Multihop Path Loss Model (Base-to-Relay and Base-to-mobile)

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Purpose:
To adopt the recommended path loss model for BS-RS and BS-MS link simulation

Introduction

- For multihop networks there are various links for which radio channel models are required:-
  - Base-to-terminal
  - Base-to-relay
  - Relay-to-relay
  - Relay-to-terminal
- In this presentation a path loss model is presented which is appropriate for the base-to-relay (BS-RS) and Base-to-mobile (BS-MS) links for different terrain categories. The model is based on the IEEE 802.16d path loss model for fixed links
- IEEE 802.16d model is attractive since it includes:
  - Frequency correction factor
  - Terminal/relay antenna height correction factor
- A model is also given for the lognormal shadowing standard deviation, including frequency dependence

IEEE 802.16d Channel Model

- This model is based on measurements by AT&T at 1.9GHz in 95 existing macrocells across the US*
- Applicable to suburban areas with three different categories:-
  - **Category A**: Hilly terrain with moderate-to-heavy tree densities
  - **Category B**: Mostly flat terrain with moderate-to-heavy tree densities, or hilly terrain with light tree densities
  - **Category C**: Flat terrain with light tree densities
- Valid for:-
  - Base antenna heights: 10 - 80m
  - Base-to-terminal distances: 0.1 - 8km

*'An empirically based path loss model for wireless channels in suburban environments', V.Erceg, L.J.Greenstein, S.Y.Tjandra, S.R.Parkoff, A.Gupta, B.Kulic, A.A.Julius, R.Bianchi, IEEE JSAC-17, No.7, July 1999, pp.1205-1211

IEEE 802.16d Channel Model

$$PL = A + 10\gamma \log\left(\frac{d}{d_0}\right) + s \qquad \text{for } d > d_0$$

where;

$$A = 20\log\left(\frac{4\pi d_0}{\lambda}\right)$$

$$\gamma = a - bh_b + \frac{c}{h_b}$$

d = distance between base and terminal

$d_0 = 100\text{m}$

h_b = height of basestation

s = shadowing

For the measurements at 1.9GHz it was found that most *A*-values were close to free space loss at 100m. This is the reason for setting the reference distance d_0 equal to 100m. For distances less than 100m the path loss can be taken to be the free space loss.

See next page for *a, b, c* values

Parameters for γ expression

Model Parameter	Terrain Type A	Terrain Type B	Terrain Type C
a	4.6	4.0	3.6
b	0.0075	0.0065	0.005
c	12.6	17.1	20

Frequency Correction Factor

Empirical predictions of mobile radio propagation loss were tabulated by Jakes and Reudink[*] using data taken in northern New Jersey and New York City suburbs at four frequencies (450MHz, 900MHz, 3.7GHz and 11.2GHz). Results showed an $f^{2.6}$ dependence. This is virtually identical to the frequency dependence in the Hata model (*26.16log(f)*).

Frequency correction factor

$$\Delta PL_f = 6\log\left(\frac{f}{2000}\right)$$

[*]'A quantification of link budget differences between the cellular and PCS bands', T-S.Chu, L.J.Greenstein, IEEE Trans VT-48, No.1, January 1999, pp.60-65

Terminal Antenna Height Correction

The IEEE 802.16d channel model specifies a correction factor for the terminal antenna height:-

