EE6604
Personal & Mobile Communications

Week 7

Path Loss Models

Shadowing

Reading: 2.6, 2.7

Okumura-Hata Model

$$L_p = \begin{cases} A + B\log_{10}(d) & \text{for urban area} \\ A + B\log_{10}(d) - C & \text{for suburban area} \\ A + B\log_{10}(d) - D & \text{for open area} \end{cases}$$

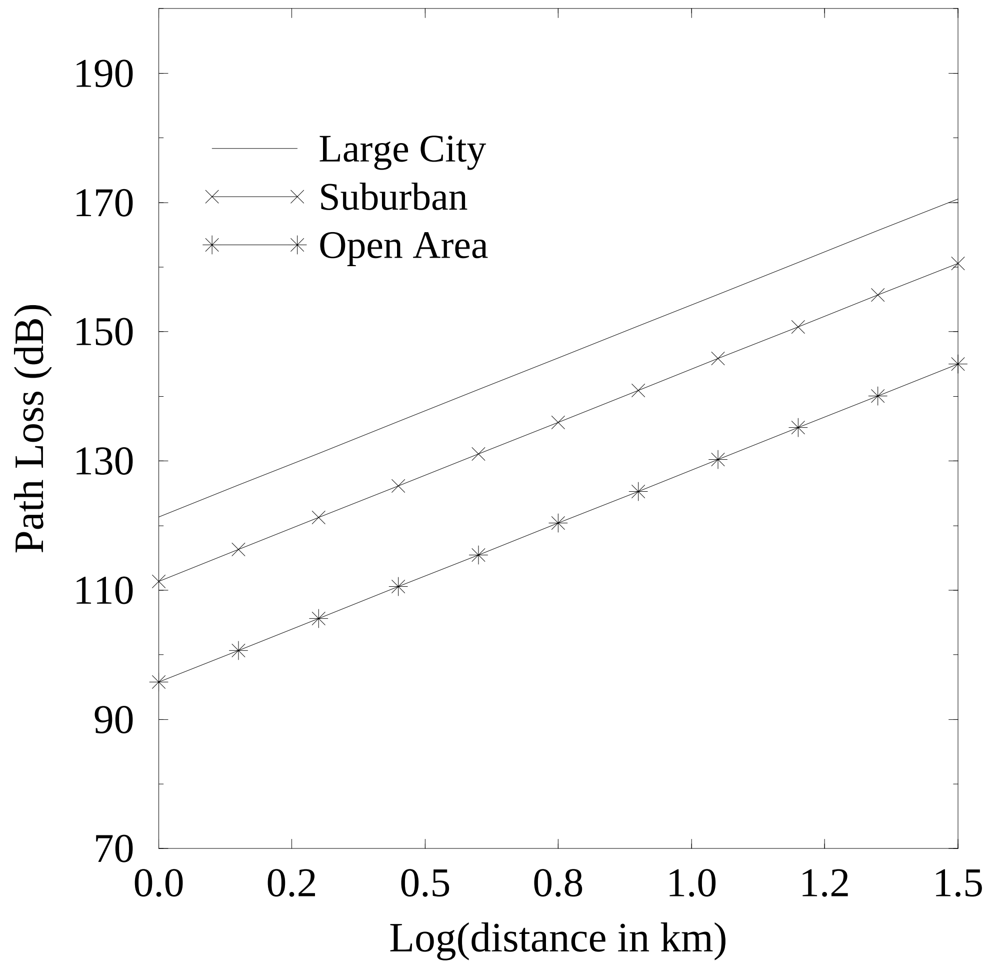
where

$$\begin{aligned} A &= 69.55 + 26.16\log_{10}(f_c) - 13.82\log_{10}(h_b) - a(h_m) \\ B &= 44.9 - 6.55\log_{10}(h_b) \\ C &= 5.4 + 2\left[\log_{10}(f_c/28)\right]^2 \\ D &= 40.94 + 4.78\left[\log_{10}(f_c)\right]^2 - 19.33\log_{10}(f_c) \end{aligned}$$

- Okumura and Hata's model is in terms of
  - carrier frequency $150 \le f_c \le 1000$ (MHz)
  - BS antenna height $30 \le h_b \le 200$ (m)
  - MS antenna height $1 \le h_m \le 10$ (m)
  - distance $1 \le d \le 20$ (km) between the BS and MS.
- The model is known to be accurate to within 1 dB for distances ranging from 1 to 20 km.

