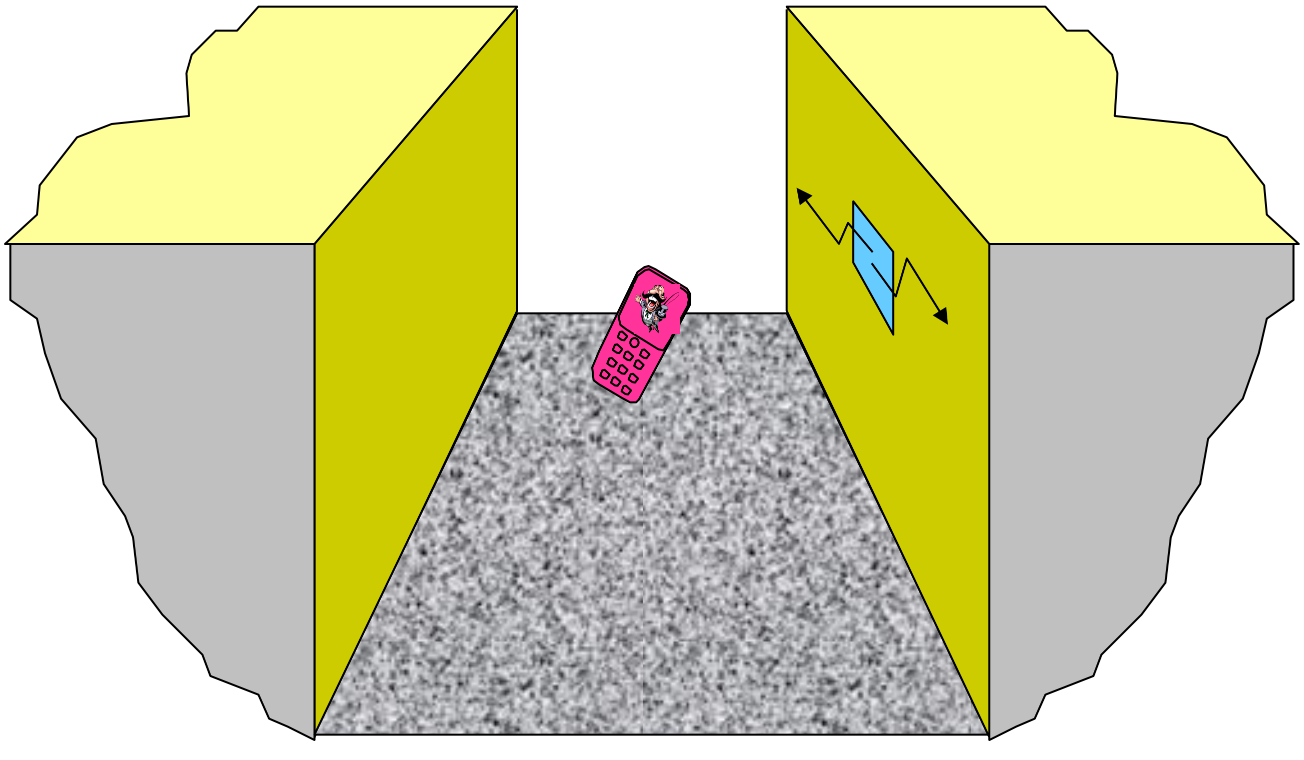
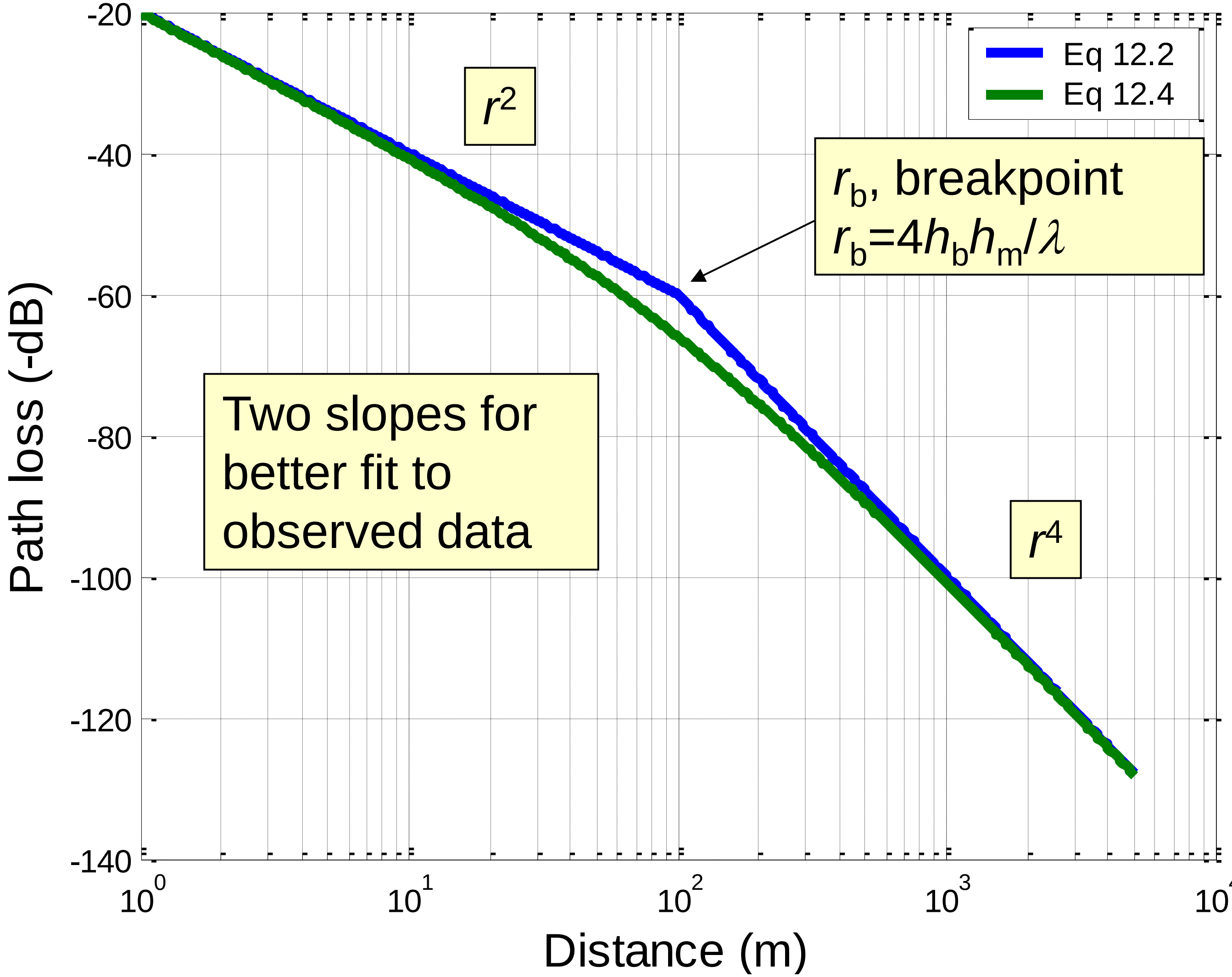
Chapter 12 Microcells

- Microcells
  - Smaller cells for increased capacity
  - Reduce base station height
  - Accurate path loss models needed

Microcell: street canyon



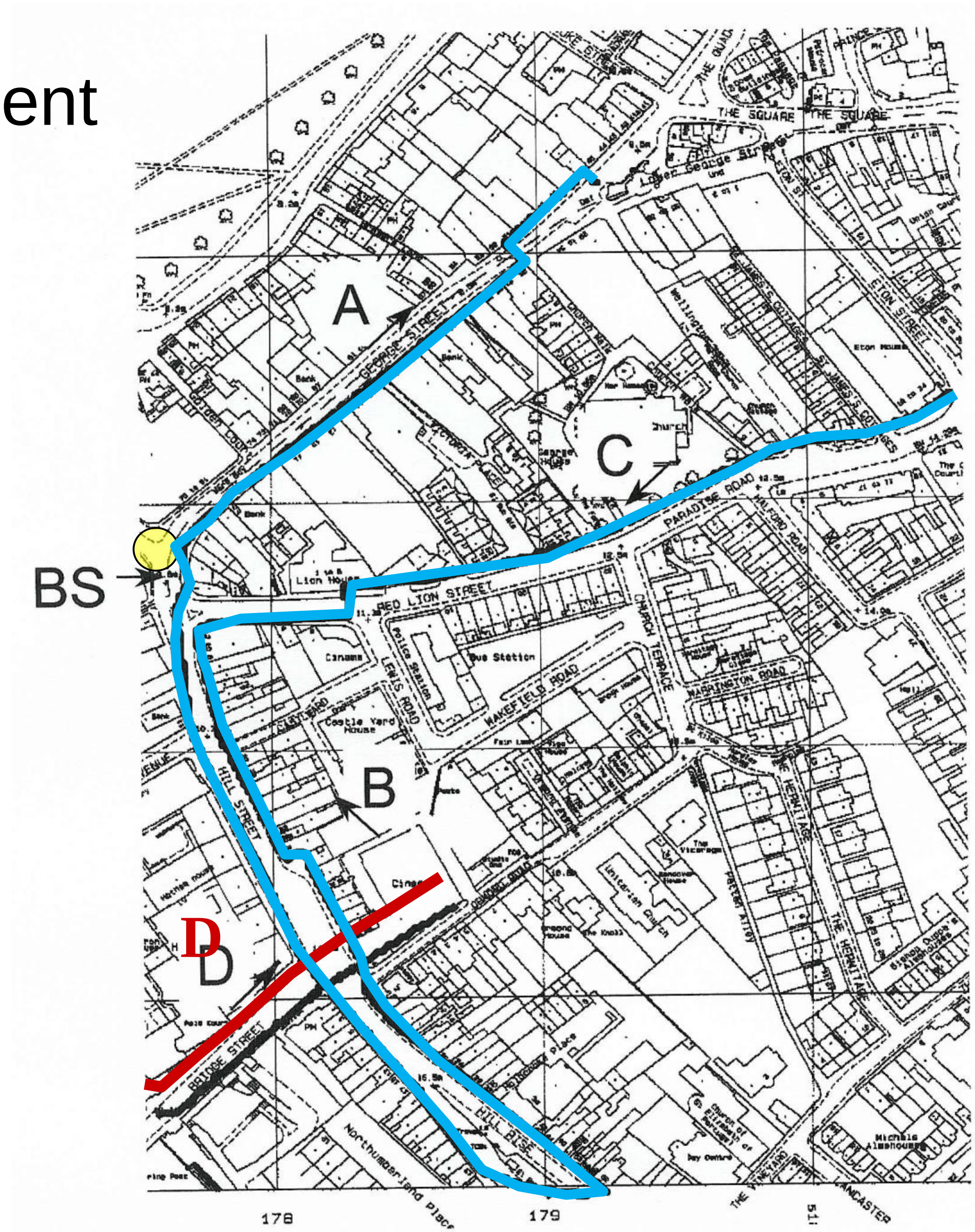
Dual-slope path loss model



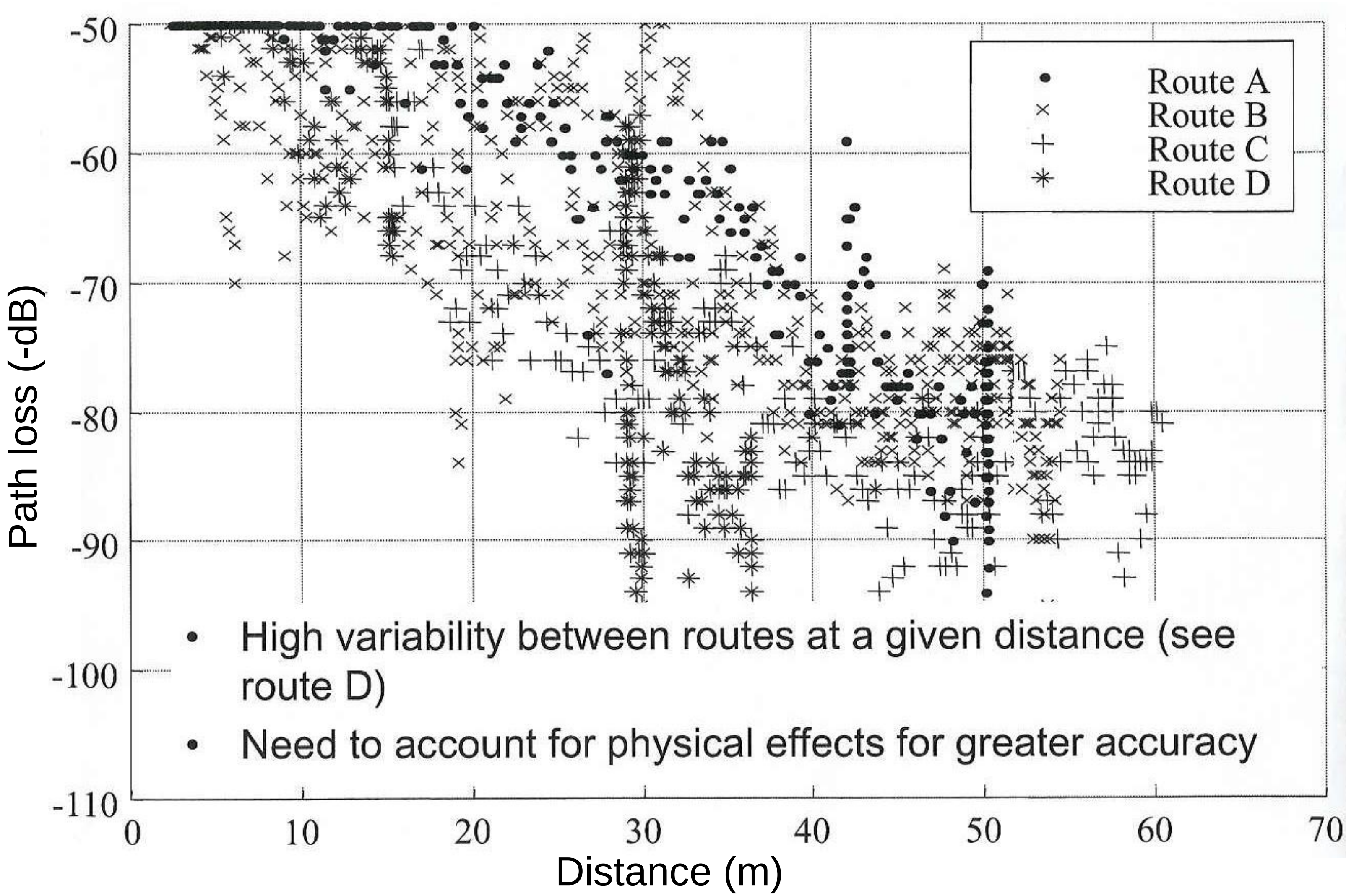
Note Plane Earth model (Ch. 5.6):
$\Delta r \approx 2h_m h_b/r$
Let $\Delta r = \lambda/2$.
Then
$r \approx 4h_m h_b/\lambda$

