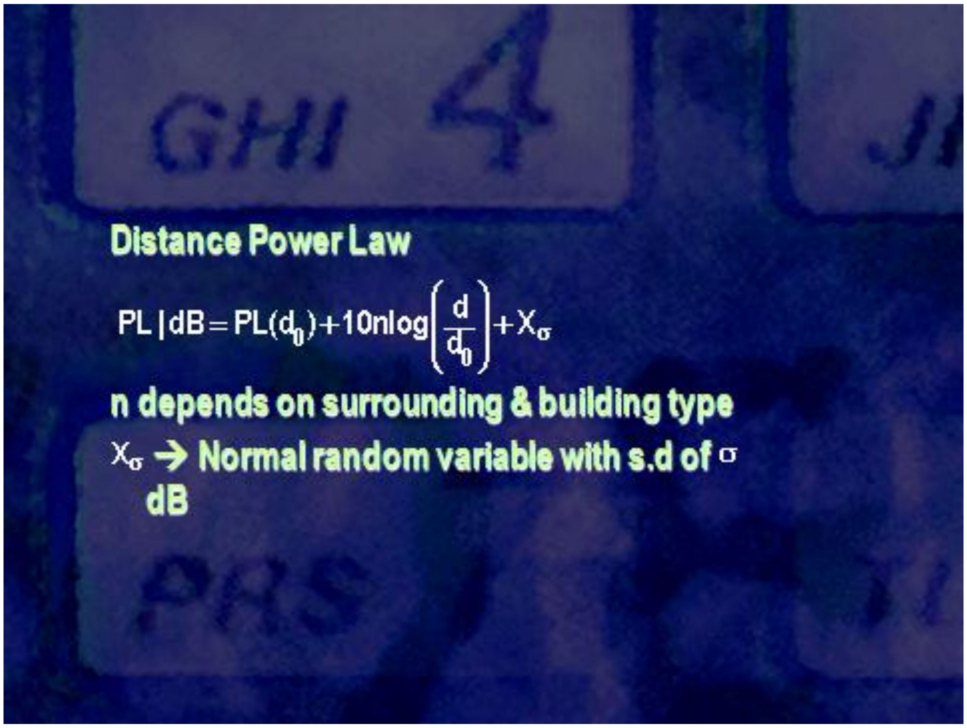
Indoor Propagation Models

- Different environment, small distances between the transmitter and the receiver with more variability of the environment
- Partition loss
- Log-distance Path loss model valid
- Signal penetration to buildings



Indoor Propagation Models

- PCS (Personal Communication System) requires good models for propagation inside buildings
- Indoor radio channel differs from outdoor models
  - Distances covered are much smaller
  - Variability of channel is much greater for a much smaller T-R separation distance
- Indoor channels may be classified as either Line-of-sight (LOS) or Obstructed (OBS)