- The parameter $a(h_m)$ is a "correction factor"

$$a(h_m) = \begin{cases} (1.1\log_{10}(f_c) - 0.7)\,h_m - (1.56\log_{10}(f_c) - 0.8) \\ \qquad\qquad\qquad\qquad\qquad \text{for medium or small city} \\ \begin{cases} 8.28\,(\log_{10}(1.54h_m))^2 - 1.1 & \text{for } f_c \leq 200 \text{ MHz} \\ 3.2\,(\log_{10}(11.75h_m))^2 - 4.97 & \text{for } f_c \geq 400 \text{ MHz} \end{cases} \\ \qquad\qquad\qquad\qquad\qquad \text{for large city} \end{cases}$$



Path loss predicted by the Okumura-Hata model. Large city, $f_c = 900$ *MHz,* $h_b = 70$ *m,* $h_m = 1.5$ *m.*

CCIR Model

- To account for varying degrees of urbanization, the CCIR (Comité International des Radio-Communication, now ITU-R) developed an empirical model for the path loss as:

$$L_{p\ (\mathrm{dB})} = A + B\log_{10}(d) - E$$

  where A and B are defined in the Okumura-Hata model with $a(h_m)$ being the medium or small city value.

- The parameter E accounts for the degree of urbanization and is given by

$$E = 30 - 25\log_{10}(\%\ \text{of area covered by buildings})$$

  where $E = 0$ when the area is covered by approximately 16% buildings.

Lee's Area-to-area Model

- Lee's area-to-area model is used to predict a path loss over flat terrain. If the actual terrain is not flat, e.g., hilly, there will be large prediction errors.
- Two parameters are required for Lee's area-to-area model; the power at a 1 mile (1.6 km) point of interception, $\mu_{\Omega_p}(d_o)$, and the path-loss exponent, β.
- The received signal power at distance d can be expressed as

$$\mu_{\Omega_p}(d) = \mu_{\Omega_p}(d_o) \left(\frac{d}{d_o}\right)^{-\beta} \left(\frac{f}{f_o}\right)^{-n} \alpha_0$$

or in decibel units

$$\mu_{\Omega_p \text{ (dBm)}}(d) = \mu_{\Omega_p \text{ (dBm)}}(d_o) - 10\beta\log_{10}\left(\frac{d}{d_o}\right) - 10n\log_{10}\left(\frac{f}{f_o}\right) + 10\log_{10}\alpha_0 \ ,$$

where d is in units of kilometers and $d_o = 1.6$ km.

- The parameter α_0 is a correction factor used to account for different BS and MS antenna heights, transmit powers, and antenna gains.

Lee's Area-to-area Model

- The following set of *nominal* conditions are assumed in Lee's area-to-area model:
  - frequency $f_o = 900$ MHz
  - BS antenna height = 30.48 m
  - BS transmit power = 10 watts
  - BS antenna gain = 6 dB above dipole gain
  - MS antenna height = 3 m
  - MS antenna gain = 0 dB above dipole gain
- If the actual conditions are different from those listed above, then we compute the following parameters:

$$
\begin{aligned}
\alpha_1 &= \left(\frac{\text{BS antenna height (m)}}{30.48 \text{ m}}\right)^2 \\
\alpha_2 &= \left(\frac{\text{MS antenna height (m)}}{3 \text{ m}}\right)^\kappa \\
\alpha_3 &= \frac{\text{transmitter power}}{10 \text{ watts}} \\
\alpha_4 &= \frac{\text{BS antenna gain with respect to } \lambda_c/2 \text{ dipole}}{4} \\
\alpha_5 &= \text{different antenna-gain correction factor at the MS}
\end{aligned}
$$

Lee's Area-to-area Model

- The parameters β and $\mu_{\Omega_p}(d_o)$ have been found from empirical measurements, and are listed in the Table below.