Street measurement example

- Routes **A**, **B** and **C** are radial, often line-of-sight
- Route **D** is transverse to path, mostly non-line-of-sight



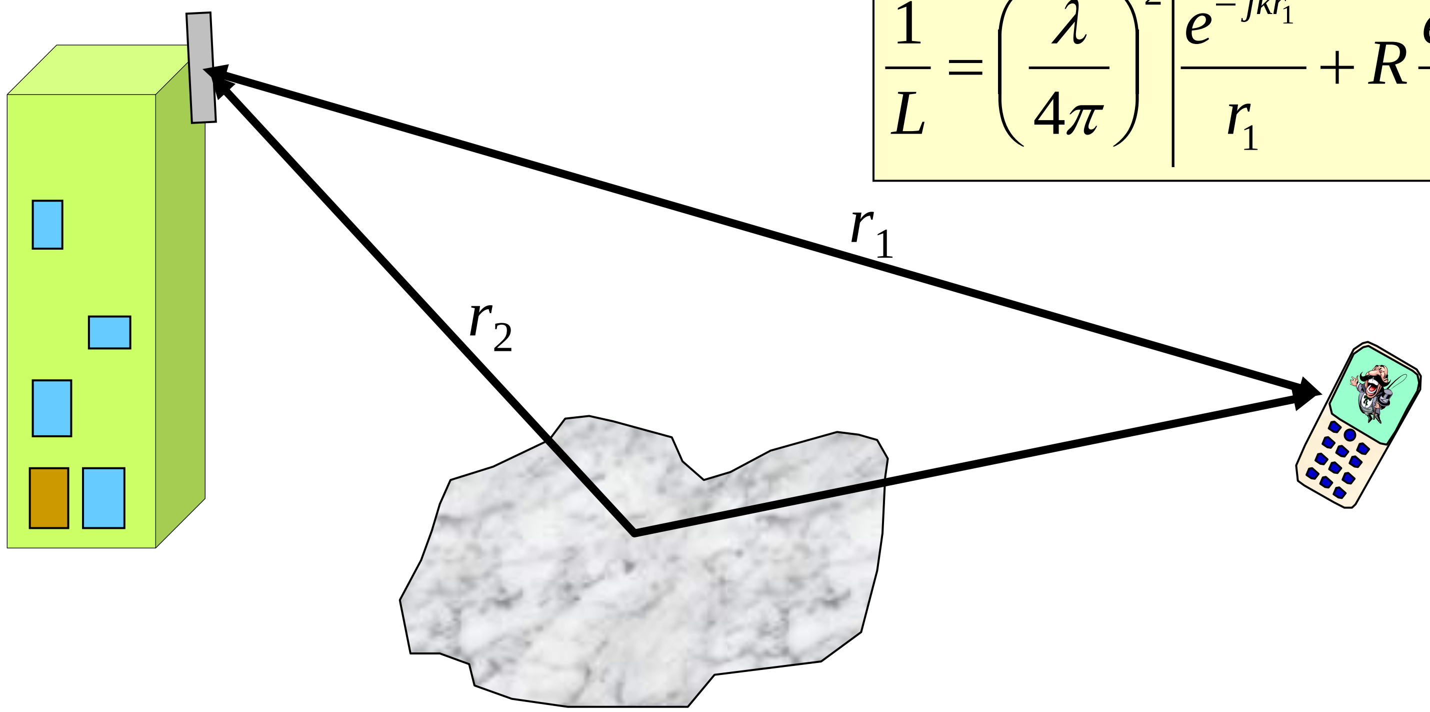
Measurements at 900 MHz



- High variability between routes at a given distance (see route D)
- Need to account for physical effects for greater accuracy

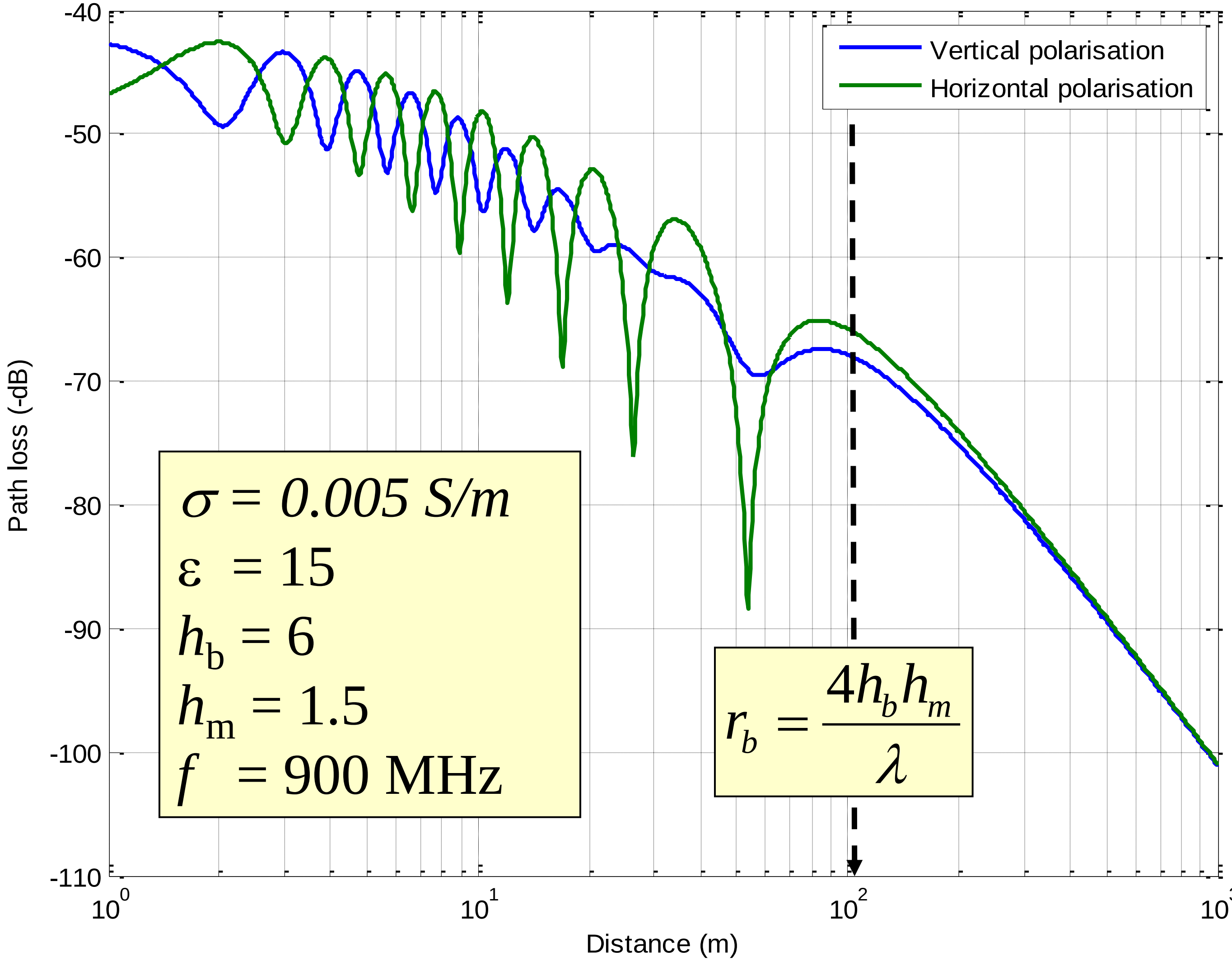
Line-of-sight physical model

$$\frac{1}{L} = \left(\frac{\lambda}{4\pi}\right)^2 \left| \frac{e^{-jkr_1}}{r_1} + R\frac{e^{-jkr_2}}{r_2} \right|^2$$

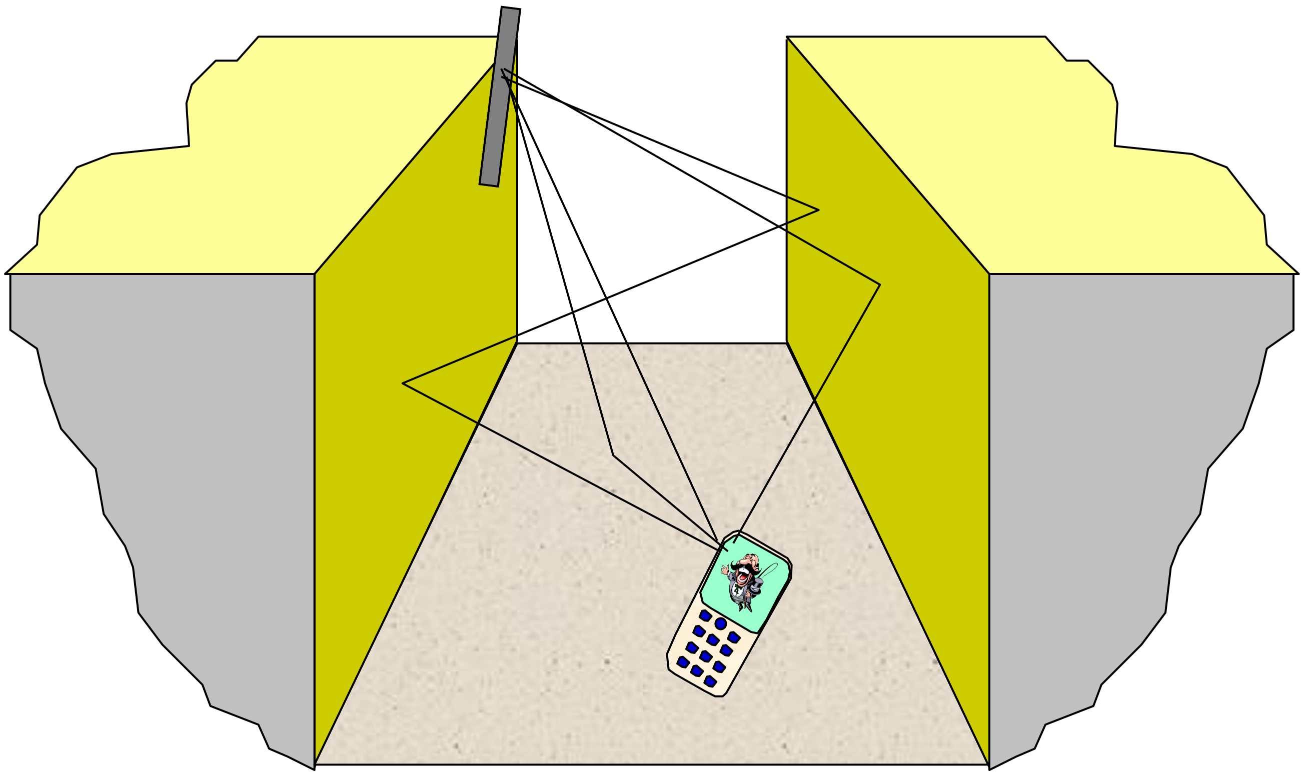


Similar to Plane Earth model, but r_1 and r_2 not necessarily similar. *R* is the reflection coefficient.