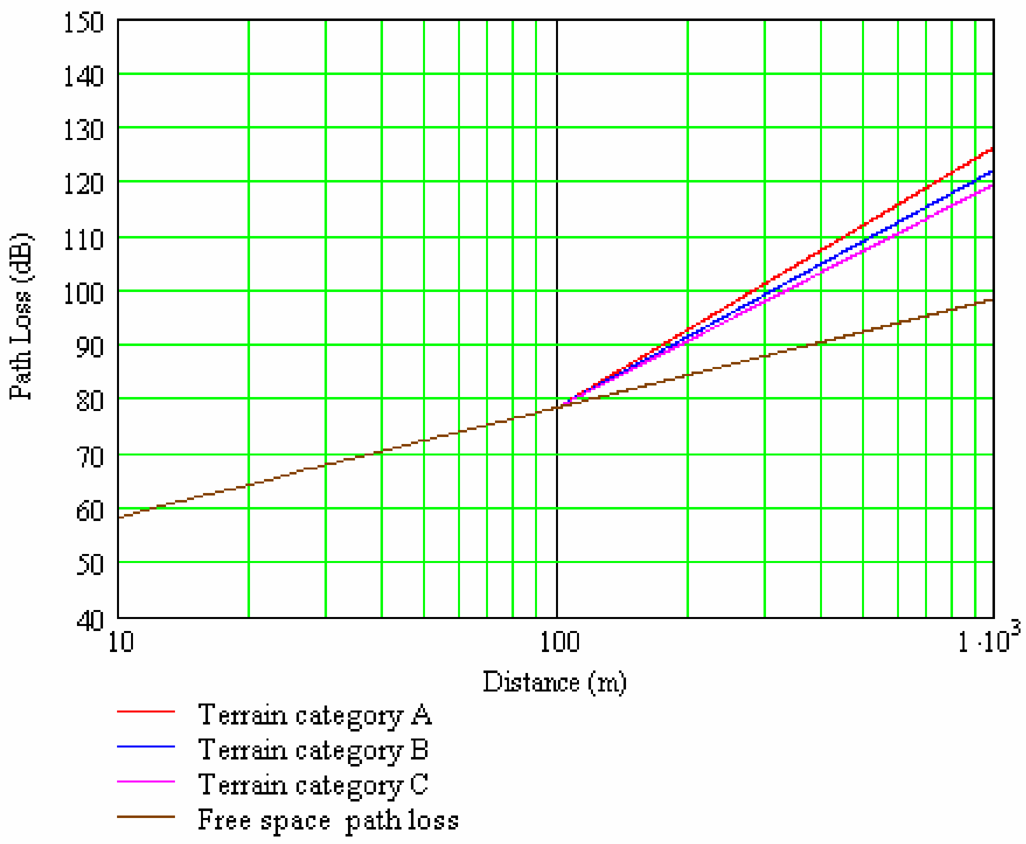
$$\Delta PL_{ht} = -10.8\log\left(\frac{h_t}{2}\right) \quad \text{for terrain categories A \& B}$$

$$\Delta PL_{ht} = -20\log\left(\frac{h_t}{2}\right) \quad \text{for terrain category C}$$

The first expression seems to come from the AT&T measurements. The second is *supposed* to be the terminal height correction factor defined by Okumura. There seems to be an error here as the Okumura correction factor is:-

$$\Delta PL_{ht} = \left.\begin{matrix} -10\log\left(\frac{h_t}{3}\right) & h_t < 3m \\ -20\log\left(\frac{h_t}{3}\right) & 10m > h_t > 3m \end{matrix}\right\}$$