Terrain	$\mu_{\Omega_p}(d_o)$ (dBm)	β
Free Space	-45	2
Open Area	-49	4.35
North American Suburban	-61.7	3.84
North American Urban (Philadelphia)	-70	3.68
North American Urban (Newark)	-64	4.31
Japanese Urban (Tokyo)	-84	3.05

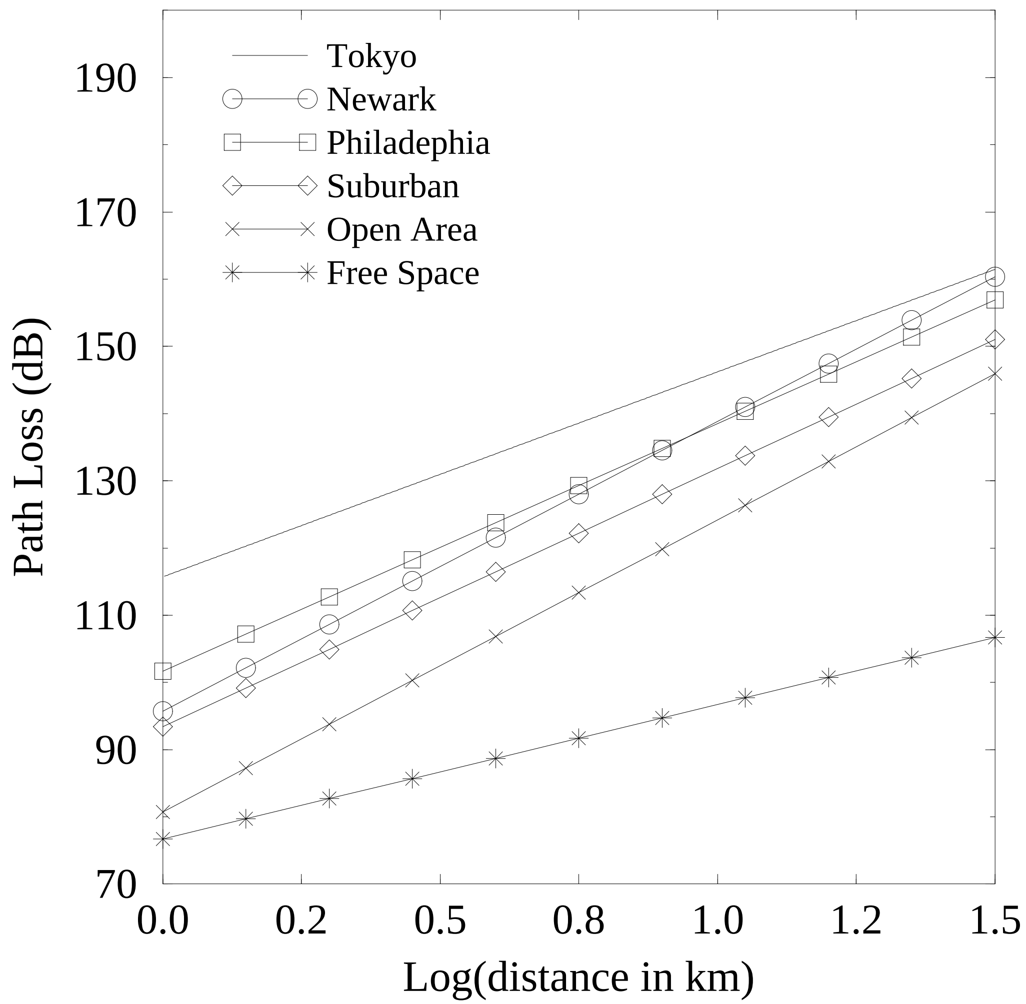
- For $f_c < 450$ MHz in a suburban or open area, $n = 2$ is recommended. In an urban area with $f_c >$ 450MHz, $n = 3$ is recommended.
- The value of κ in is also determined from empirical data as

$$\kappa = \begin{cases} 2 & \text{for a MS antenna height } > \text{ 10 m} \\ 3 & \text{for a MS antenna height } < \text{ 3 m} \end{cases} .$$

Lee's Area-to-area Model

- The path loss $L_{p\ (\mathrm{dB})}$ is the difference between the transmitted and received field strengths, $L_{p\ (\mathrm{dB})} = \mu_{\Omega_{p\ (\mathrm{dBm})}}(d) - \mu_{\Omega_{t\ (\mathrm{dBm})}}$.
- To compare with the Okumura-Hata model, we assume a half wave dipole BS antenna, so that $\alpha_4 = -6$ dB.
- Then by using the same parameters as before, $h_b = 70$ m, $h_m = 1.5$m, $f_c = 900$ MHz, a nominal BS transmitter power of 40 dBm (10 watts), and the parameters in the Table for $\mu_{\Omega_{p\ (\mathrm{dBm})}}(d_o)$ and β, the following path losses are obtained:

$$L_{p\ (\mathrm{dB})} = \begin{cases} 85.74 + 20.0 \log_{10} d & \text{Free Space} \\ 84.94 + 43.5 \log_{10} d & \text{Open Area} \\ 98.68 + 38.4 \log_{10} d & \text{Suburban} \\ 107.31 + 36.8 \log_{10} d & \text{Philadelphia} \\ 100.02 + 43.1 \log_{10} d & \text{Newark} \\ 122.59 + 30.5 \log_{10} d & \text{Tokyo} \end{cases}$$