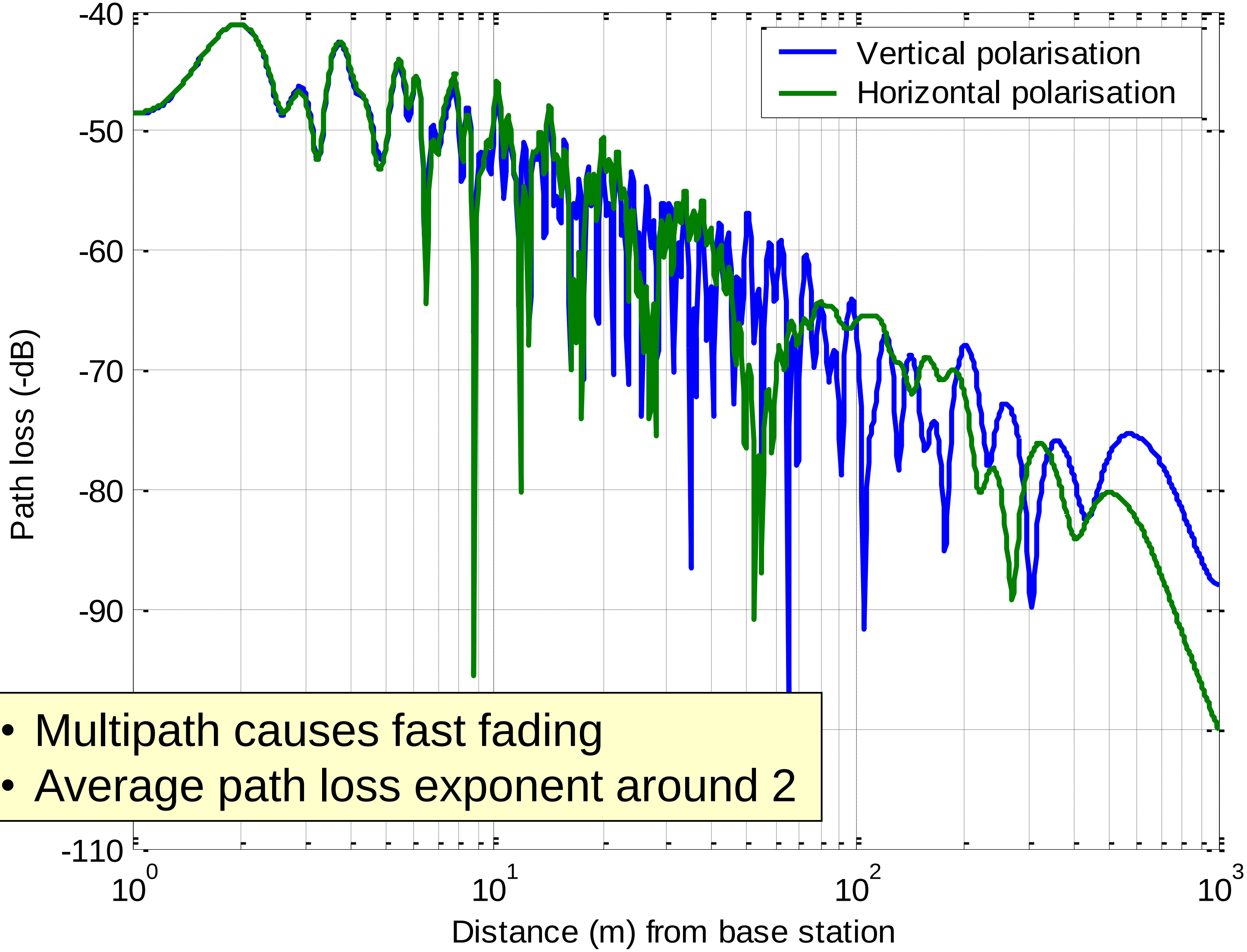
Two-ray predictions



Street canyon geometry

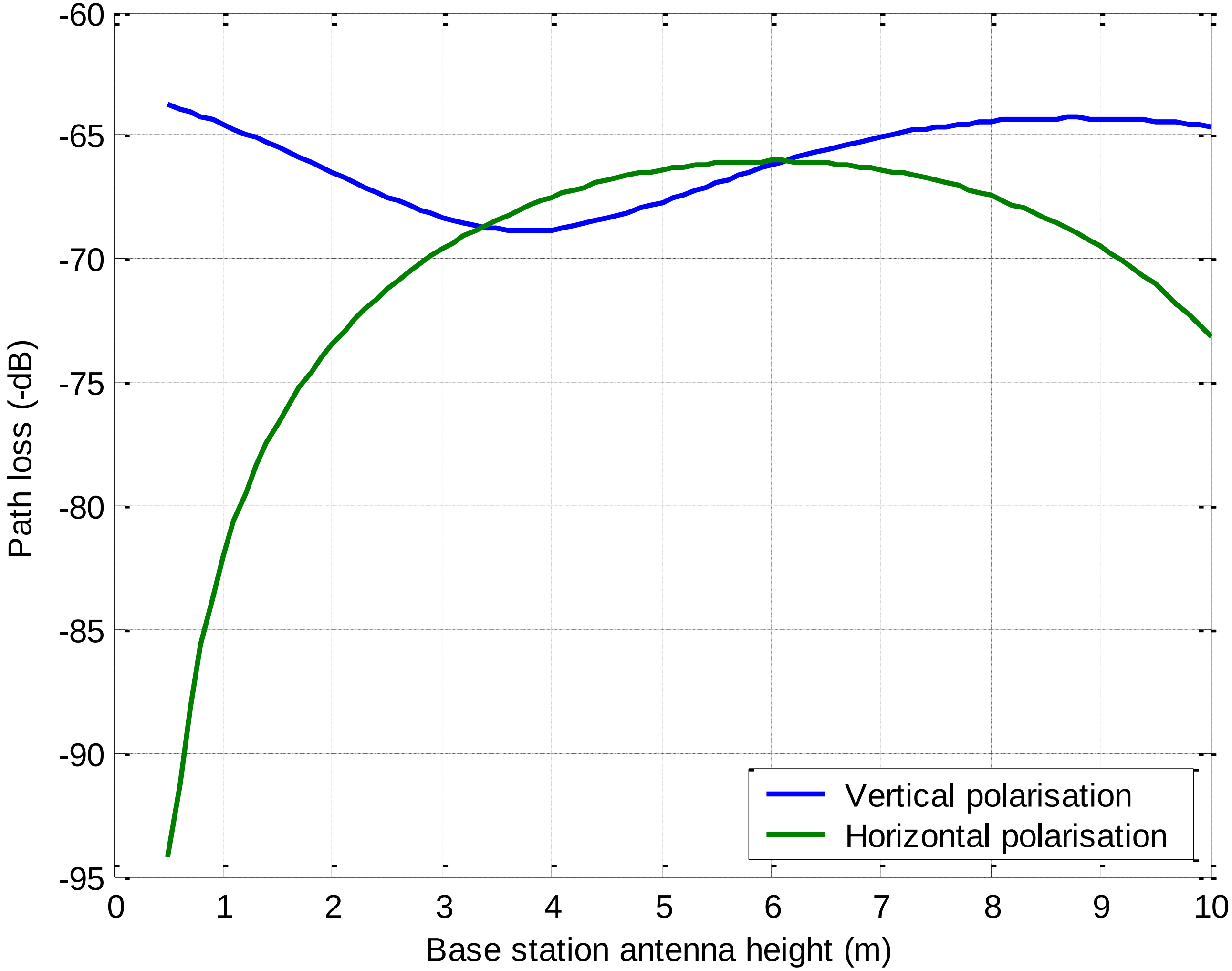


Four-ray predictions



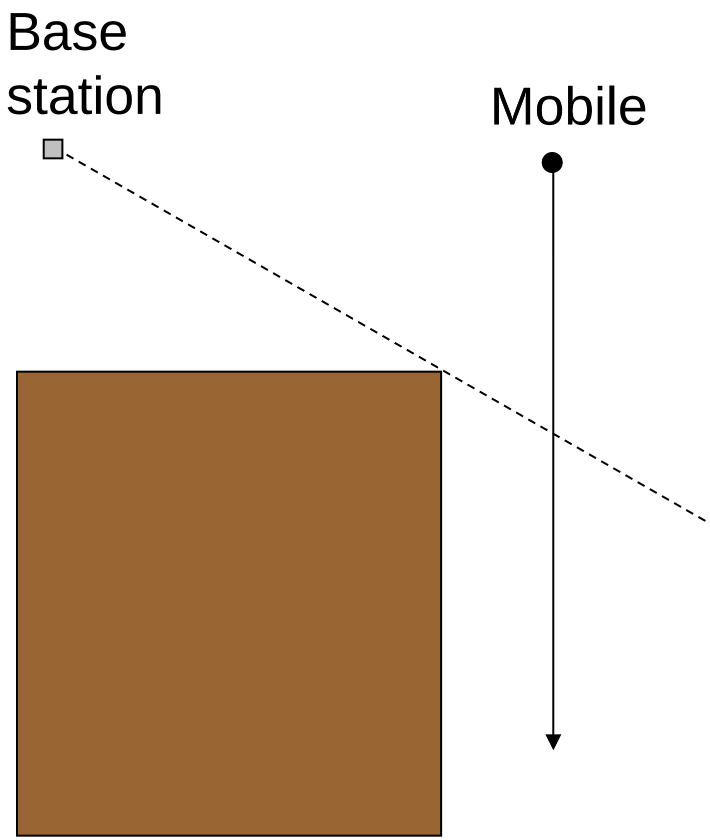
- Multipath causes fast fading
- Average path loss exponent around 2