Distance Power Law

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

n depends on surrounding & building type

X_σ → Normal random variable with s.d of σ dB

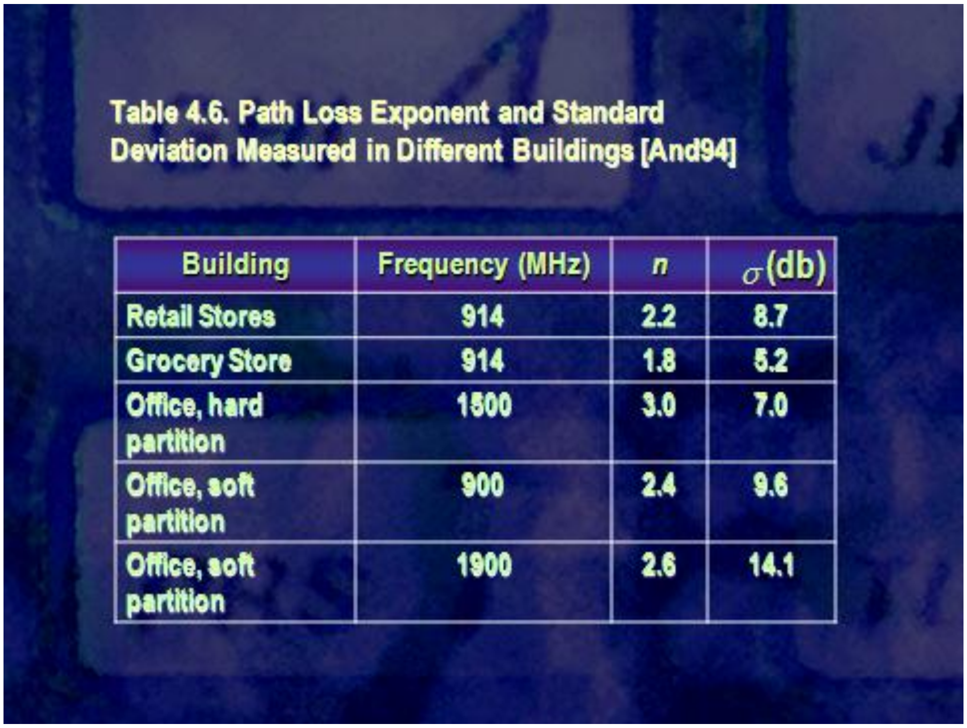
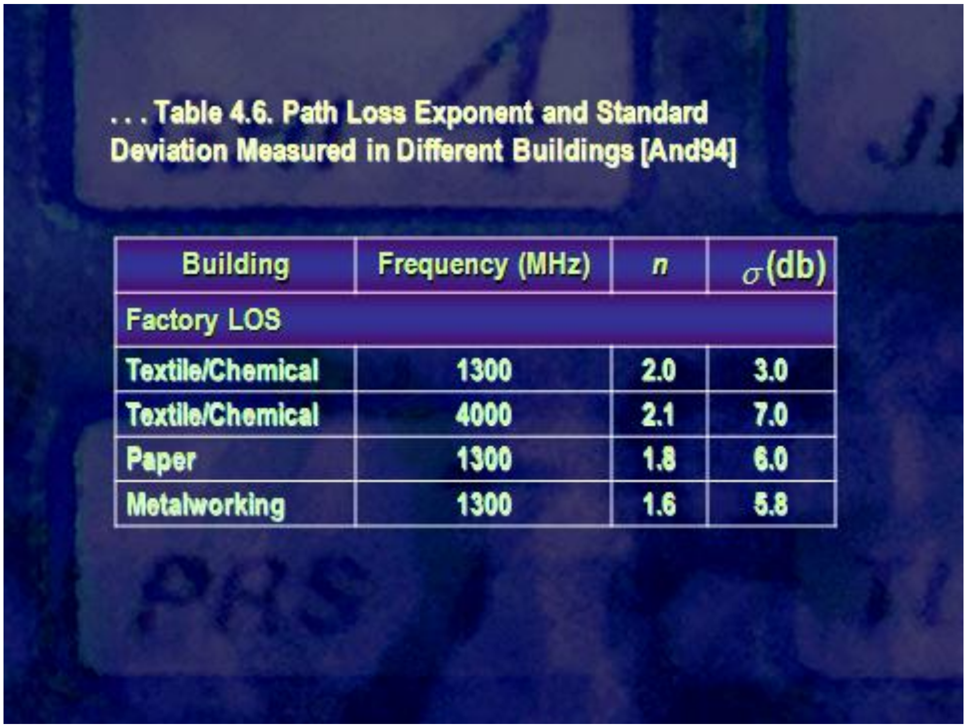