Path loss obtained by using Lee's method; $h_b = 70$ *m,* $h_m = 1.5$ *m,* $f_c = 900$ *Mhz, and an isotropic BS antenna.*

COST231-Hata Model

- COST231 models are for propagation in the PCS band.
- Path losses experienced at 1845 MHz are about 10 dB larger than those experienced at 955 MHz.
- The COST-231 Hata model for NLOS propagation is

$$L_p = A + B\log_{10}(d) + C$$

where

$$\begin{aligned} A &= 46.3 + 33.9\log_{10}(f_c) - 13.82\log_{10}(h_b) - a(h_m) \\ B &= 44.9 - 6.55\log_{10}(h_b) \\ C &= \begin{cases} 0 & \text{medium city and suburban areas} \\ & \quad \text{with moderate tree density} \\ 3 & \text{for metropolitan centers} \end{cases} \end{aligned}$$

COST231-Walfish-Ikegami LOS Model

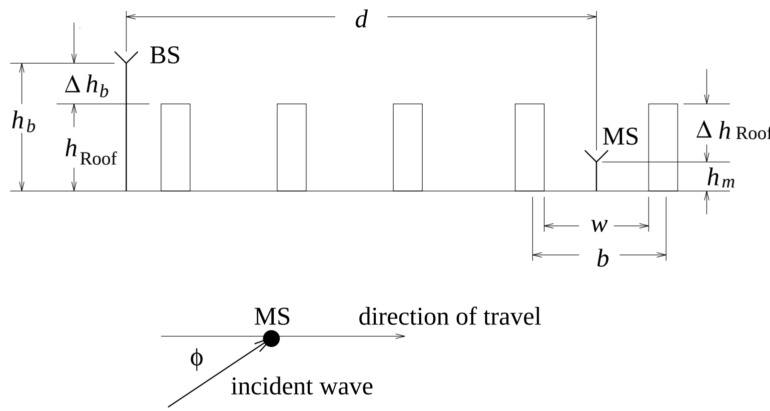
- For LOS propagation in a street canyon, the path loss is

$$L_p = 42.6 + 26\log_{10}(d) + 20\log_{10}(f_c), \quad d \geq 20\ m$$

  where the first constant is chosen so that L_p is equal to the free-space path loss at a distance of 20 m.

- The model parameters are the distance d (km) and carrier frequency f_c (MHz).

COST231-Walfish-Ikegami NLOS Model



Definition of parameters used in the COST231-Walfish-Ikegami model.

- For NLOS propagation, the path loss is composed of three terms, viz.,

$$L_p = \begin{cases} L_o + L_{\rm rts} + L_{\rm msd} & \text{for } L_{\rm rts} + L_{\rm msd} \geq 0 \\ L_o & \text{for } L_{\rm rts} + L_{\rm msd} < 0 \end{cases}$$

  - The free-space loss is

$$L_o = 32.4 + 20\log_{10}(d) + 20\log_{10}(f_c)$$

  - The roof-top-to-street diffraction and scatter loss is

$$L_{\rm rts} = -16.9 - 10\log_{10}(w) + 10\log_{10}(f_c) + 20\log_{10}\Delta h_m + L_{\rm ori}$$

    where

$$\begin{aligned} L_{\rm ori} &= \begin{cases} -10 + 0.354(\phi)\ , & 0 \leq \phi \leq 35^{\rm o} \\ 2.5 + 0.075(\phi - 35)\ , & 35 \leq \phi \leq 55^{\rm o} \\ 4.0 - 0.114(\phi - 55)\ , & 55 \leq \phi \leq 90^{\rm o} \end{cases} \\ \Delta h_m &= h_{\rm Roof} - h_m \end{aligned}$$