Effect of base station height evaluated at 100 m

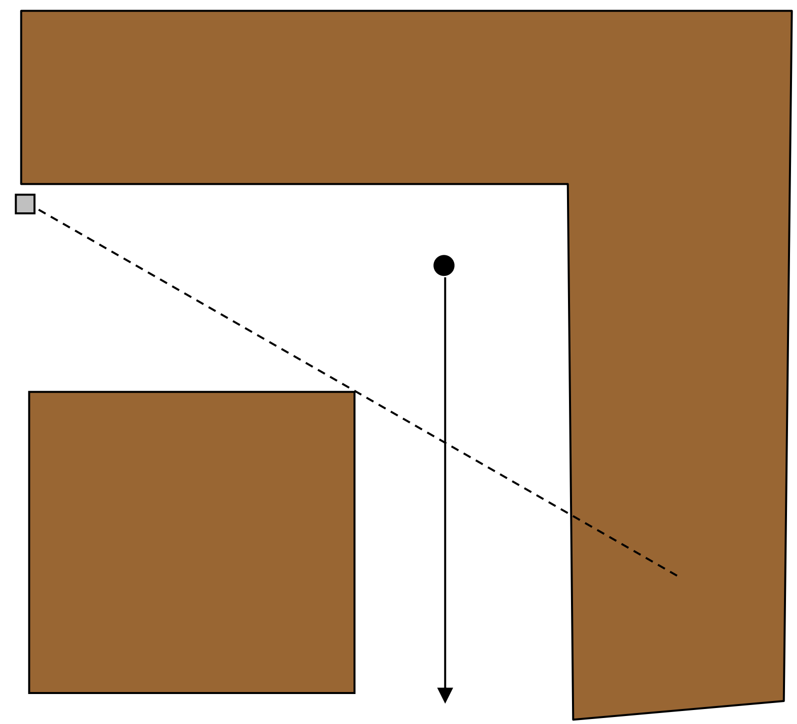


Street geometries

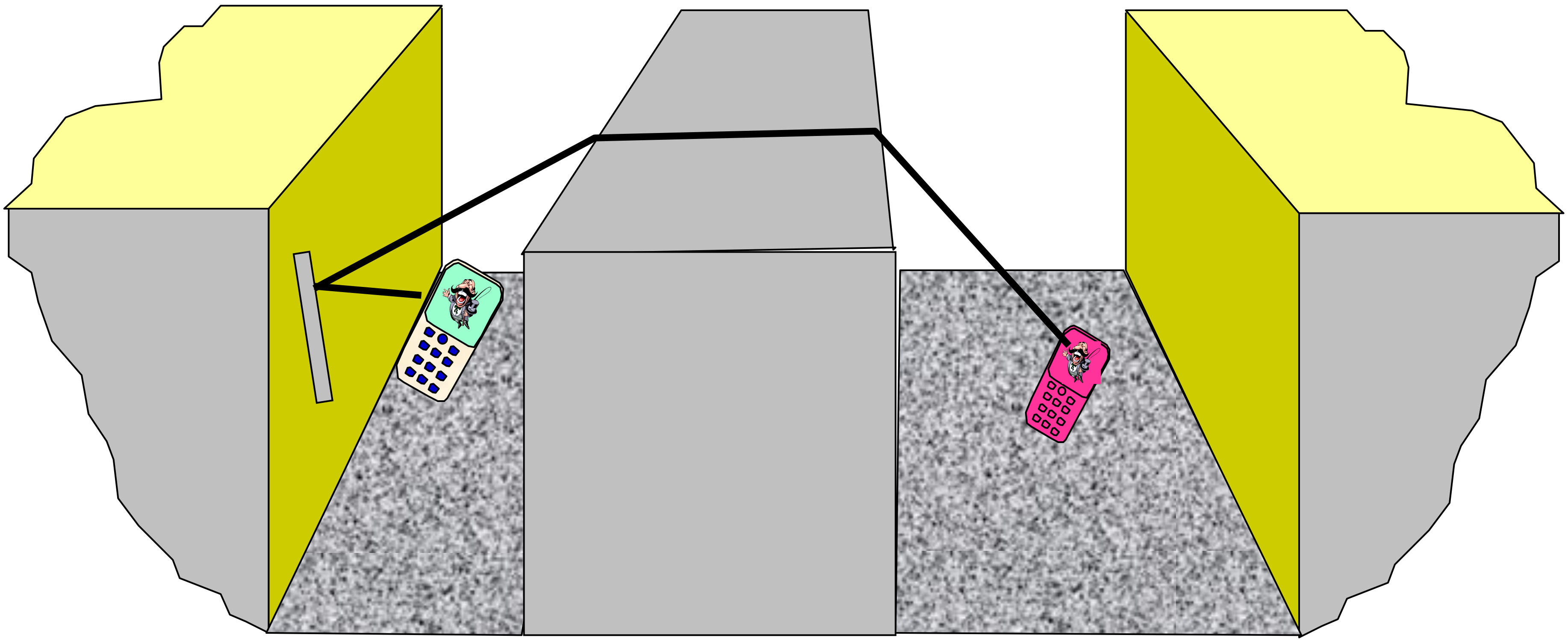
a) Dominating diffraction



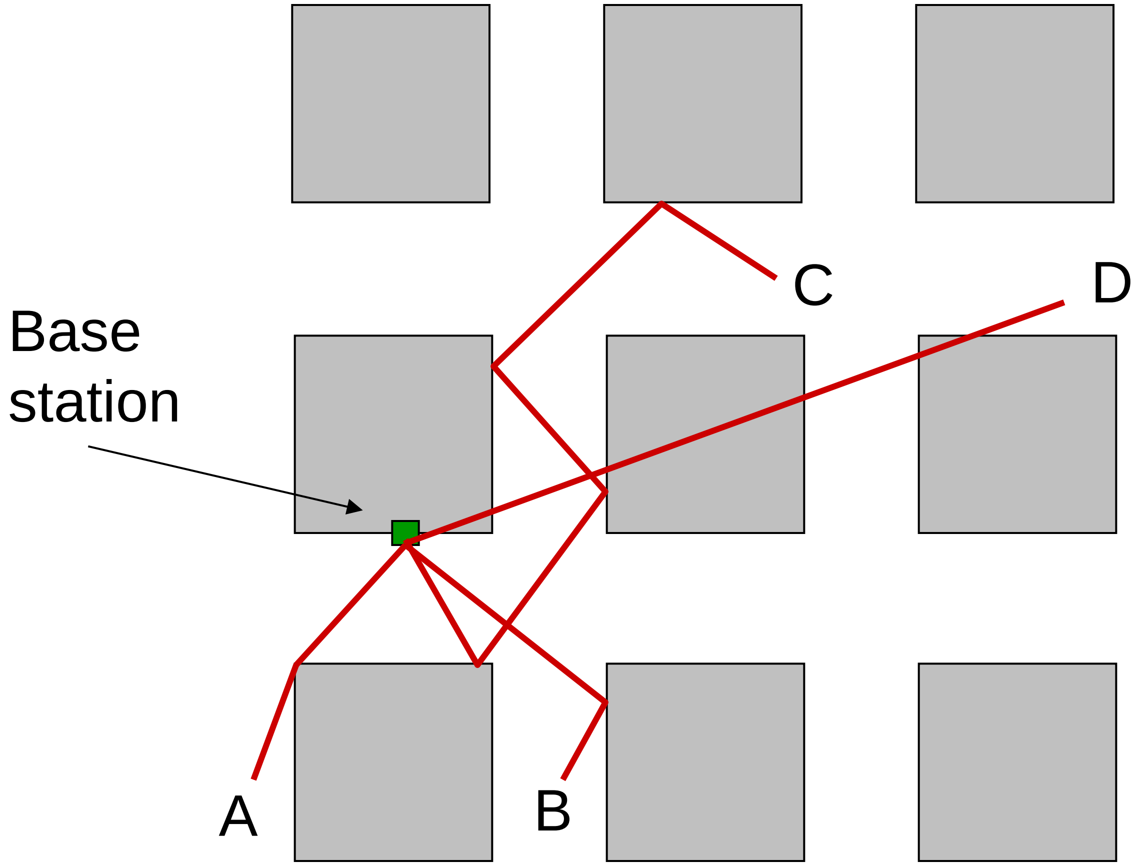
b) Dominating reflection



Rooftop diffraction



Non-LOS propagation mechanisms

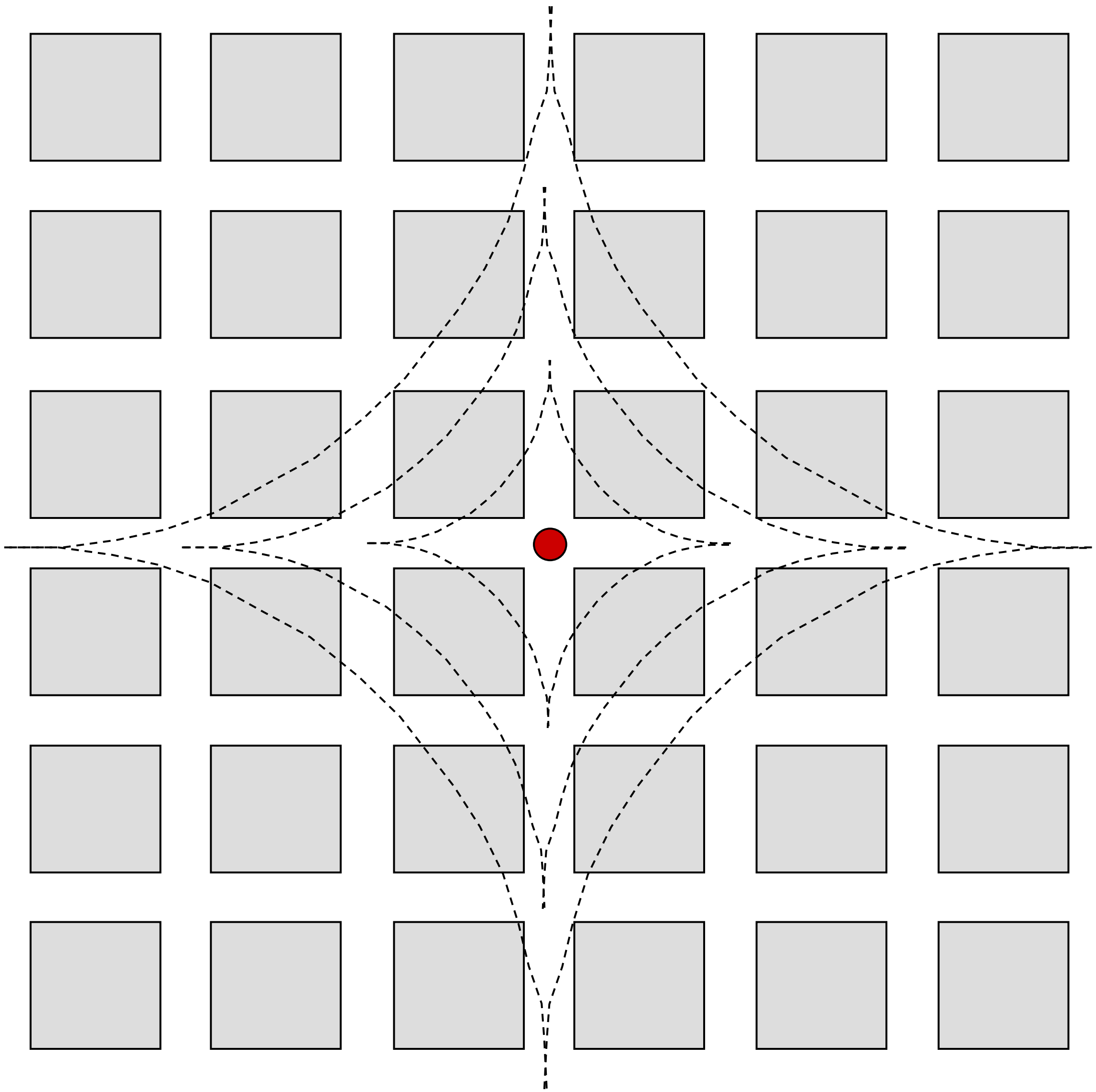


A, **B** strong paths, dominated by diffraction or reflection

C involves multiple reflection so weak relative to roof-top diffracted **D**

Path loss contours

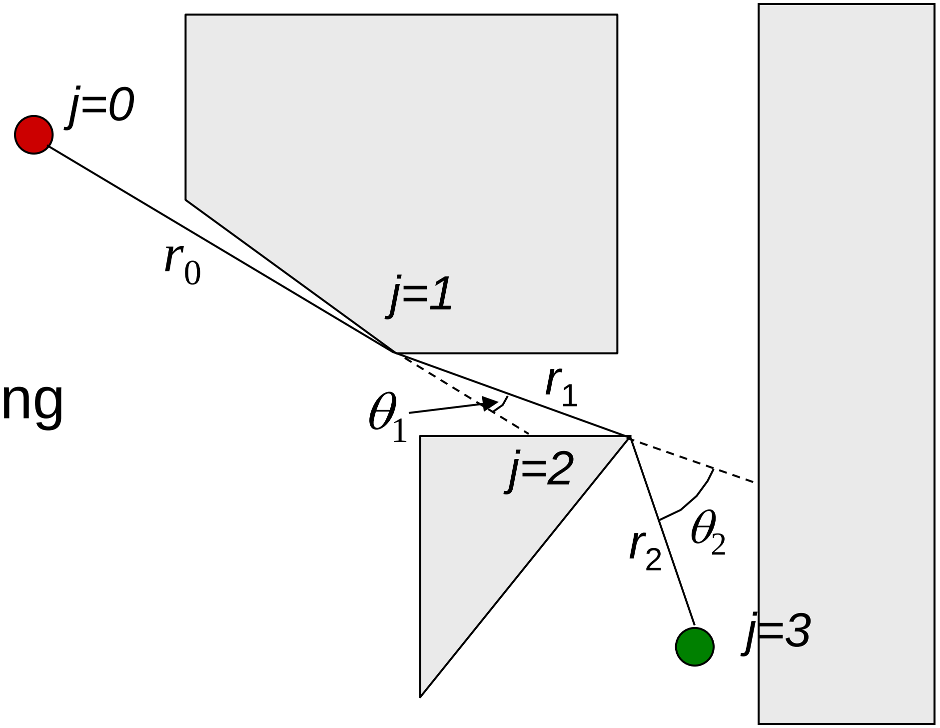
Greater path loss across streets (diffraction) compared to along streets (reflection)



Recursive model

Find illusory distance:

$$d_j = k_j \cdot r_{j-1} + d_{j-1}$$
$$k_j = k_{j-1} + d_{j-1} \cdot q(\theta_{j-1})$$
$$k_0 = 1 \text{ and } d_0 = 0$$



Distance increases with turning angle:

$$q(\theta_j) = \left(\frac{0.5\theta_j}{90} \right)^{1.5}$$

Then path loss has dual-slope behaviour:

$$L = 20 \log \left(\frac{4\pi d_n}{\lambda} D\left(\sum_{j=1}^{n} r_{j-1} \right) \right) \quad \text{where} \quad D(r) = \begin{cases} r / r_b & \text{for } r > r_b \\ 1 & \text{for } r \le r_b \end{cases}$$

$$r_b = 4 h_b h_m / \lambda$$

ITU-R P.1411 Non-line of sight model in street canyon

Method based on multiple knife-edge diffraction

Parameters

w1: street width (m) at base station (BS)

w2: street width (m) at mobile station (MS)

x1: distance (m) from BS to street crossing

x2: distance (m) from MS to street crossing

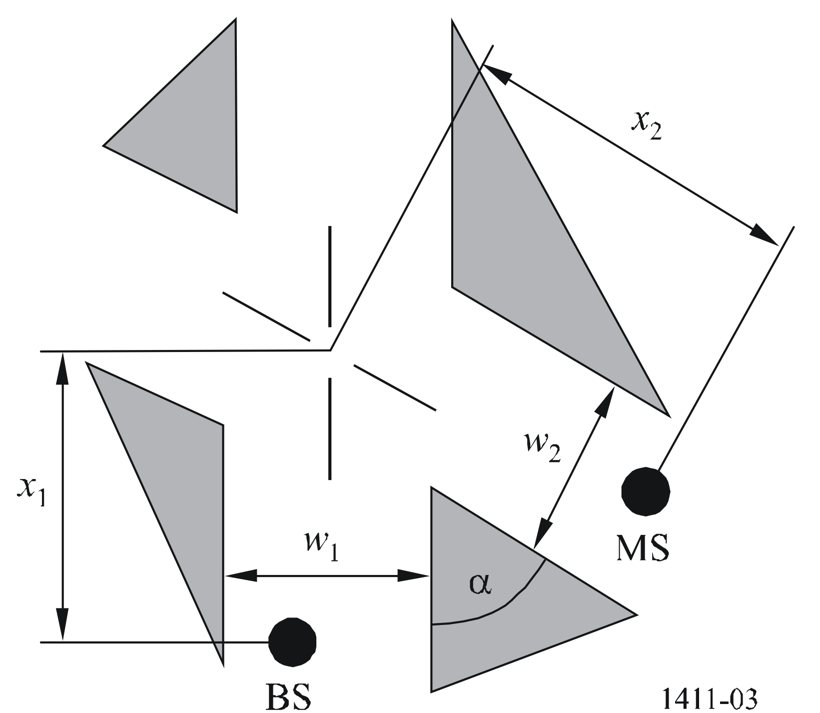
α: angle (rad) of corner

$$L_{NLoS2} = -10\log\left(10^{-L_r/10} + 10^{-L_d/10}\right)$$

where L_r is the reflection path loss and L_d the diffraction path loss

FIGURE 3

Definition of parameters for the NLoS2 case



ITU-R P.411 NloS2

$$L_{NLoS2} = -10\log\left(10^{-L_r/10} + 10^{-L_d/10}\right)$$

$$L_r = 20\log(x_1 + x_2) + x_1 x_2 \frac{f(\alpha)}{w_1 w_2} + 20\log\left(\frac{4\pi}{\lambda}\right)$$

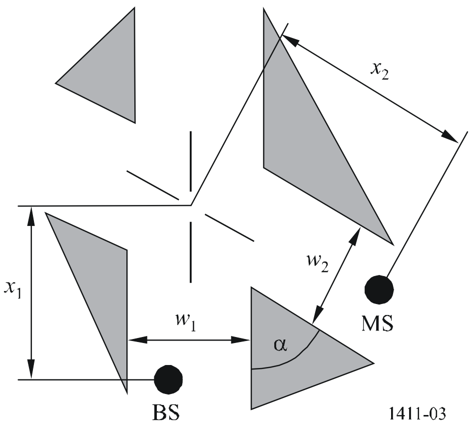
$$\text{where } f(\alpha) = \frac{3.86}{\alpha^{3.5}} \qquad 0.6 < \alpha < \pi$$

$$L_d = 10\log\left[x_1 x_2 (x_1 + x_2)\right] + 2D_a - 0.1\left(90 - \alpha\frac{180}{\pi}\right) + 20\log\left(\frac{4\pi}{\lambda}\right)$$

$$\text{where } D_a = \left(\frac{40}{2\pi}\right)\left[\arctan\left(\frac{x_2}{w_2}\right) + \arctan\left(\frac{x_1}{w_1}\right) - \frac{\pi}{2}\right]$$