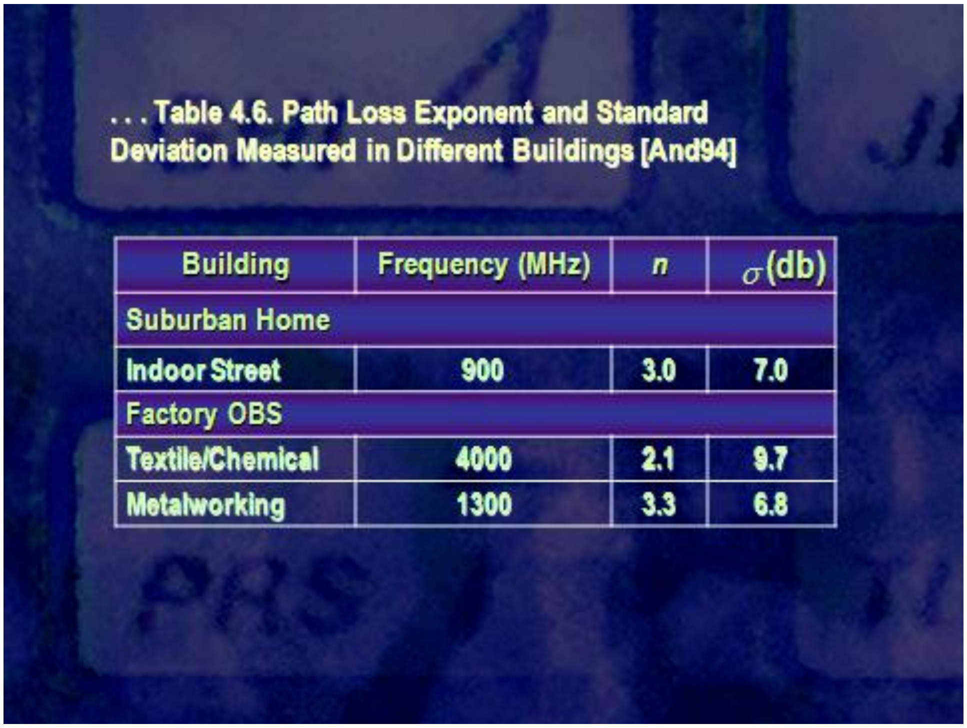
Table 4.6. Path Loss Exponent and Standard Deviation Measured in Different Buildings [And94]

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



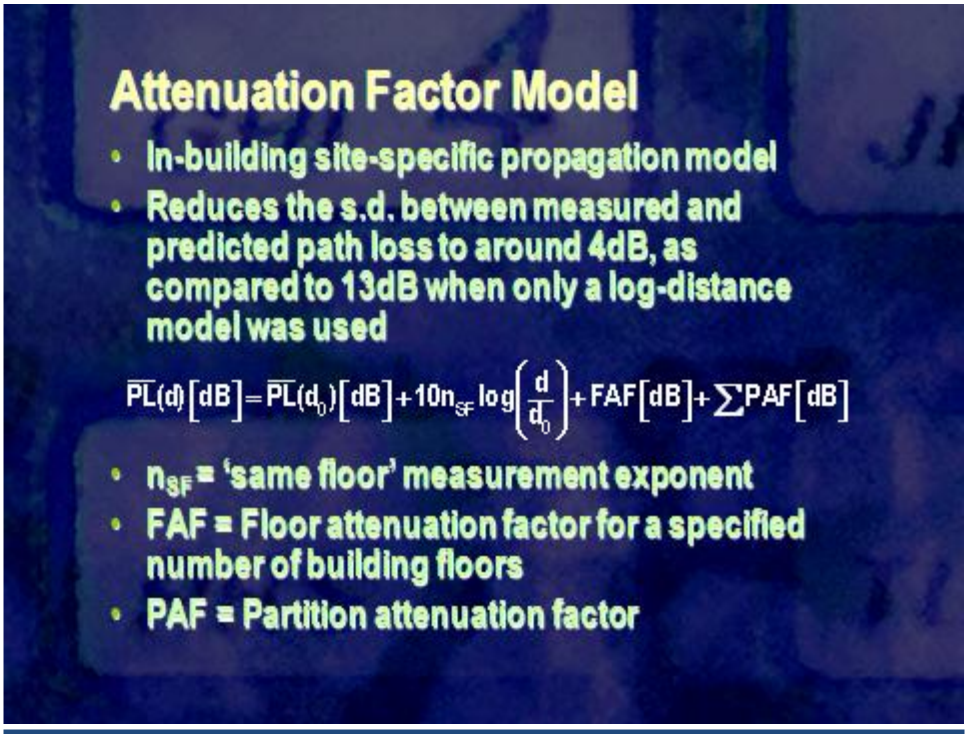
. . . Table 4.6. Path Loss Exponent and Standard Deviation Measured in Different Buildings [And94]