- The multi-screen diffraction loss is

$$L_{\rm msd} = L_{\rm bsh} + k_a + k_d \log_{10}(d) + k_f \log_{10}(f_c) - 9\log_{10}(b)$$

where

$$\begin{aligned}
L_{\rm bsh} &= \begin{cases} -18\log_{10}(1+\Delta h_b) & h_b > h_{\rm Roof} \\ 0 & h_b \leq h_{\rm Roof} \end{cases} \\
k_a &= \begin{cases} 54\ , & h_b > h_{\rm Roof} \\ 54 - 0.8\Delta h_b\ , & d \geq 0.5\text{km and } h_b \leq h_{\rm Roof} \\ 54 - 0.8\Delta h_b d/0.5\ , & d < 0.5\text{km and } h_b \leq h_{\rm Roof} \end{cases} \\
k_d &= \begin{cases} 18\ , & h_b > h_{\rm Roof} \\ 18 - 15\Delta h_b/h_{\rm Roof}\ , & h_b \leq h_{\rm Roof} \end{cases} \\
k_f &= -4 + \begin{cases} 0.7(f_c/925 - 1)\ , & \text{medium city and suburban} \\ 1.5(f_c/925 - 1)\ , & \text{metropolitan area} \end{cases}
\end{aligned}$$

and

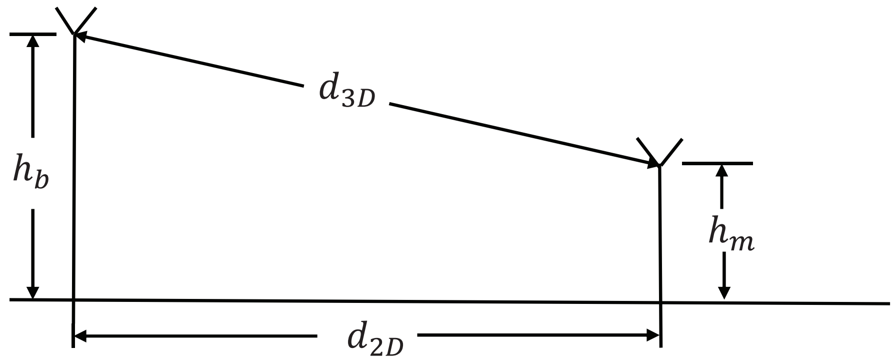
$$\Delta h_b = h_b - h_{\rm Roof}\ .$$

- k_a is the increase in path loss for BS antennas below the roof tops of adjacent buildings.
- k_d and k_f control the dependency of the multi-screen diffraction loss on the distance and frequency, respectively.
- The model is valid for the following ranges of parameters, $800 \leq f_c \leq 2000$ (MHz), $4 \leq h_b \leq 50$ (m), $1 \leq h_m \leq 3$ (m), and $0.02 \leq d \leq 5$ (km).
- The following default values are recommended, $b = 20 \ldots 50$ (m), $w = b/2$, $\phi = 90^{\mathrm{o}}$, and $h_{\mathrm{Roof}} = 3 \times \text{number of floors} + \text{roof}$ (m), where roof $= 3$ (m) pitched and 0 (m) flat.

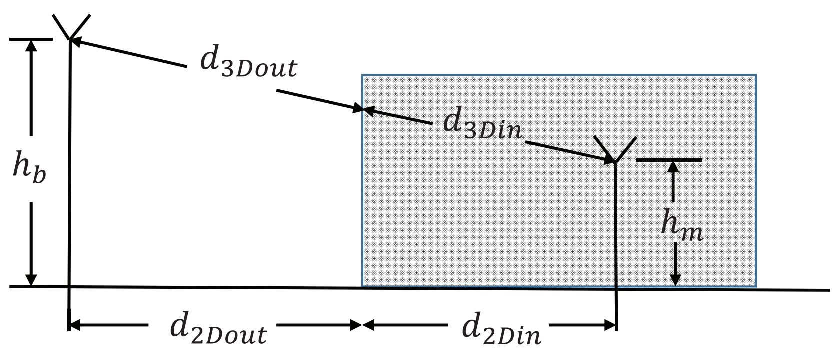
3GPP 3-D Path Loss Models

- The 3GPP path loss models are valid from 2 to 6 GHz for different BS and MS antenna heights.
- The 3GPP path loss models are categorized into urban macrocell (UMa) and urban microcell (UMi) cases, corresponding to BS antenna heights of 25 m or less and 25 m or more, respectively.
- The UMa and UMi cases are further categorized into LoS, NLoS, and outdoor-to-indoor scenarios.
- The distance definitions are defined below for outdoor scenarios and for outdoor-indoor scenarios.