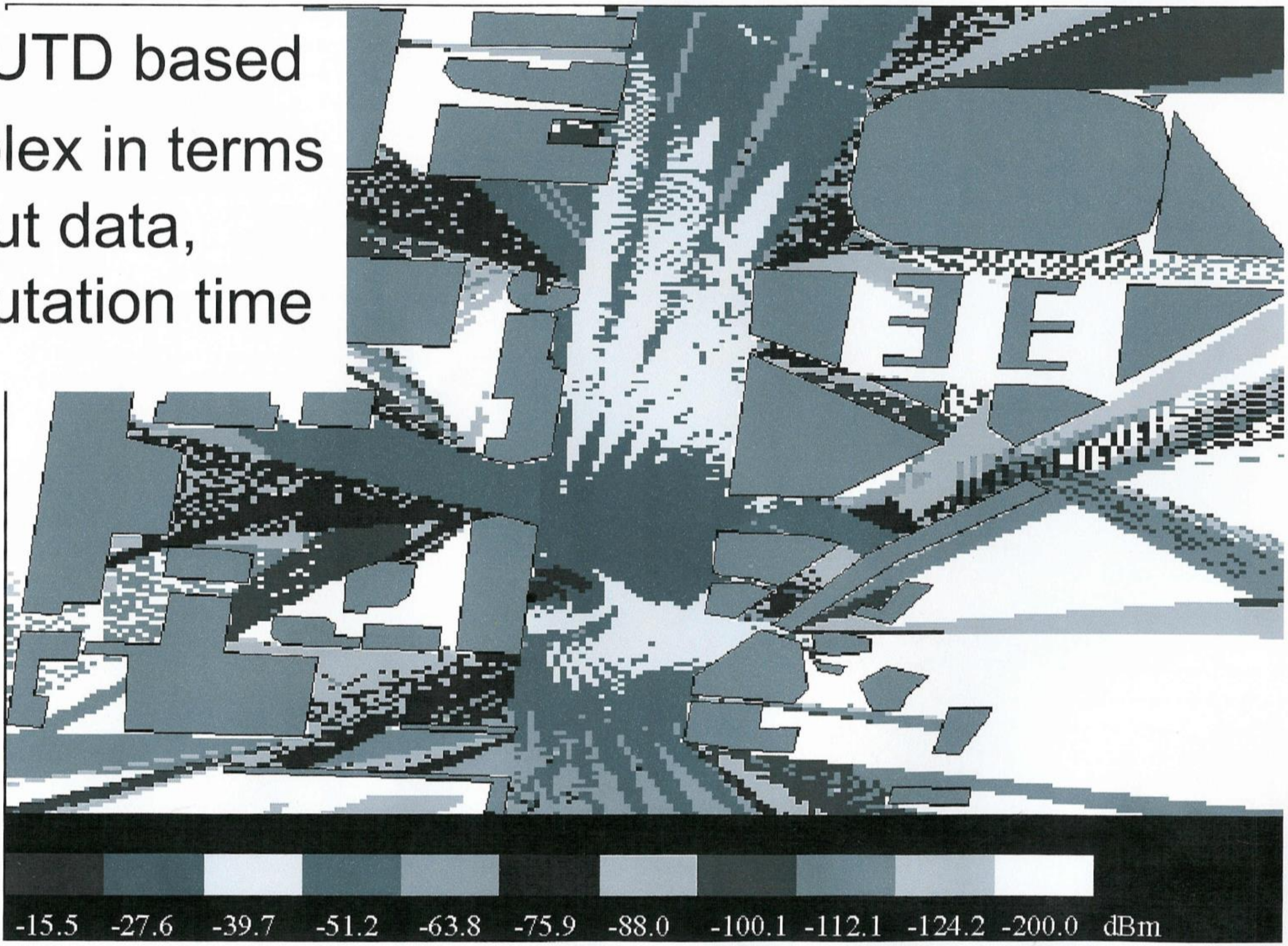
FIGURE 3

Definition of parameters for the NLoS2 case

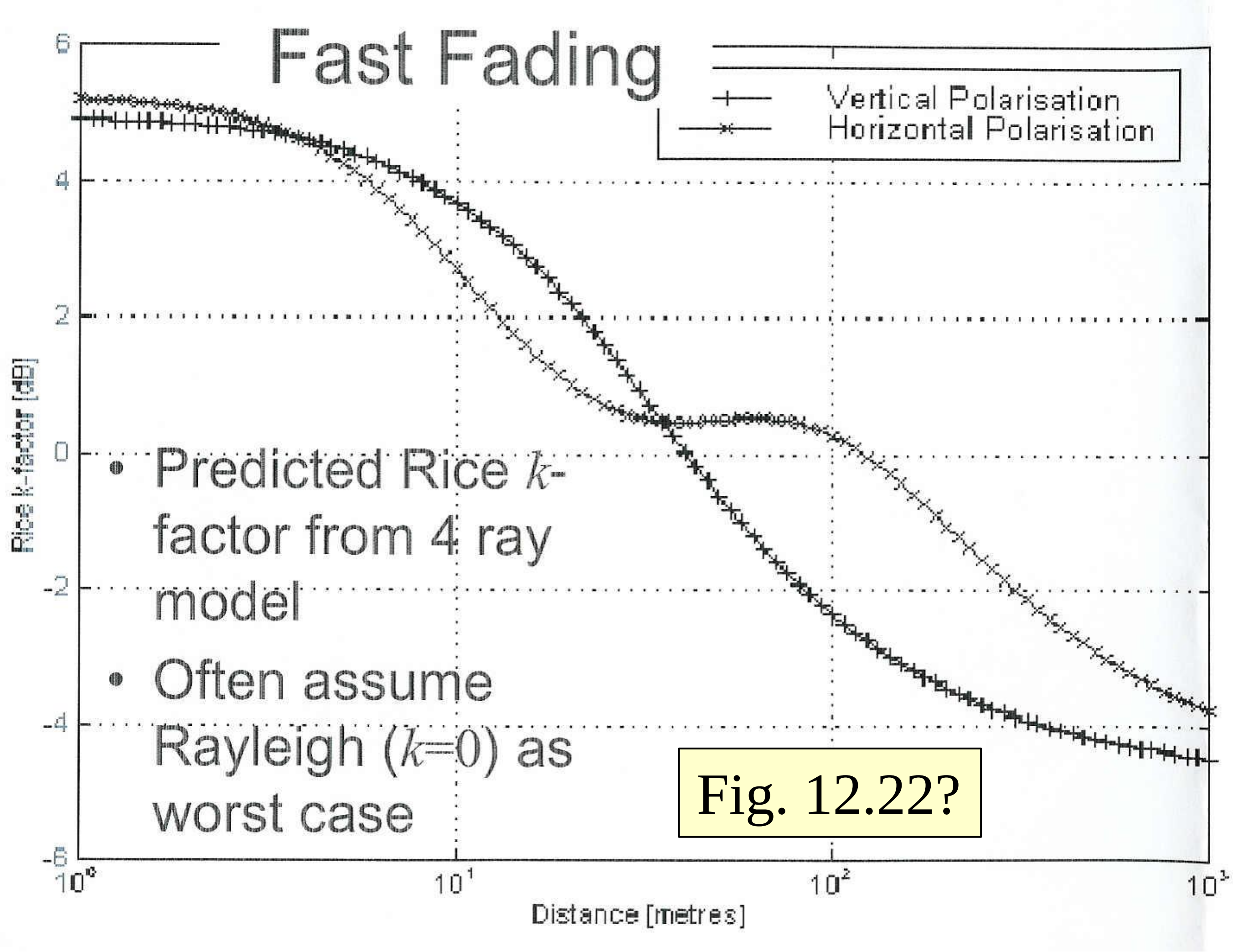


Site specific ray model

- GTD/UTD based
- Complex in terms of input data, computation time



Narrowband Rician fading



Wideband effects

- Reduced delay spread
- Typical RMS delay spread about 0.5 μs
- Of interest as wideband applications are becoming more important

ITU-R P.1411 microcell delay spread model

Delay spread follow normal distribution with mean a_s and standard deviation σ_s, given with parameters from the table. Developed for 2.5-15.75 GHz and 50 to 400 m distances.

$$a_s = C_a d^{\gamma_a}$$

$$\sigma_s = C_\sigma d^{\gamma_\sigma}$$

<table>
<tr><th colspan="4">Measurement conditions</th><th colspan="2">aa_s</th><th colspan="2">s_s</th></tr>
<tr><th>Area</th><th>f (GHz)</th><th>h_b (m)</th><th>h_m (m)</th><th>C_a</th><th>γ_a</th><th>C_s</th><th>γ_s</th></tr>
<tr><td rowspan="5">Urban</td><td>2.5</td><td>6.0</td><td>3.0</td><td>55</td><td>0.27</td><td>12</td><td>0.32</td></tr>
<tr><td rowspan="2">3.35-15.75</td><td rowspan="3">4.0</td><td>2.7</td><td>23</td><td>0.26</td><td>5.5</td><td>0.35</td></tr>
<tr><td>1.6</td><td rowspan="2">10</td><td rowspan="2">0.51</td><td rowspan="2">6.1</td><td rowspan="2">0.39</td></tr>
<tr><td>3.35-8.45</td><td>0.5</td></tr>
<tr><td>8.05</td><td>5</td><td>2.5</td><td>0.97</td><td>0.78</td><td>1.42</td><td>0.52</td></tr>
<tr><td rowspan="2">Residential</td><td>3.35</td><td rowspan="2">4.0</td><td>2.7</td><td>2.1</td><td>0.53</td><td>0.54</td><td>0.77</td></tr>
<tr><td>3.35-15.75</td><td>1.6</td><td>5.9</td><td>0.32</td><td>2.0</td><td>0.48</td></tr>
</table>

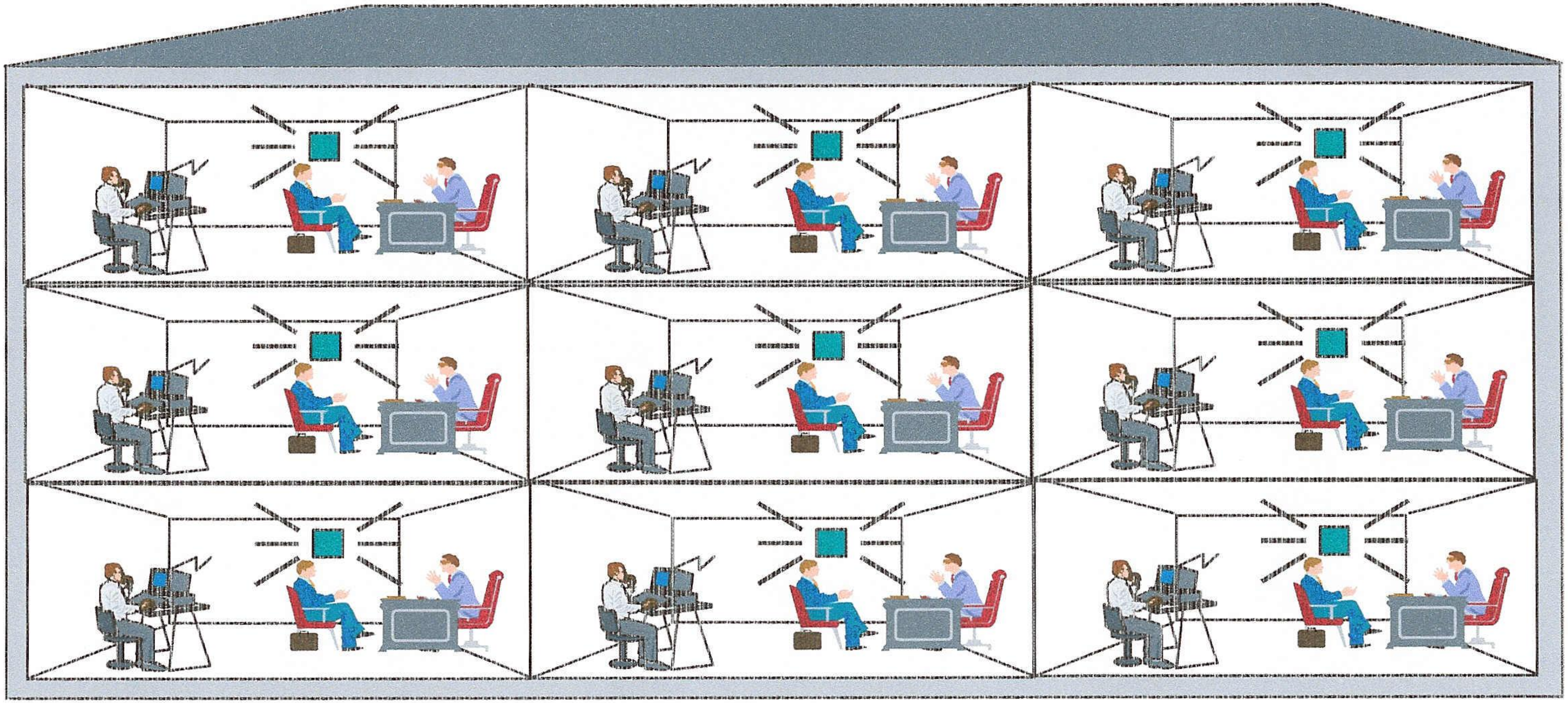
Microcells summary

- Microcells essential for high capacity systems
- Clutter has major effect on cell coverage and interference
- Empirical models require dual slope behaviour
- Physical models attractive (but more complex)
- Antenna patterns often destroyed by clutter

Chapter 13 Picocells

- Picocells
  - Base station inside buildings
  - High telephone density areas (shopping centres etc)
  - High data rate applications (WLAN)
  - In building propagation relevant to macro/micro penetration

Picocells



Pico cell models

- Significantly affected by environment geometry
- Simple path loss models inadequate
- Must account for wall and floor penetration

Empirical methods for indoor propagation

- Based on measured data
- Characterised by distance, perhaps frequency and then walls and floors penetrated
- Fixed wall or floor attenuation only partly dependent on frequency and type of material

Wall and floor factor models

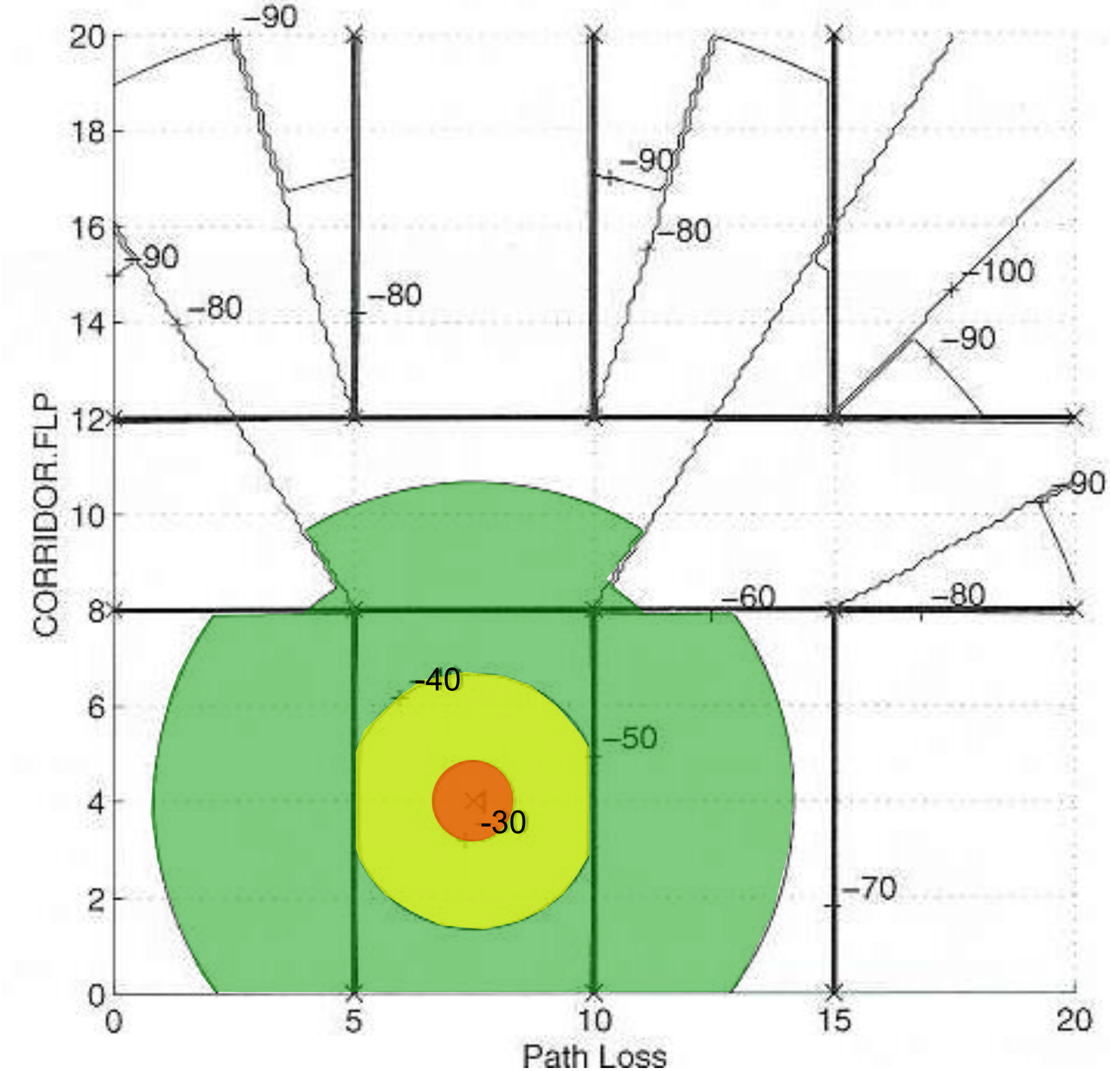
Other empirical methods needed for indoor propagation.