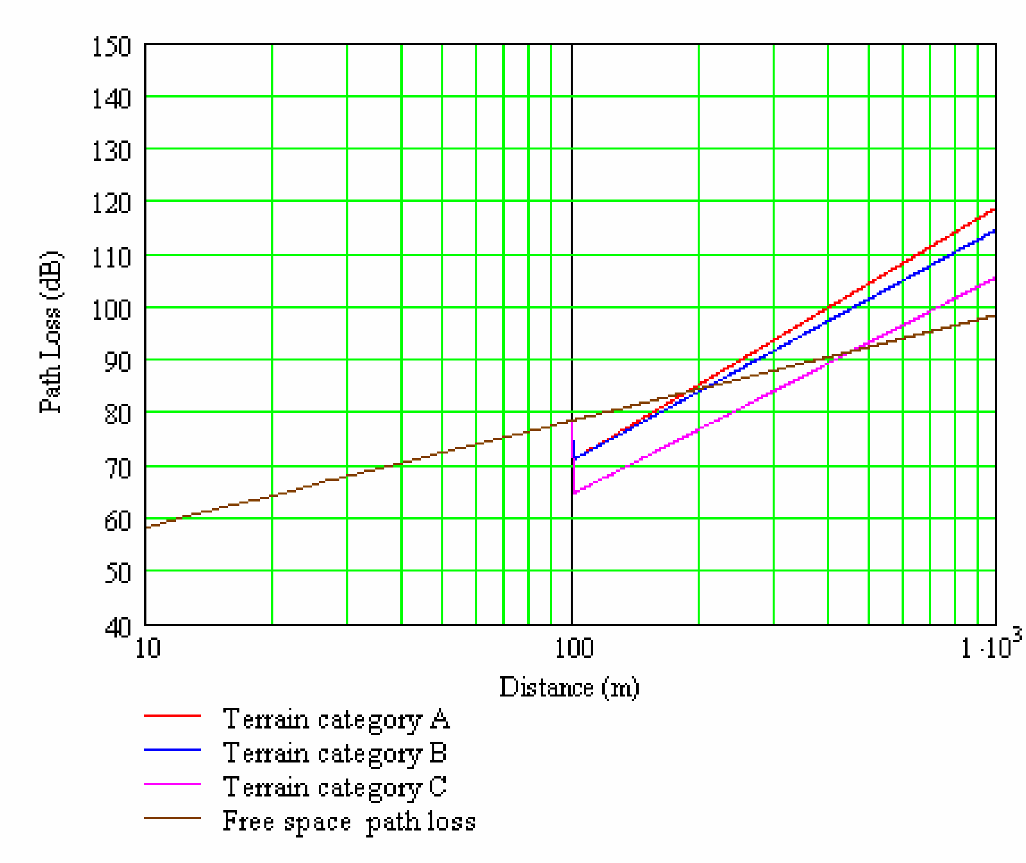
Path loss with no correction factors



Path loss at 2GHz;

h_b = 30m
h_m = 2m

Effect of height correction factor. Path loss with 10m terminal height.