3GPP 3-D Path Loss Model Distance Definitions



Definition of d_{2D} *and* d_{3D} *for outdoor mobile stations.*



Definition of d_{2Dout}, d_{2Din}, d_{3Dout} *and* d_{3Din} *for indoor mobile stations.*

LoS Probability

- The various 3GPP path loss models make use of the probability of LoS condition. For microcells and outdoor MSs, the probability of LoS is

$$\mathrm{P}_{\mathrm{LoS}} = \min(18/d_{2D}, 1)(1 - \mathrm{e}^{-d_{2D}/36}) + \mathrm{e}^{-d_{2D}/36}$$

- For microcells and indoor MSs, the above formula is used with d_{2D} replaced by d_{2Dout}.
- For macrocells and outdoor MSs, the probability of LoS is

$$\mathrm{P}_{\mathrm{LoS}} = \left(\min(18/d_{2D}, 1)(1 - \mathrm{e}^{-d_{2D}/63}) + \mathrm{e}^{-d_{2D}/63}\right)(1 + C(d_{2D}, h_m))$$

  where

$$C(d_{2D}, h_m) = \begin{cases} 0 & , \quad h_m < 13\ m \\ \left(\frac{h_m - 13}{10}\right)^{1.5} g(d_{2D}) & , \quad 13\ m \leq h_m \leq 23\ m \end{cases}$$

  and

$$g(d_{2D}) = \begin{cases} (1.25\mathrm{e}^{-6}) d_{2D}^2 \mathrm{e}^{d_{2D}/150} & , \quad d_{2D} > 18\ m \\ 0 & , \quad \text{otherwise} \end{cases}$$

- For macrocells and indoor MSs, the above formulas are used with d_{2D} replaced by d_{2Dout}.

3GPP 3D-UMa LoS

- For macrocells with LoS conditions

$$L_{\text{UMaLoS (dB)}} = 22.0\log_{10}(d_{3D}) + 28.0 + 20\log_{10}(f_c) \ , \quad 10\ m < d_{2D} < d_{BP}$$

$$L_{\text{UMaLoS (dB)}} = 40\log_{10}(d_{3D}) + 28.0 + 20\log_{10}(f_c) - 9\log_{10}\left(d_{BP}^2 + (h_b - h_m)^2\right) \ ,$$
$$d_{BP} < d_{2D} < 5000\ m;\ h_b = 25\ m;\ 1.5\ m \leq h_m \leq 22.5\ m$$

- The break point distance is given by $d_{BP} = 4h_b h_m f_c / c$ corresponding to the last local maxima in the flat earth model. In the 3D-UMa scenario the effective antenna heights h_b and h_m are computed as follows: $h_b = \hat{h}_b - h_E$, $h_m = \hat{h}_m - h_E$, where $\hat{h}_b$ and $\hat{h}_m$ are the actual antenna heights, and the effective environment height h_E depends on the link between a BS and a MS. For LoS links, $h_E = 1\ m$ with probability $1/(1 + C(d_{2D}, h_m))$, where the function $C(d_{2D}, h_m)$ is defined earlier. Otherwise, h_E is chosen from a discrete uniform distribution on the set $\{12, 15, \ldots, (h_m - 1.5)\}$.

- The shadow standard deviation is $\sigma_\Omega = 4$ dB.

3GPP 3D-UMa NLoS

- For macrocells with NLoS conditions

$$L_{\text{UMaNLoS (dB)}} = \max\left\{L_{\text{UMaNLoS (dB)}},\ L_{\text{UMaLoS (dB)}}\right\} \quad ,$$

where

$$\begin{aligned} L_{\text{UMaNLoS (dB)}} \;=\; & 161.04 - 7.1\log_{10}(W) + 7.5\log_{10}(h_{\text{build}}) \\ & - \left(24.37 - 3.7(h_{\text{build}}/h_b)^2\right)\log_{10}(h_b) \\ & + (43.42 - 3.1\log_{10}(h_b))\,(\log_{10}(d_{3D}) - 3) \\ & +20\log_{10}(f_c) - \left(3.2(\log_{10}(17.625))^2 - 4.97\right) - 0.6(h_m - 1.5) \end{aligned}$$

and

$$10\ m < d_{2D} < 5,000\ m$$

$$h_{\text{build}} = \text{average building height}$$

$$W = \text{street width}$$

$$h_b = 25\ m,\ 1.5\ m \leq h_m \leq 22.5\ m,\ W = 20\ m,\ h_{\text{build}} = 20\ m$$

Applicable ranges:

$$5\ m < h_{\text{build}} < 50\ m$$

$$5\ m < W < 50\ m$$

$$10\ m < h_b < 150\ m$$

$$1.5\ m \leq h_m \leq 22.5\ m$$

- The shadow standard deviation is $\sigma_\Omega = 6$ dB.