Free space loss (dB) plus attenuation term for each wall and floor intersected by direct path between transmitter and receiver

$$L = L_1 + 20\ \log r + n_f a_f + n_w a_w$$

where n is number and a attenuation factors of floors (f) or walls (w)

Example wall factor prediction



ITU-R model

- Loss per floor dependent on number of floors
- Walls not explicitly accounted for; instead path loss exponent dependent on environment and frequency

$$L_T = 20\log f_c + 10n\log r + L_f(n_f) - 28$$

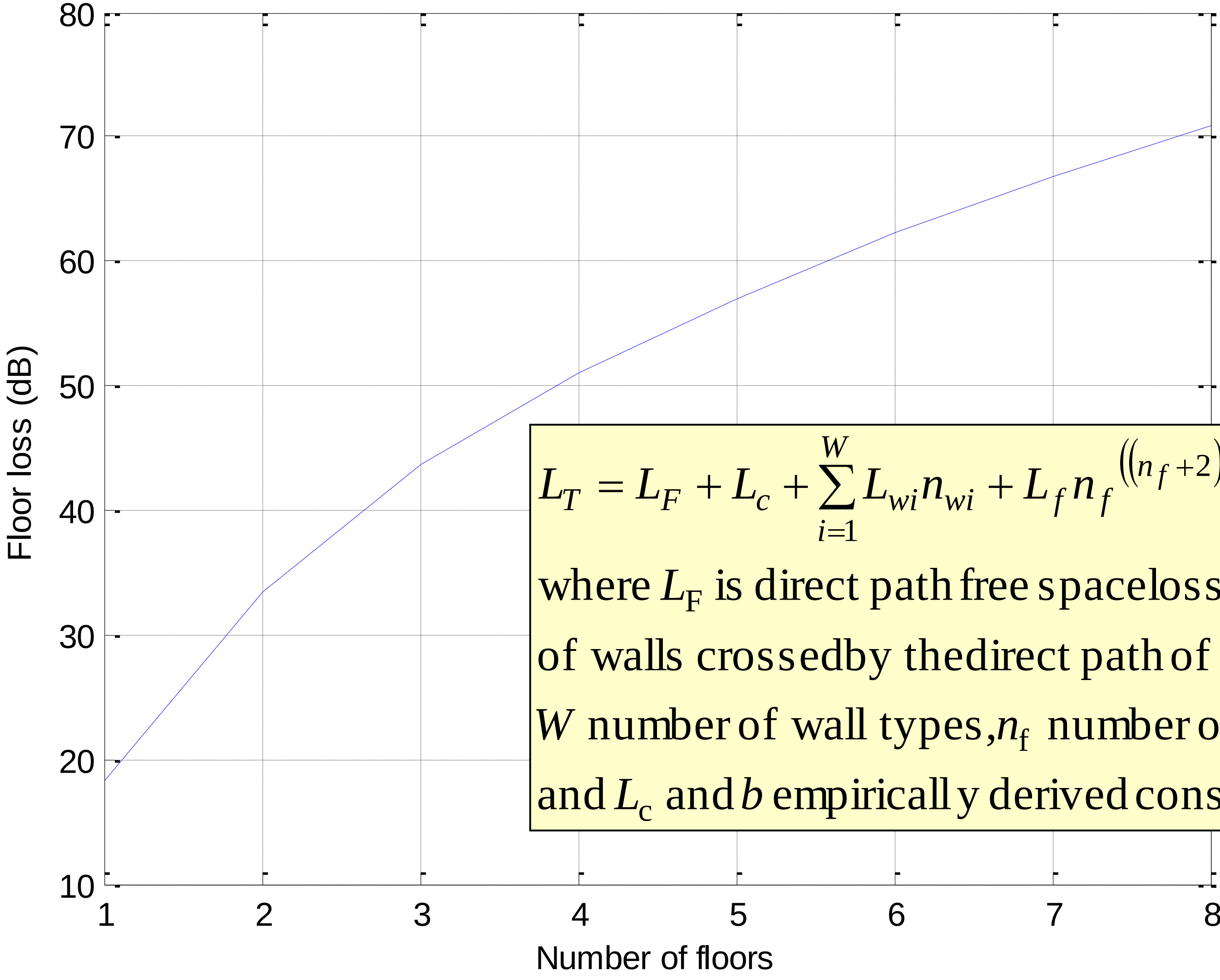
Path loss exponent, *n*

Frequency (GHz)	Environment		
	Residential	Office	Commercial
0.9	-	3.3	2.0
1.2-1.3	-	3.2	2.2
1.8-2.0	2.8	3.0	2.2
4.0	-	2.8	2.2
60	-	2.0	1.7

Floor penetration factor, $L_f(n_f)$

Freq. (GHz)	Environment		
	Res.	Office	Comm.
0.9	-	9 (1 floor)	-
		19 (2 floors)	
		24 (3 floors)	
1.8-2.0	$4n_f$	$15+4(n_f-1)$	$6+3(n_f-1)$

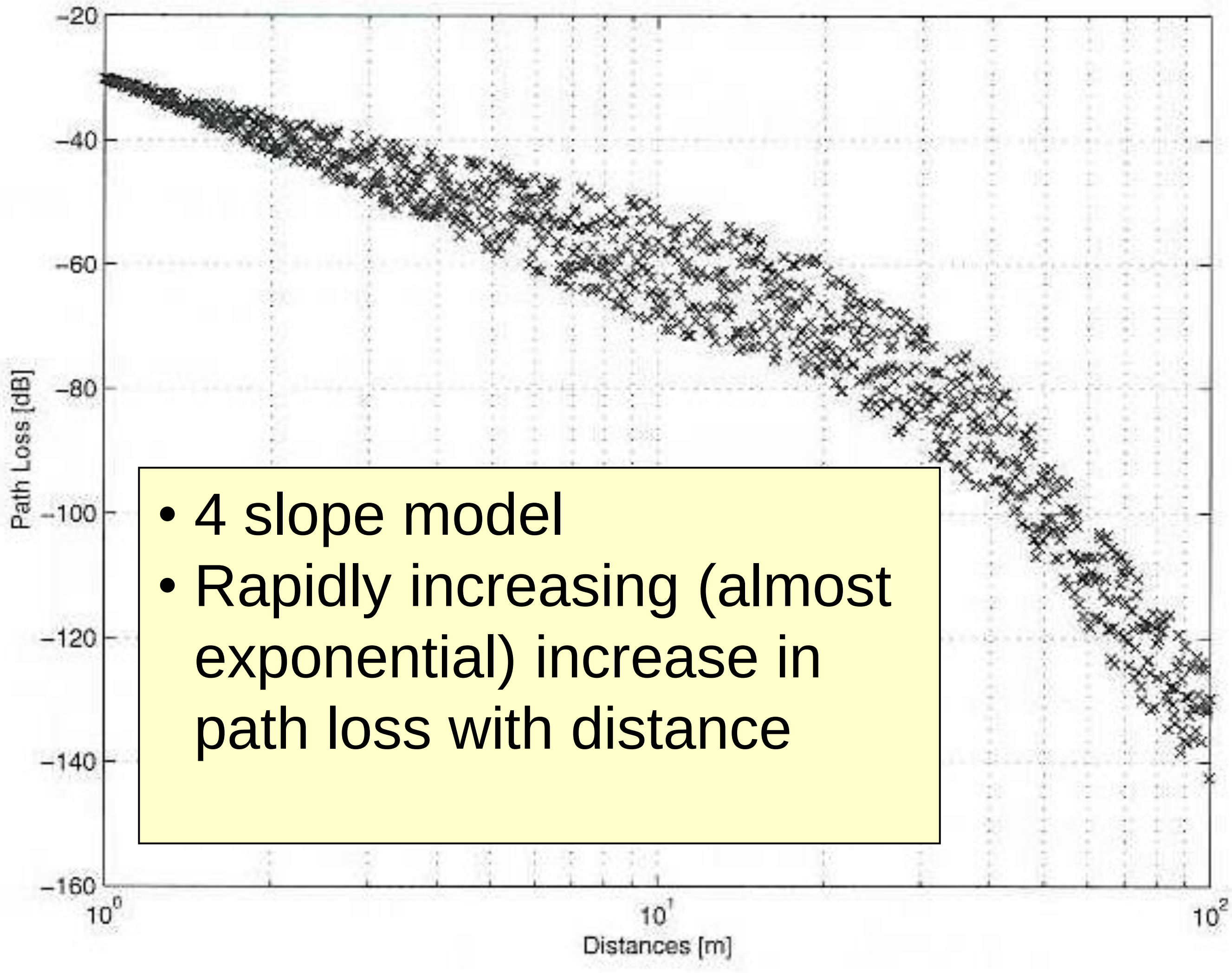
COST 231 multi-wall model



$$L_T = L_F + L_c + \sum_{i=1}^{W} L_{wi} n_{wi} + L_f n_f^{\left(\left(n_f+2\right)/\left(n_f+1\right)-b\right)}$$

where L_F is direct path free space loss, n_{wi} number of walls crossed by the direct path of type i, W number of wall types, n_f number of floors, and L_c and b empirically derived constants

Ericsson model



- 4 slope model
- Rapidly increasing (almost exponential) increase in path loss with distance

Propagation method for wireless local area network

- Empirical method for Wi-Fi (2.4 GHz or 5.2 GHz)

  $L_T = 19.7+37.3\log f +18.3\log r + n_w[21\sin\theta+12.2(1-\sin\theta)] +8.6n_f$

  where θ is the wave incidence angle to the wall
- Obtained in a frequency range 0.9-5.7 GHz and assumed valid for office environments
- Such a model is fitted to measurement data and will need a large number of measurements for various environments. May change with new or other measurements

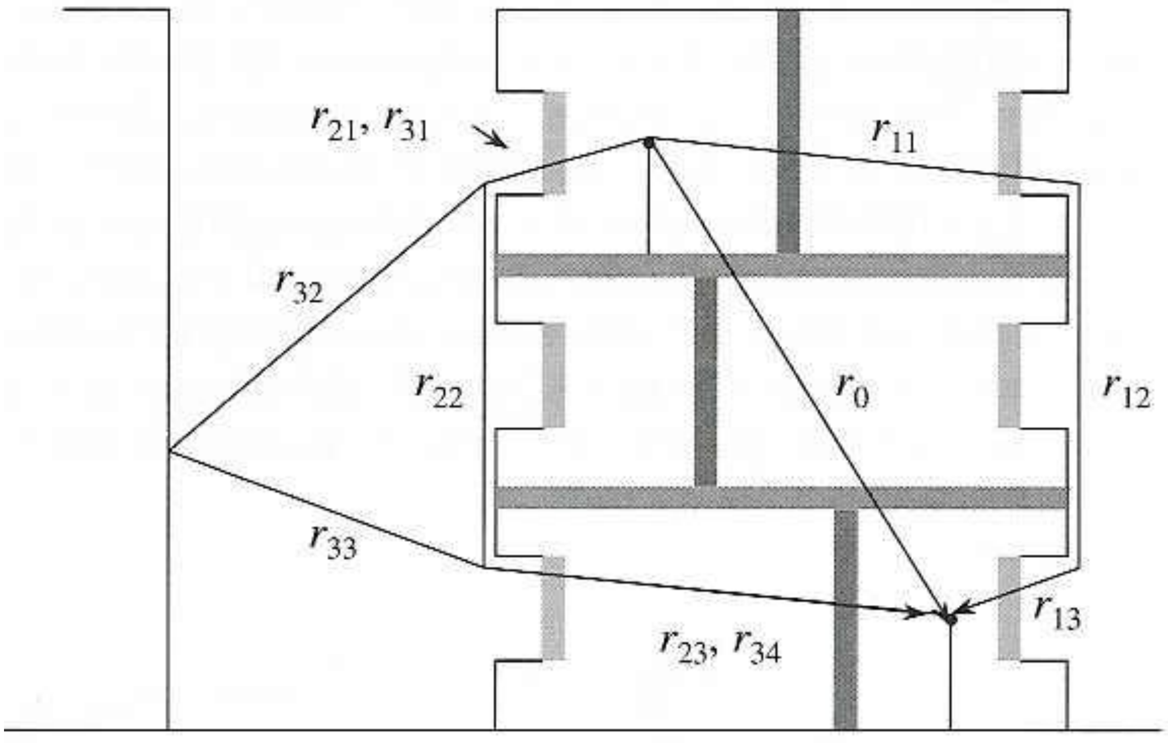
Physical based indoor propagation methods

Ray tracing, here ray *i*

$$E_i = E_0 f_{ti} f_{ri} L_{FSL}(r) \left[\prod_j \bar{R}_j \prod_k \bar{T}_k \prod_l \bar{D}_l A_l \left(S_l, S_l^{'} \right) \right] e^{-jkr}$$

where E is the electric field, f_{ti}, f_{ri} the transmit and receive antenna gains, L_{FSL} the free space loss, *R* the reflection coefficient, *T* the transmission coefficient, D the diffractions coefficient and A the spreading attenuation, and e^{-jkr} the phase factor