Building	Frequency (MHz)	*n*	σ(db)
Factory LOS			
Textile/Chemical	1300	2.0	3.0
Textile/Chemical	4000	2.1	7.0
Paper	1300	1.8	6.0
Metalworking	1300	1.6	5.8



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

Building	Frequency (MHz)	*n*	σ(db)
Suburban Home			
Indoor Street	900	3.0	7.0
Factory OBS			
Textile/Chemical	4000	2.1	9.7
Metalworking	1300	3.3	6.8



Attenuation Factor Model

- In-building site-specific propagation model
- Reduces the s.d. between measured and predicted path loss to around 4dB, as compared to 13dB when only a log-distance model was used

$$\overline{PL}(d)\left[dB\right]=\overline{PL}(d_0)\left[dB\right]+10n_{SF}\log\left(\frac{d}{d_0}\right)+FAF\left[dB\right]+\sum PAF\left[dB\right]$$

- n_{SF} = 'same floor' measurement exponent
- FAF = Floor attenuation factor for a specified number of building floors
- PAF = Partition attenuation factor

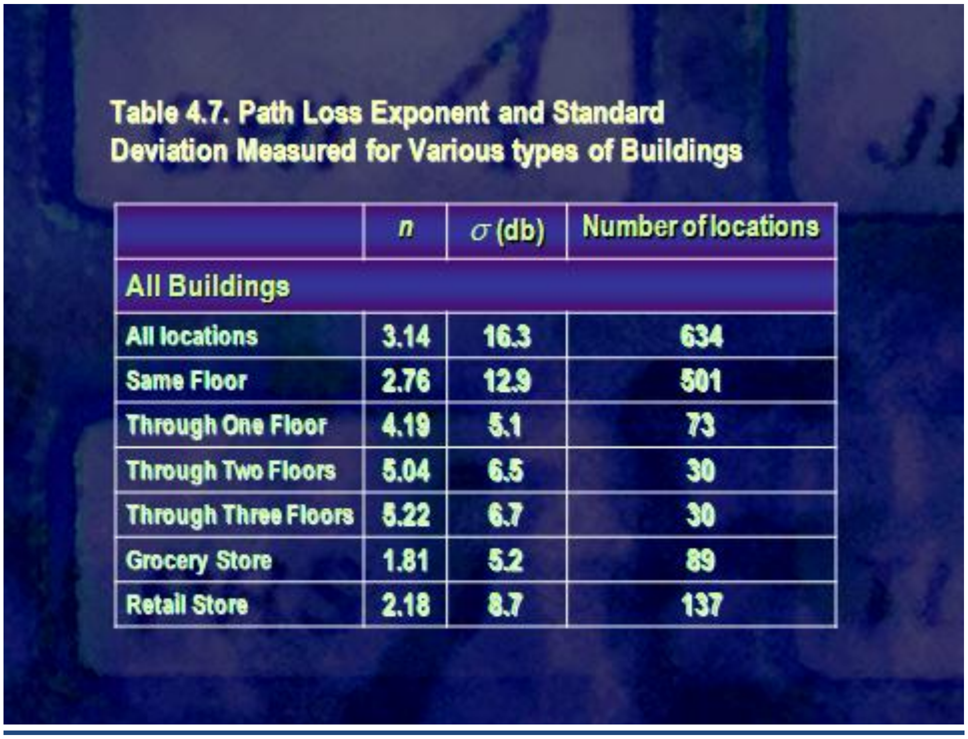
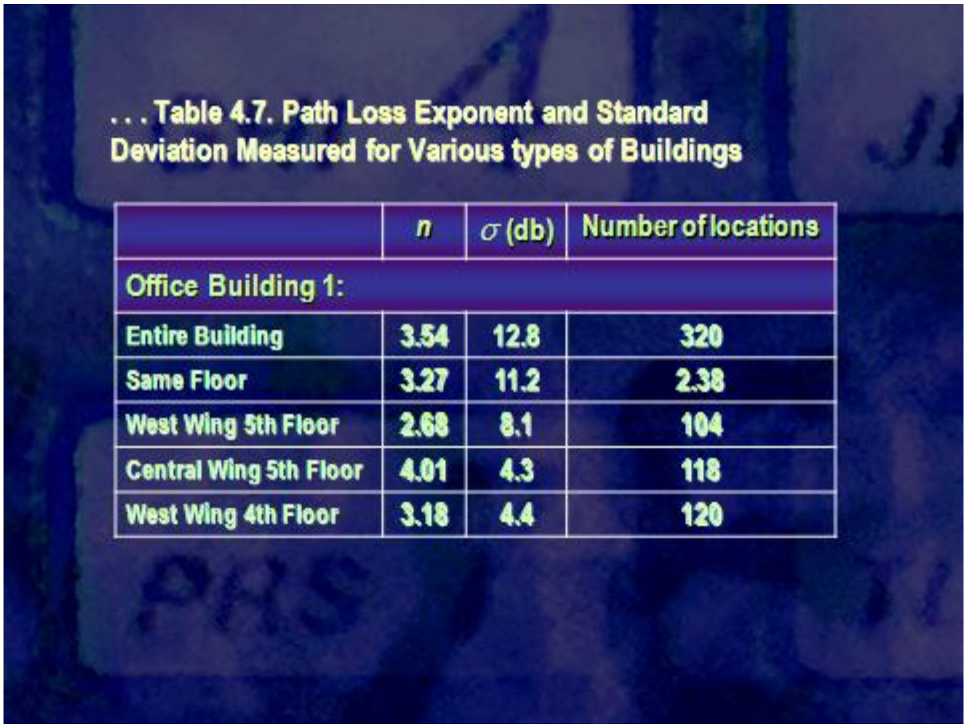