3GPP 3D-UMa O-to-I

- For macrocells with outdoor-to-indoor conditions

$$L_{\text{UMaO−to−I (dB)}} = L_{\text{b (dB)}} + L_{\text{tw (dB)}} + L_{\text{in (dB)}}$$

For a hexagonal cell layout:

$$\begin{aligned} L_{\text{b (dB)}} &= L_{\text{UMa (dB)}}(d_{3D-out} + d_{3D-in}) \\ L_{\text{tw (dB)}} &= 20 \quad \text{(loss through wall)} \\ L_{\text{in (dB)}} &= 0.5 d_{2D-in} \quad \text{(inside loss)} \end{aligned}$$

where

$$10\ m < d_{2D-out} + d_{2D-in} < 1000\ m$$
$$0\ m < d_{2D-in} < 25\ m$$
$$h_b = 25\ m, h_m = 3(n_{fl} - 1) + 1.5\ , \quad n_{fl} = 1, 2, 3, 4, 5, 6, 7, 8$$

d_{2D-in} is assumed uniformly distributed between 0 and 25 .

- The shadow standard deviation is $\sigma_\Omega = 7$ dB.

- The building penetration loss (BPL) or "loss through wall" in the 3GPP 3D-UMa O-to-I model is 20 dB. However, this will vary greatly depending on the building. Moreover, the building penetration loss increases with frequency. An empirical BPL model is

$$\text{BPL}_{\text{(dB)}} = 10 \log_{10} \left(A + B f_c^2 \right) \ ,$$

where f_c is the frequency in GHz, $A = 5$ and $B = 0.03$ for low loss buildings and $A = 10$ and $B = 5$ for high loss buildings.

3GPP 3D-UMi LoS, NLoS and 3D-UMi O-to-I

- The microcell LoS path loss is the same as the macrocell LoS path loss $L_{\text{UMaLOS (dB)}}$, except that $h_E = 1\ m$ with probability one and the shadow standard deviation is $\sigma_\Omega = 3$ dB.
- For NLoS and a hexagonal cell layout

$$L_{\text{UMiNLoS (dB)}} = \max\left\{L_{\text{UMiNLoS (dB)}},\ L_{\text{UMiLoS (dB)}}\right\} \quad ,$$

where

$$L_{\text{UMiNLoS (dB)}} = 36.7\log_{10}(d_{3D}) + 22.7 + 26\log_{10}(fc) - 0.3(h_m - 1.5)$$

$$10\ m < d_{2D} < 2000\ m$$
$$h_b = 10\ m$$
$$1.5\ m \leq h_m \leq 22.5m$$

The shadow standard deviation is $\sigma_\Omega = 4$ dB.

- The microcell outdoor-to-indoor path loss is the same as the macrocell outdoor-to-indoor path loss $L_{\text{UMaO-to-I (dB)}}$, except that $h_b = 10$ m instead of $h_b = 25$ m. The shadow standard deviation remains at $\sigma_\Omega = 7$ dB.

Shadowing

- Shadows are very often modeled as being log-normally distributed.
- Let

$$\Omega_v = \mathrm{E}[\alpha(t)], \qquad \mu_{\Omega_v} = \mathrm{E}[\Omega_v]$$
$$\Omega_p = \mathrm{E}[\alpha^2(t)], \qquad \mu_{\Omega_p} = \mathrm{E}[\Omega_p]$$

- Then distributions of Ω_v and Ω_p are

$$p_{\Omega_v}(x) = \frac{2\xi}{x\sigma_\Omega\sqrt{2\pi}}\exp\left\{-\frac{\left(10\log_{10}x^2 - \mu_{\Omega_v\ (\mathrm{dBm})}\right)^2}{2\sigma_\Omega^2}\right\}$$
$$p_{\Omega_p}(x) = \frac{\xi}{x\sigma_\Omega\sqrt{2\pi}}\exp\left\{-\frac{\left(10\log_{10}x - \mu_{\Omega_p\ (\mathrm{dBm})}\right)^2}{2\sigma_\Omega^2}\right\}$$

where

$$\mu_{\Omega_v\ (\mathrm{dBm})} = 10\mathrm{E}[\log_{10}\Omega_v^2]$$
$$\mu_{\Omega_p\ (\mathrm{dBm})} = 10\mathrm{E}[\log_{10}\Omega_p]$$

and $\xi = \ln 10/10$.