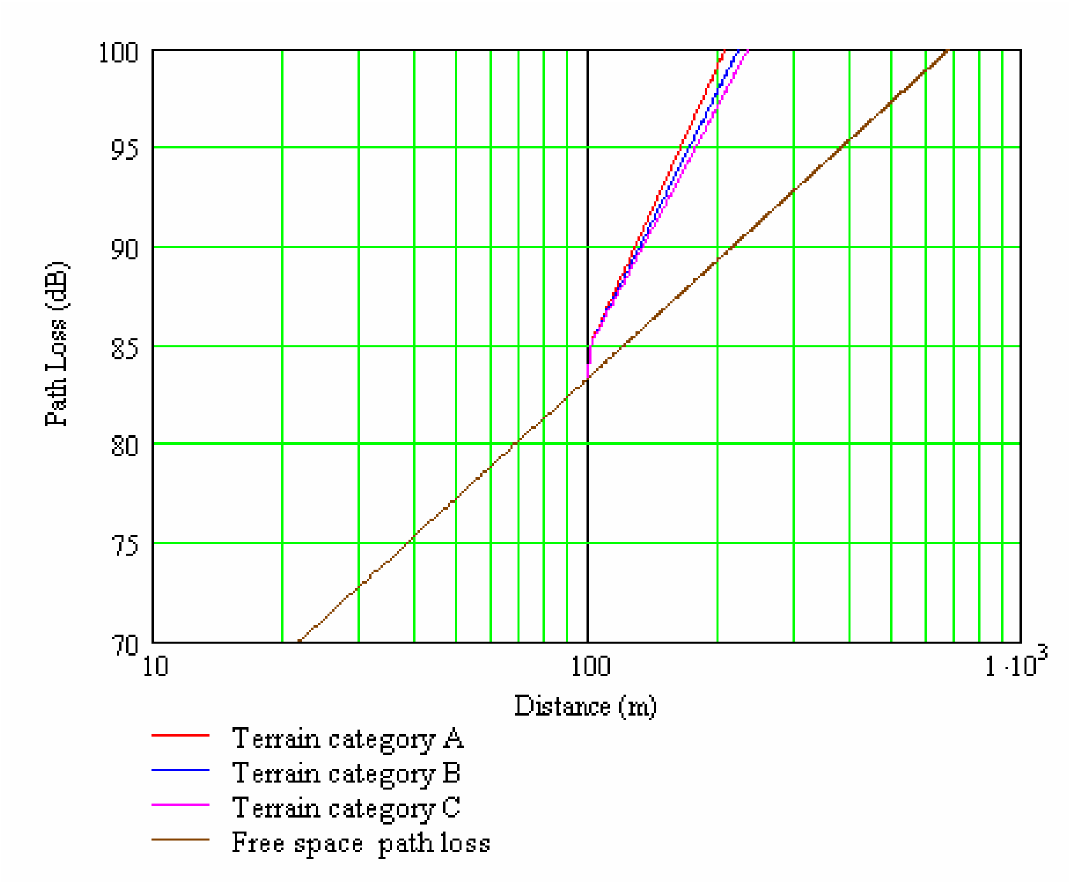
Frequency = 2GHz

h_b = 30m
h_t = 10m

The terminal antenna height correction factor is used in this case. It can be seen that because of the fixed reference distance a discontinuity occurs at 100m, and the path loss is better than free space for some base-to-terminal separations. The model needs to be modified to correct for this.

The model needs correcting so that the reference distance increases with terminal height.

Effect of frequency correction factor. Path Loss at 3.5GHz.



Frequency = 3.5GHz

h_b = 30m
h_t = 2m

The frequency correction factor is used in this case. It can be seen that because of the fixed reference distance a discontinuity occurs at 100m. To preserve the $f^{2.6}$ relationship in the 'non-free space region' the breakpoint needs to decrease with frequency.

The model needs correcting so that the reference distance decreases with frequency.

Calculating the new breakpoint distance.

At the breakpoint :-

$$20\log\left(\frac{4\pi d_0^{'}}{\lambda}\right) = 10\gamma\log\left(\frac{d_0^{'}}{d_0}\right) + \Delta PL_{ht} + \Delta PL_f + 20\log\left(\frac{4\pi d_0^{'}}{\lambda}\right)$$

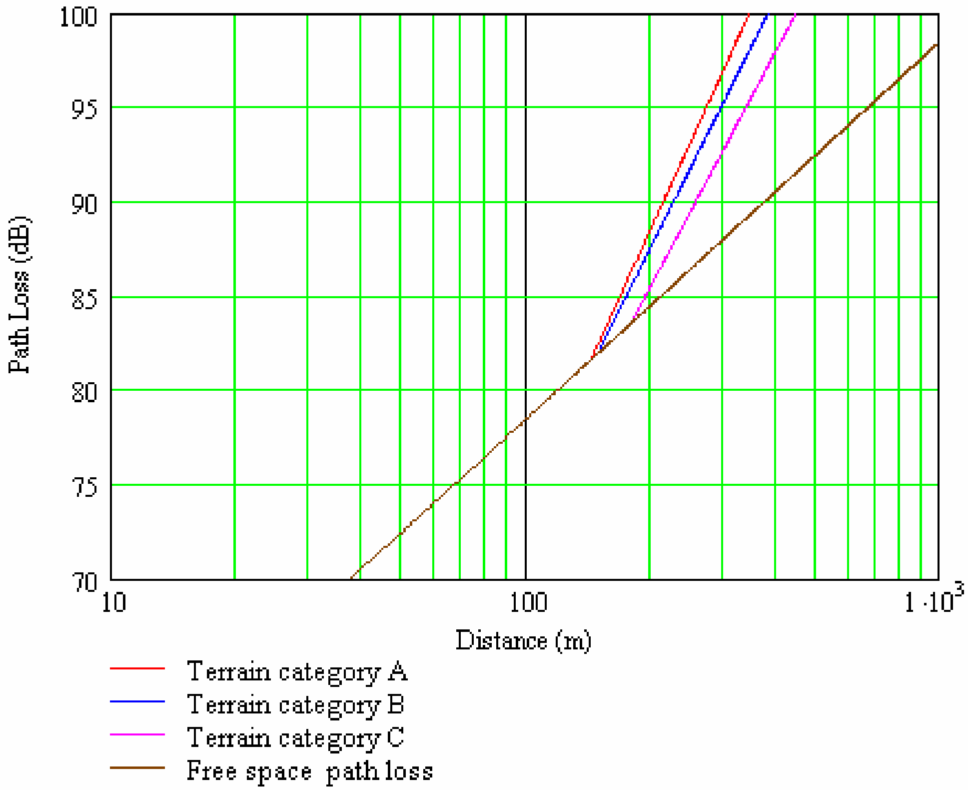
which means that :-

$$10\gamma\log\left(\frac{d_0^{'}}{d_0}\right) = -\left(\Delta PL_{ht} + \Delta PL_f\right)$$