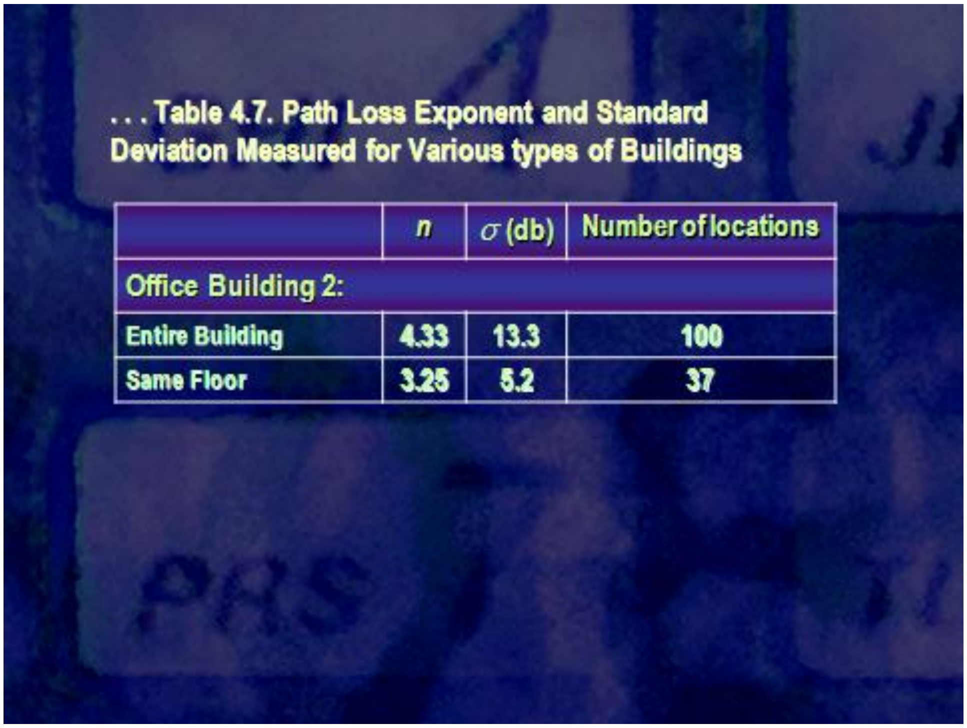
Table 4.7. Path Loss Exponent and Standard Deviation Measured for Various types of Buildings