Shadowing

- By using a transformation of random variables, $\Omega_{v\ (\text{dBm})} = 10\log_{10}\Omega_v^2$ and $\Omega_{p\ (\text{dBm})} = 10\log_{10}\Omega_p$ have the Gaussian densities

$$
\begin{aligned}
p_{\Omega_{v\ (\text{dBm})}}(x) &= \frac{1}{\sqrt{2\pi}\sigma_\Omega} \exp\left\{ -\frac{(x - \mu_{\Omega_{v\ (\text{dBm})}})^2}{2\sigma_\Omega^2} \right\} \\
p_{\Omega_{p\ (\text{dBm})}}(x) &= \frac{1}{\sqrt{2\pi}\sigma_\Omega} \exp\left\{ -\frac{(x - \mu_{\Omega_{p\ (\text{dBm})}})^2}{2\sigma_\Omega^2} \right\} \quad .
\end{aligned}
$$

- Note that the standard deviation σ_Ω of $\Omega_{v\ (\text{dBm})}$ and $\Omega_{p\ (\text{dBm})}$ are the same. However, for Rician fading channels the means differ by

$$\mu_{\Omega_p\ (\text{dBm})} = \mu_{\Omega_v\ (\text{dBm})} + 10 \cdot \log_{10} C(K)$$

where

$$C(K) = \frac{4e^{2K}(K+1)}{\pi_1 F_1^2(3/2, 1; K)}$$

${}_1F_1(\cdot, \cdot; \cdot)$ is the confluent hypergeometric function (see Chap. 2, Appendix 3).

- Note that $C(0) = 4/\pi$, $C(\infty) = 1$, and $1 \le C(K) \le 4/\pi$ for $0 \le K \le \infty$.

Shadow Simulation

- Shadows can be modelled by low-pass filtering white noise.
  - Here we suggest a first-order low pass digital filter.
- In a discrete-time simulation, the local mean $\Omega_{k+1\ (\mathrm{dBm})}$ at step $k+1$ is generated recursively as follows:

$$\Omega_{k+1\ (\mathrm{dBm})} = \xi \Omega_{k\ (\mathrm{dBm})} + (1-\xi) v_k$$

  - k is the step index.
  - $\{v_k\}$ is a sequence of independent zero-mean Gaussian random variables with variance $\tilde{\sigma}^2$.
  - ξ controls the shadow correlation
- The autocorrelation function of $\Omega_{k\ (\mathrm{dBm})}$ can be derived as:

$$\phi_{\Omega_{(\mathrm{dBm})}\Omega_{(\mathrm{dBm})}}(n) = \frac{1-\xi}{1+\xi}\tilde{\sigma}^2 \xi^{|n|}$$

- The variance of log-normal shadowing is

$$\sigma_\Omega^2 = \phi_{\Omega_{(\mathrm{dBm})}\Omega_{(\mathrm{dBm})}}(0) = \frac{1-\xi}{1+\xi}\tilde{\sigma}^2$$

  - Consequently, we can express the autocorrelation of Ω_k as

$$\phi_{\Omega_{(\mathrm{dBm})}\Omega_{(\mathrm{dBm})}}(n) = \sigma_\Omega^2 \xi^{|n|}$$

  - Notice that the shadows decorrelated exponentially with the time lag in the autocorrelation function.

- Suppose we use discrete-time simulation, where each simulation step corresponds to T seconds.
  - For a mobile station traveling at velocity v, the distance traveled in T seconds is vT meters.
  - Let ξ_D be the shadow correlation between two points separated by a spatial distance of D meters.
  - Then the time autocorrelation of the shadowing is

$$\phi_{\Omega_{(\mathrm{dBm})}\Omega_{(\mathrm{dBm})}}(n) \equiv \phi_{\Omega_{(\mathrm{dBm})}\Omega_{(\mathrm{dBm})}}(nT) = \sigma_\Omega^2 \xi_D^{(vT/D)|n|}$$

  - Measurements in Stockholm have shown $\xi_D = 0.1$ for $D = 30$ meters (roughly). However, this can vary greatly depending on local topography.