$$d_0^{'} = d_0 10^{-\left(\frac{\Delta PL_{ht} + \Delta PL_f}{10\gamma}\right)}$$

where $d_0^{'}$ is the corrected breakpoint distance and $d_0 = 100m.$

Effect of terminal height correction factor with new breakpoint. Path loss at 10m terminal height.



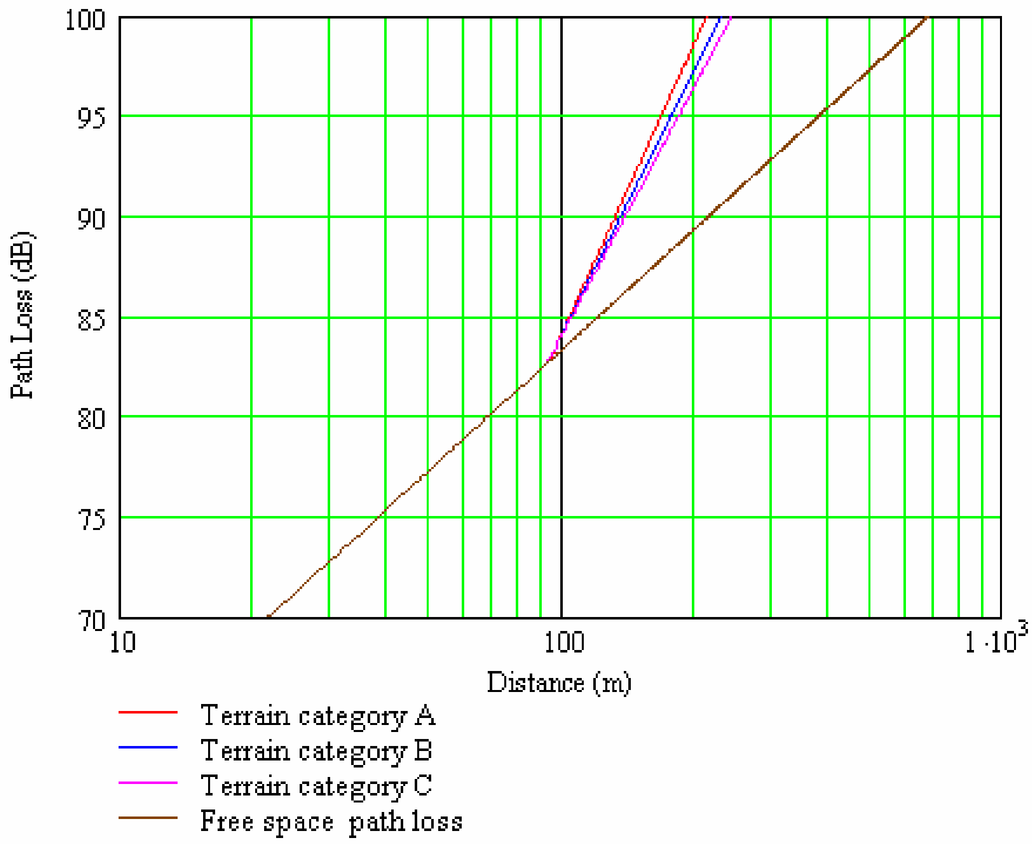
The corrected breakpoint increases with terminal antenna height, as expected.

h_b = 30m
h_t = 10m
f = 2GHz

For this calculation the Okumura height correction factor has been used for terrain category C:-

$$\Delta PL_{ht} = -20\log\left(\frac{h_t}{3}\right)$$

Effect of frequency correction factor with new breakpoint. Path loss at 3.5GHz.