	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



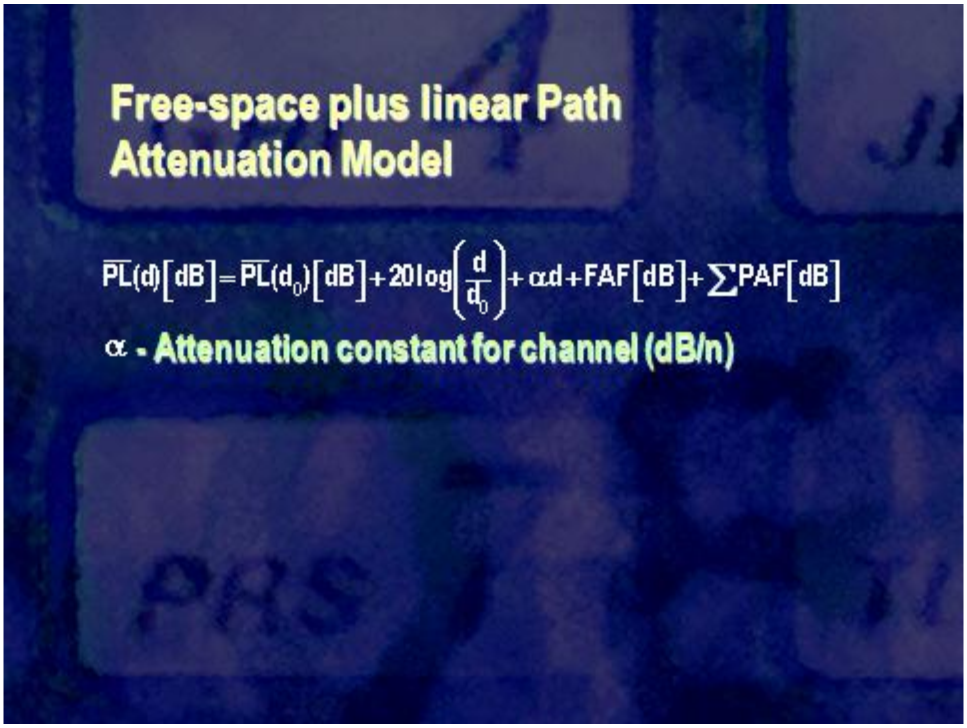
. . . Table 4.7. Path Loss Exponent and Standard Deviation Measured for Various types of Buildings

	n	σ (db)	Number of locations
Office Building 1:			
Entire Building	3.54	12.8	320
Same Floor	3.27	11.2	2.38
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



. . . Table 4.7. Path Loss Exponent and Standard Deviation Measured for Various types of Buildings

	n	σ (db)	Number of locations
Office Building 2:			
Entire Building	4.33	13.3	100
Same Floor	3.25	5.2	37



Free-space plus linear Path Attenuation Model

$$\overline{PL}(d)\left[dB\right]=\overline{PL}(d_0)\left[dB\right]+20\log\left(\frac{d}{d_0}\right)+\alpha d+FAF\left[dB\right]+\sum PAF\left[dB\right]$$

α - Attenuation constant for channel (dB/n)