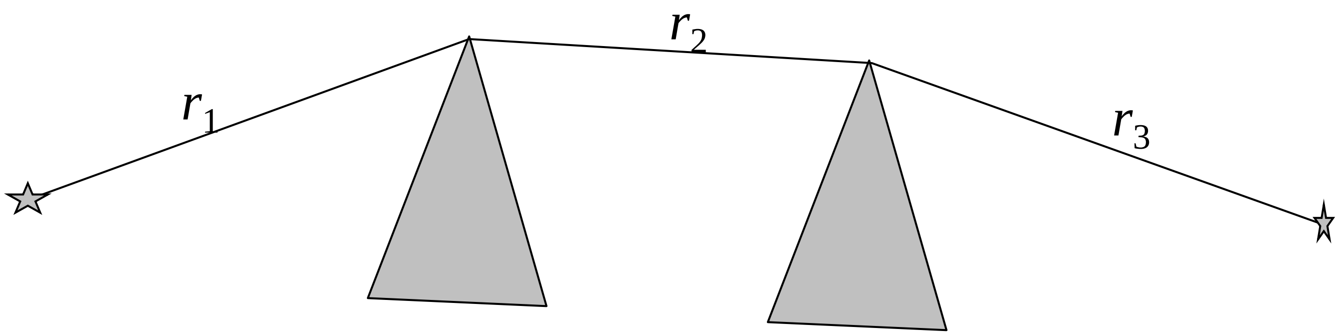
Physical indoor propagation model



For Path 0 $P_r \propto \dfrac{P_T}{r_0^2 \gamma^n}$ where γ is attenuation per floor and *n* number of floors

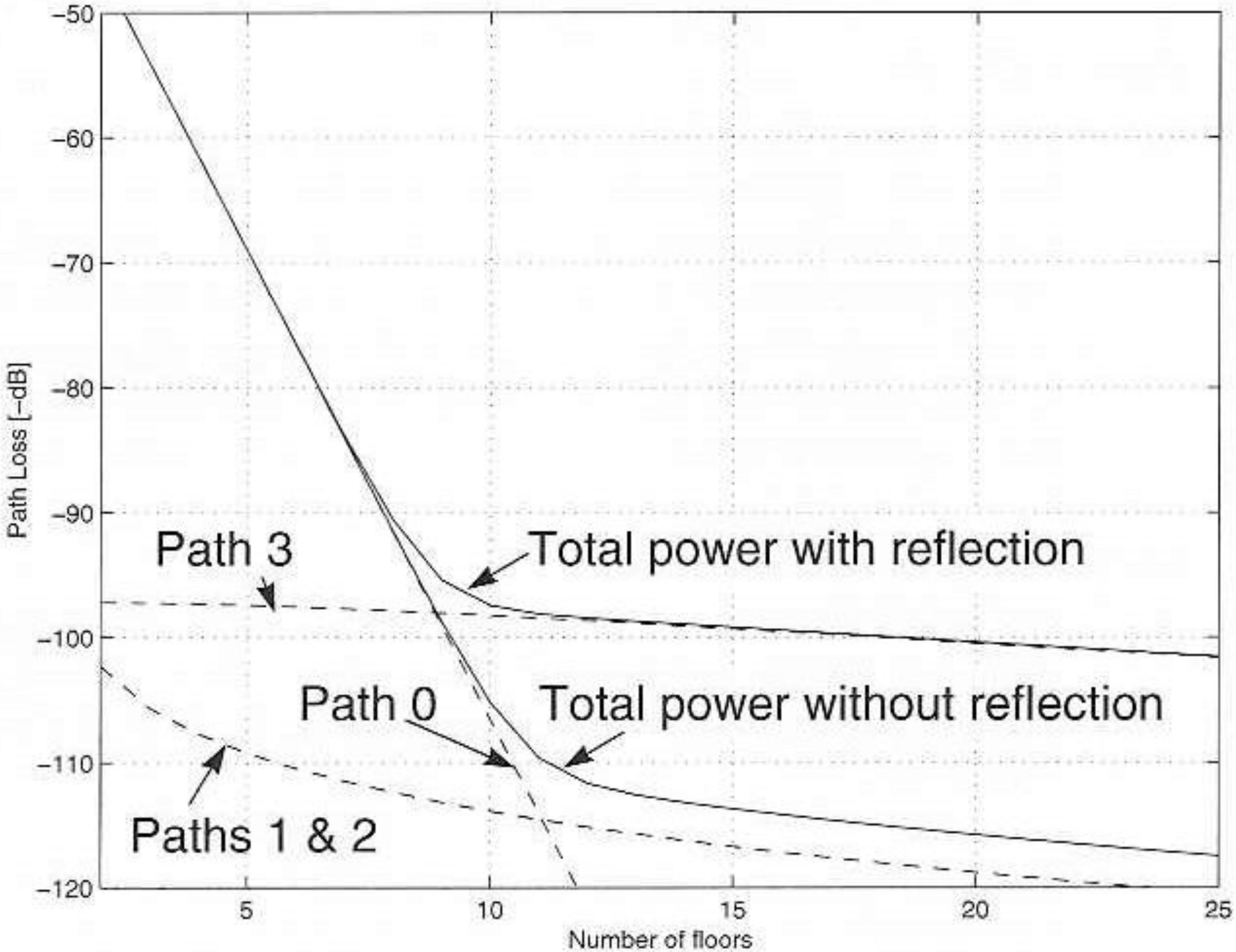
Diffraction

Using GTD for paths 1,2 and 3:



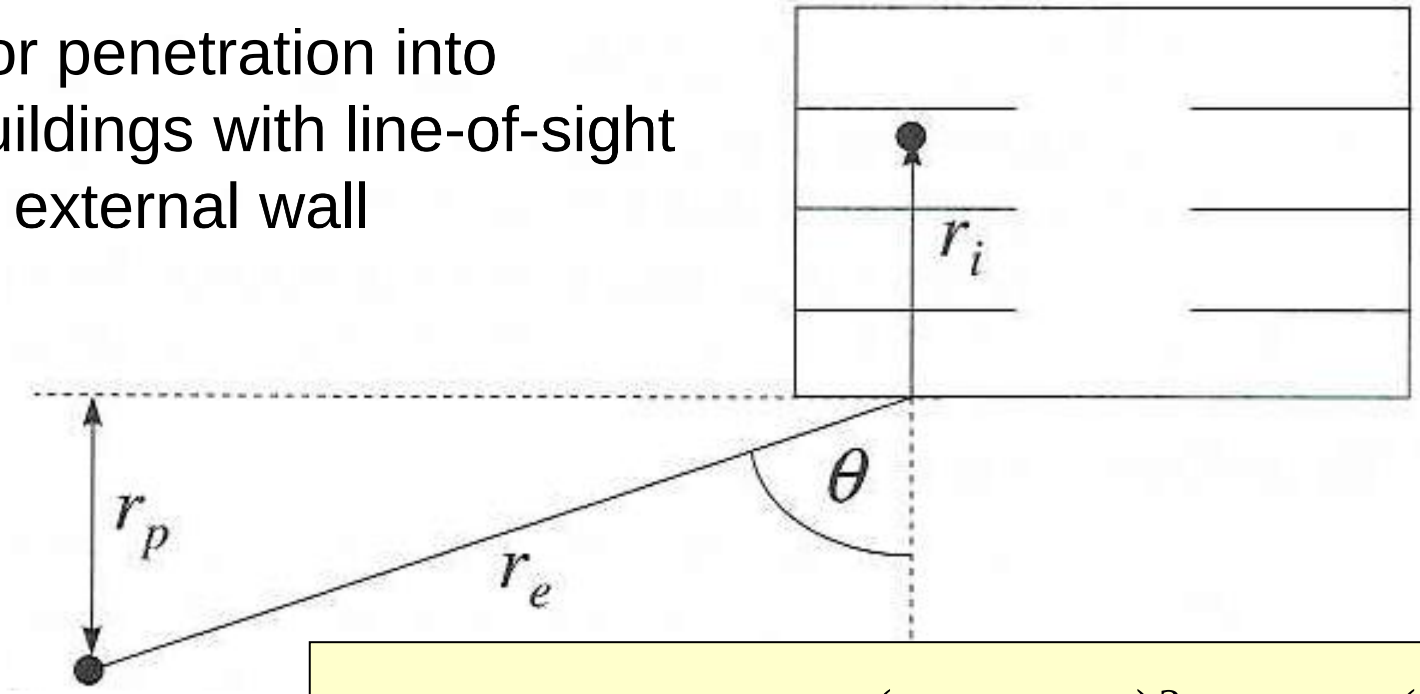
$$P_r = P_t \left(\frac{\lambda}{4\pi} \right)^2 \frac{D_1^2 D_2^2}{r_1 r_2 r_3 \left(r_1 + r_2 + r_3 \right)}$$

Path loss versus number of floors



COST 231 line-of-sight model

For penetration into buildings with line-of-sight to external wall



$$L_T = L_F + L_e + L_g (1 - \cos\theta)^2 + \max(L_1, L_2)$$

where L_e is external wall loss, L_g additional wall loss, and L_1,L_2 loss within buildings

$$L_1 = n_W L_i \qquad L_2 = \alpha (r_1 - 2)(1 - \cos\theta)^2$$

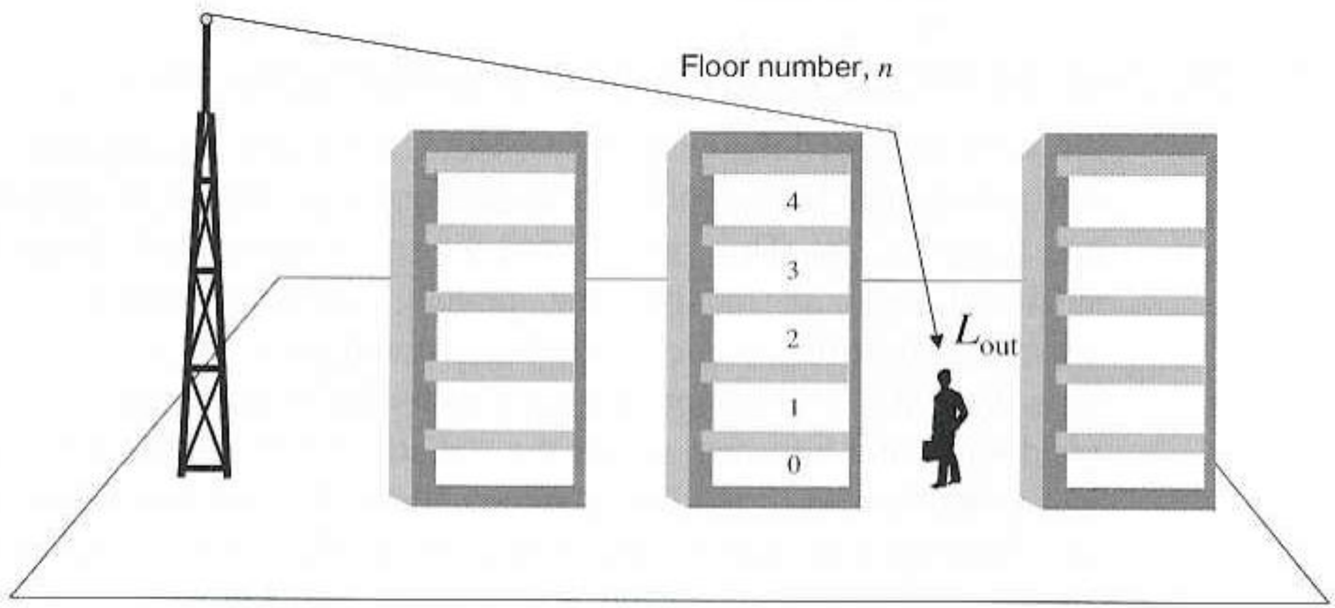
COST 231 loss model parameters

- Valid for distances up 500 m
- 900 - 1800 MHz

Parameter	Material	Approximate value
L_e or L_i (dB/m)	Wooden wall	4
	Concrete with non-metallised windows	7
	Concrete without windows	10-20
L_g (dB)	Unspecified	20
α (dB/m)	Unspecified	0.6

Floor gain referred to street level

- For non-line-of-sight incidence
- Internal loss related to external loss at street level: $L_p = L_f(n) - L_{out}$



Floor gain model parameters

Frequency [MHz]	Ground Floor Penetration Loss $Lf(0)$ [dB]
900	14.2
1800	13.4
2300	12.8

- Loss decreases with height at around 2dB per floor up to some threshold floor (9-15), probably depending on height of surrounding buildings
- Subsequently increases with height

COST 231 Non-LOS model

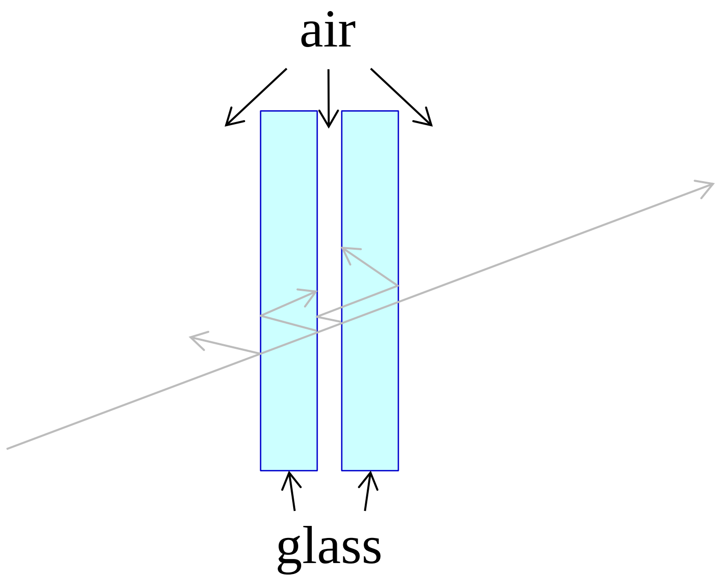
$$L_T = L_{out} + L_e + L_{ge} + \max(L_1, L_3) - G_{jh}$$

where $L_3 = \alpha r_i$ and r_i, L_e, and L_1 are as in the LOS model, and $G_{jh} = nG_n$ or $G_{jh} = hG_h$

Parameter	Approximate value
L_{ge} at 900 MHz	4 dB
L_{ge} at 1800 MHz	6 dB
G_n at 900 or 1800 MHz	1.5-2 dB normal buildings 4-7 dB floor heights above 4m

Propagation mechanisms building penetration

Complicated, but with information about the dielectric material and geometry some calculations can be done. Example double-glazed window and transmission line theory. In addition a window is an aperture and the Fresnel zone size for penetrating through the window comes into account.