The result shows that the new breakpoint distance has the desired effect. It has now reduced for the path loss calculation at 3.5GHz.

h_b = 30m
h_t = 2m

Proposed model – corrected 802.16d model

$$PL = \begin{cases} A + 10\gamma \log\left(\frac{d}{d_0}\right) + \Delta PL_f + \Delta PL_{ht} + s & \text{for } d > d_0^{'} \\ 20\log\left(\frac{4\pi d}{\lambda}\right) + s & \text{for } d \le d_0^{'} \end{cases}$$

where;

$$A = 20\log\left(\frac{4\pi d_0^{'}}{\lambda}\right)$$

$$d_0 = 100m$$

$$d_0^{'} = d_0 10^{-\left(\frac{\Delta PL_{ht} + \Delta PL_f}{10\gamma}\right)}$$

$$\gamma = a - bh_b + \frac{c}{h_b}$$

d = distance between base and terminal

h_b = height of basestation

s = shadowing

$$\Delta PL_f = 6\log\left(\frac{f}{2000}\right) \quad \text{(frequency in MHz)}$$

$$\Delta PL_{ht} = \begin{cases} -10.8\log\left(\frac{h_t}{2}\right) & \text{for terrain categories A \& B} \\ -20\log\left(\frac{h_t}{3}\right) & \text{for terrain category C} \end{cases}$$

Note that this model is valid for low base heights (>10m) and therefore ought to be appropriate for RS-MS paths for relays mounted above rooftop height in suburban areas. It is not known how valid this model is for above rooftop-to-above rooftop RS-RS links.

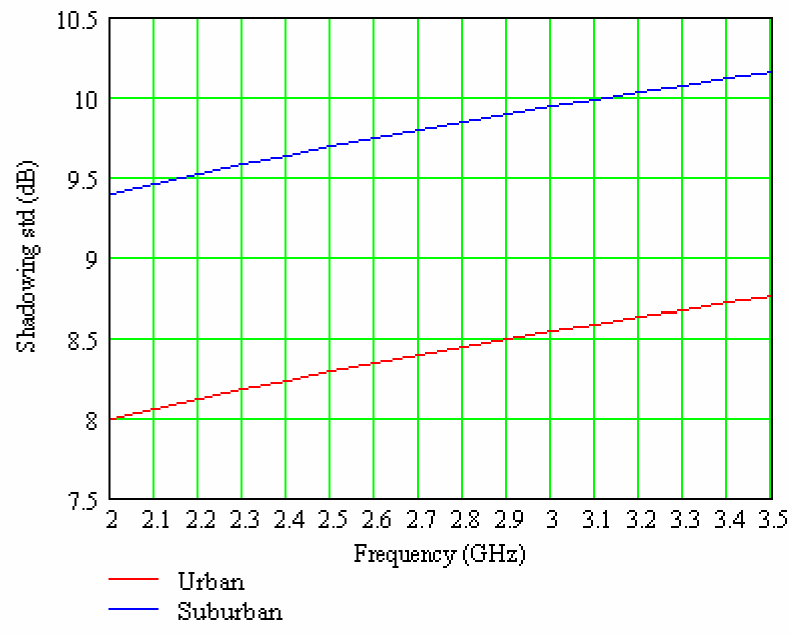
Lognormal Shadowing

The variation of the lognormal shadowing with frequency needs to be taken into account. For this, the expression given by Okumura* can be used:-

$$\sigma = 0.65[\log(f)]^2 - 1.3\log(f) + A$$

with f in MHz,

A = 5.2dB (urban) or 6.6dB (suburban)



***'Field strength and its variability in VHF and UHF land-mobile radio service', Y.Okumura et al., Rev. Elec. Comm. Lab., pp.825-873, 1968**

Summary

- A modified IEEE 802.16d path loss model has been proposed with a variable breakpoint, dependant on frequency and terminal/relay antenna height
- Lognormal shadowing standard deviation increases with frequency and the Okumura model presented models this effect
- Recommend to adopt this model for BS-MS and BS-Relay links