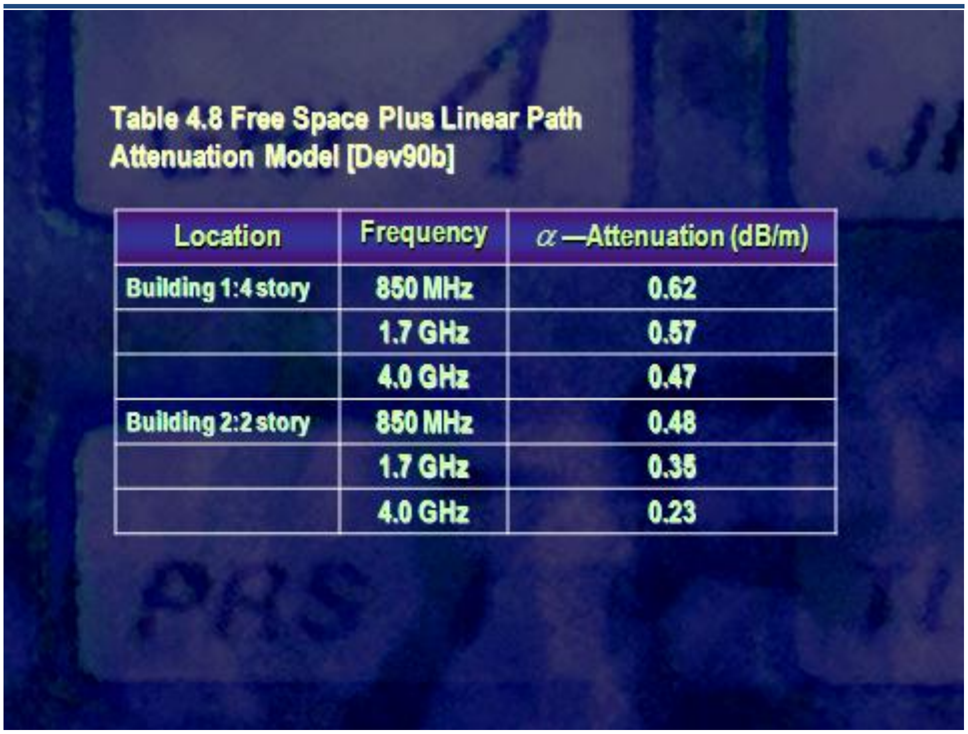


Table 4.8 Free Space Plus Linear Path Attenuation Model [Dev90b]

Location	Frequency	α —Attenuation (dB/m)
Building 1:4 story	850 MHz	0.62
	1.7 GHz	0.57
	4.0 GHz	0.47
Building 2:2 story	850 MHz	0.48
	1.7 GHz	0.35
	4.0 GHz	0.23

Longley-Rice Model

- Point-to-point from 40MHZ to 100GHz. irregular terrain model (ITS).
- Predicts median transmission loss, Takes terrain into account, Uses path geometry, Calculates diffraction losses
- Inputs:
  - Frequency
  - Path length
  - Polarization and antenna heights
  - Surface refractivity
  - Effective radius of earth
  - Ground conductivity
  - Ground dielectric constant
  - Climate
- Disadvantages
  - Does not take into account details of terrain near the receiver
  - Does not consider Buildings, Foliage, Multipath
- Original model modified by Okamura for urban terrain

Durkin's Model

- Line of sight or non-LOS
- Edge diffractions using Fresnel zone
- The disadvantage are that it can not adequately predict propagation effects due to foliage, building, and it cannot account for multipath propagation.

2-D Propagation Raster data

- Digital elevation models (DEM) United States Geological Survey (USGS)

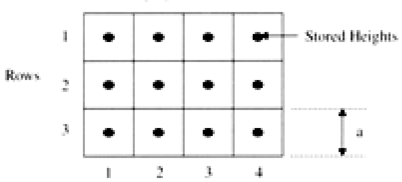
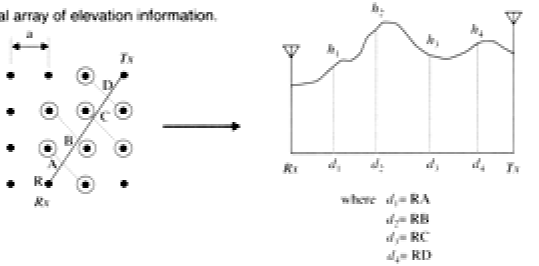


Figure 4.19 Illustration of a two-dimensional array of elevation information.



(a) Top view of interpolated map and line between Tx and Rx

(b) Side view showing reconstructed terrain profile between Tx and Rx

Figure 4.20 Illustration of terrain profile reconstruction using diagonal interpolation.