Constitutive parameters of building material

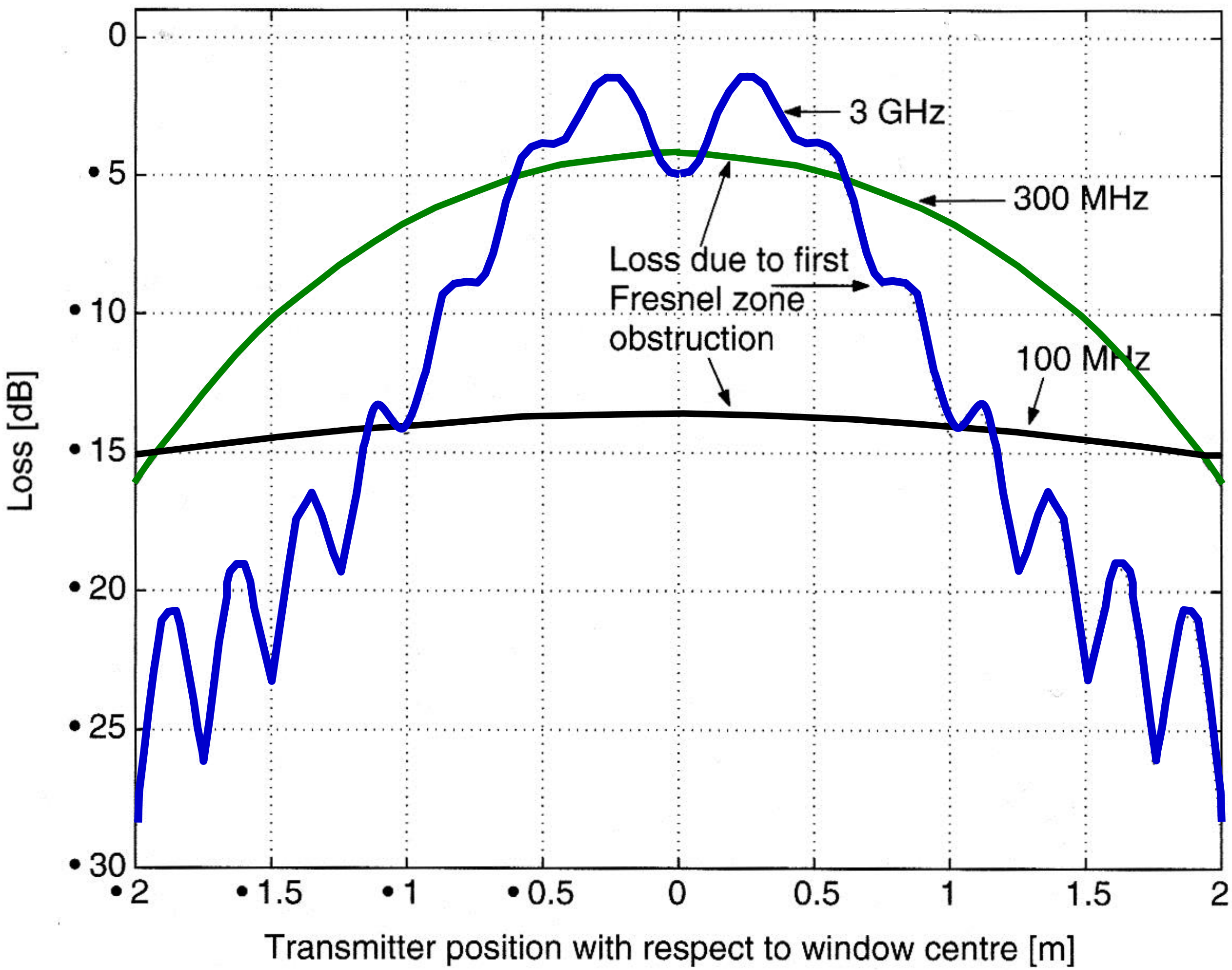
Complex permittivity of some materials

	1 GHz	57.5 GHz	95.9 GHz
Concrete	$7 - j0.85$	$7.0 - j0.43$	$6.2 - j0.34$
Glass	$7 - j0.1$	$6.81 - j0.17$	

Constitutive parameters of some materials

	Frequency range	Permittivity	Conductivity
Brick	1.7 – 18 GHz	4.62 - 4.11	0.0174 – 0.0364
Concrete	3 – 24 GHz	5 - 7	0.0138 – 0.025
Wood	20 Hz – 100 GHz	1.2 – 6.8	0.005 – 0.063
Glass	VHF - microwave	4 - 9	0.00005 – 0.035

Transmission loss through a window

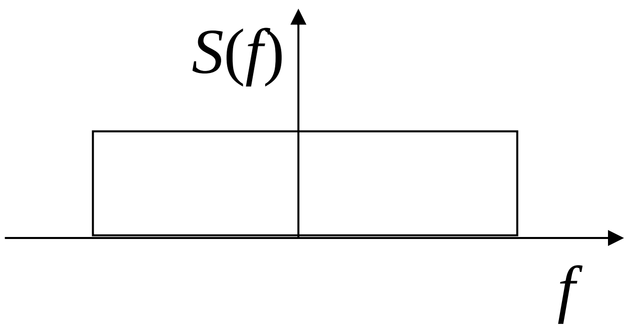


Window in brick wall. Size 0.8 m². Single 8 mm glass, $\varepsilon = 0.4$ and loss tangent = 0.0012. Transmitter and receiver 30 m and 2 m from window centre, respectively.

Multipath effects

- Doppler spectrum of individual taps may be assumed uniform due to 3D angle-of-arrival distribution
- Note that f_m may arise from moving scatterers as well as moving terminals

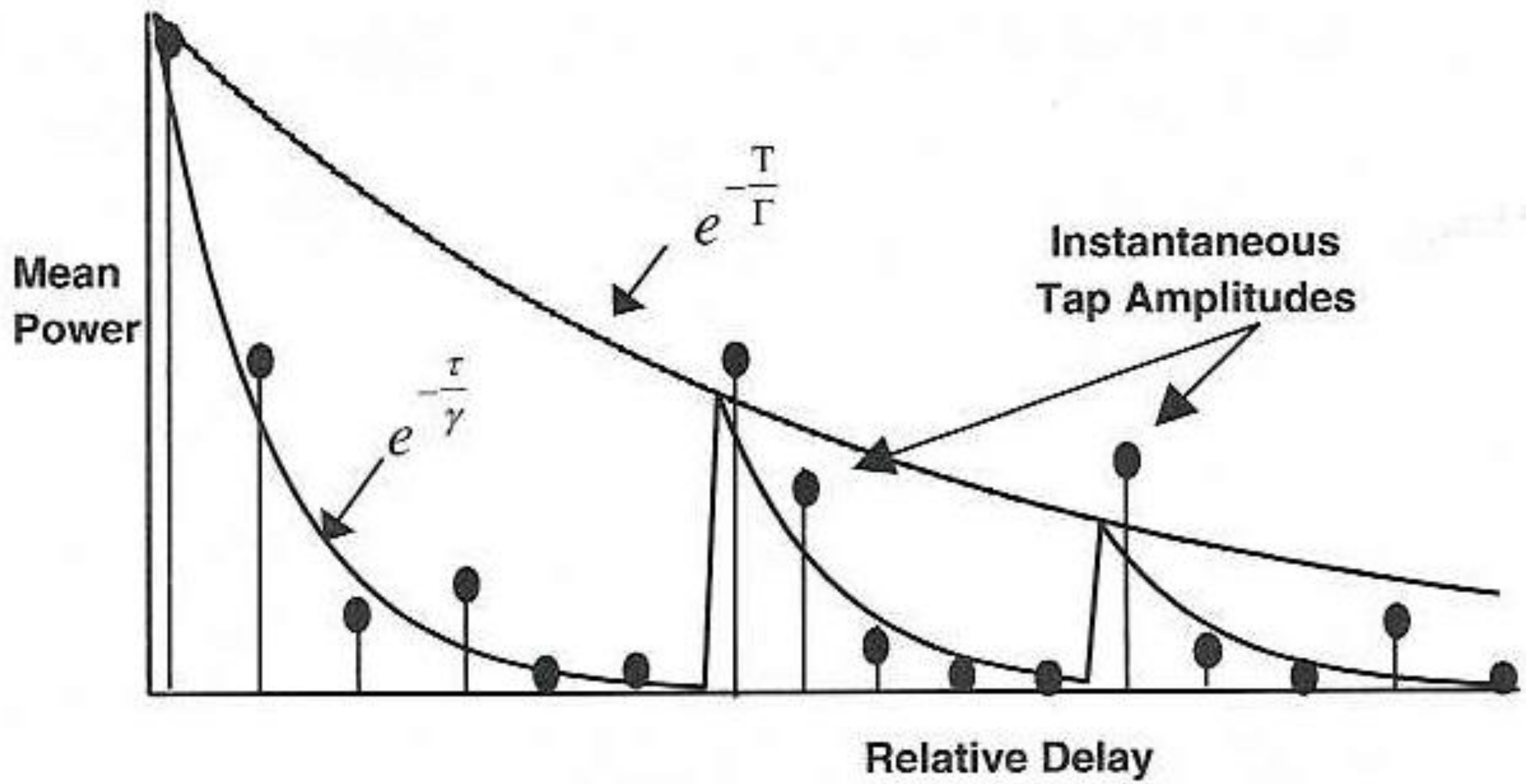
$$S(f) = \begin{cases} \dfrac{1}{2 f_m} & |f| \le f_m \\ 0 & f > f_m \end{cases}$$



Indoor office wideband channel parameters at 2 GHz, ETSI

Median channel τ_{rms} = 35 ns		Bad channel τ_{rms} = 100 ns	
Rel. delay (ns)	Rel. power (dB)	Rel. delay (ns)	Rel. power (dB)
0	0	0	0
50	-3	100	-3.6
110	-10	200	-7.2
170	-18	300	-10.8
290	-26	500	-18
310	-32	700	-25.2

Indoor double exponential power-delay profiles

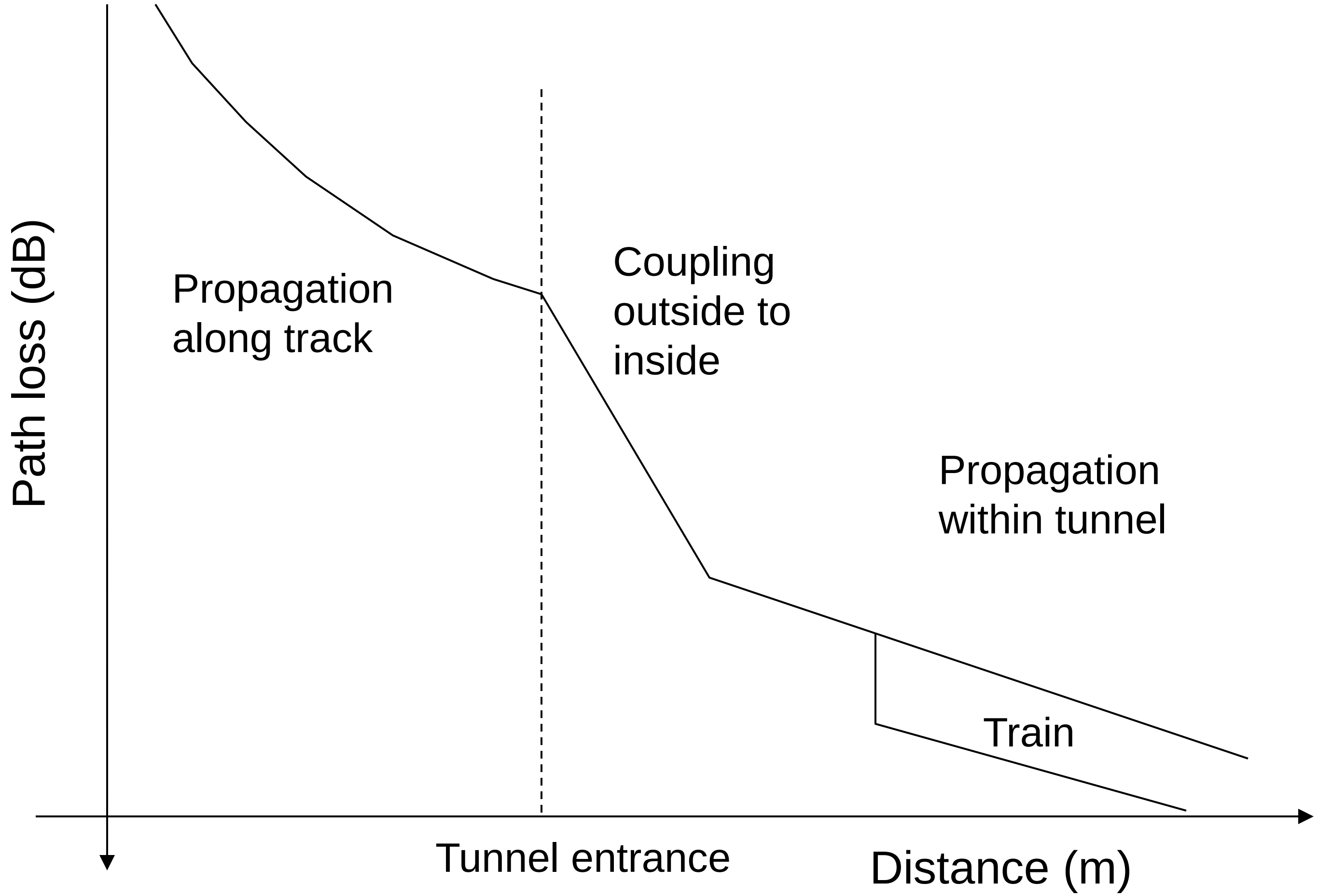


Ultra wide band (UWB) indoor propagation

- UWB much larger bandwidth transmitted than required for the information, practical systems occupies as much as 7.5 GHz. Can be used for very high data rates over short distances
- The power spectral density is small and interference to other systems negligible
- Simple theory, γ (dB/m) attenuation coefficient, for the received power P_r(r) and the power delay profile $P(\tau)$

$$\frac{P_r(r)}{P_t} = \frac{1}{4\pi r^2} e^{\frac{-r^{\gamma}}{10}} \qquad P(\tau) = \frac{1}{\tau_{RMS}} e^{\frac{-\tau}{\tau_{RMS}}}$$

Propagation in tunnels, main features



Picocells summary

- In- building coverage biggest growth area
- Must incorporate effects of geometry for accurate path loss prediction
- Reasonable estimates available from simple models
- Wideband effects essential for high data rate applications