Project: IEEE P802.15 Working Group for Wireless Personal Area Networks

Submission Title: [A New Shadow Fading Model For 60 GHz]
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Abstract:[A new shadow model that predicts mean path loss, standard deviation of the mean path loss and angular correlation of the path loss using circular polarization.]

Purpose: [Contribution to mmW SG3c at November 2004 plenary in San Antonio]

Outline

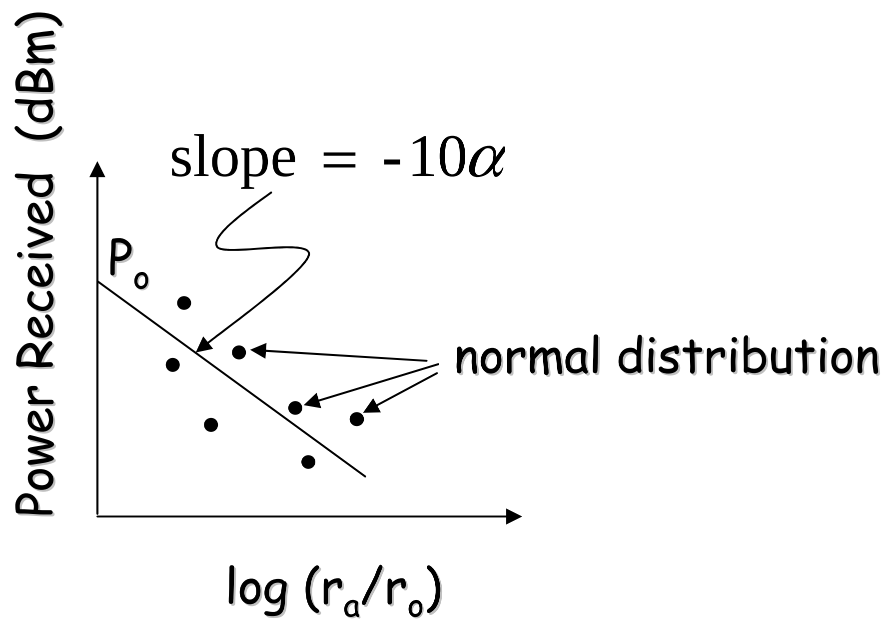
1. Summary of Previous Work at 60 GHz
2. New Shadow Fading Model
3. Analytical Formulas and Numerical Results
4. Conclusions

Existing Shadow Models

Log-normal fading:

$$P_{\text{rec}}(r_a) = P_{rec}(r_o) - 10\alpha \log\left(\frac{r_a}{r_o}\right) + \sigma X_n$$

- **Mean received power versus distance** $P_{rec}(r_a)$
- **Power intercept** $P_o = P_{rec}(r_o)$
- **Path loss exponent** α
- **Standard deviation of loss** σ



Data on Existing Log-Normal Models

Smulders and Correia [1997]: $\alpha = 4.4$ (NLOS < 15 m, 90^o sector)

Xu, Kukshya, Rappaport [2002]: $\alpha = 1.88 - 2$, $\sigma = 8.6$ dB (LOS < 70 m, Omni)

Hansen, Reitzner [2004]: $\alpha = 1.5 - 2$ (LOS Corridors < 50 m, Omni)

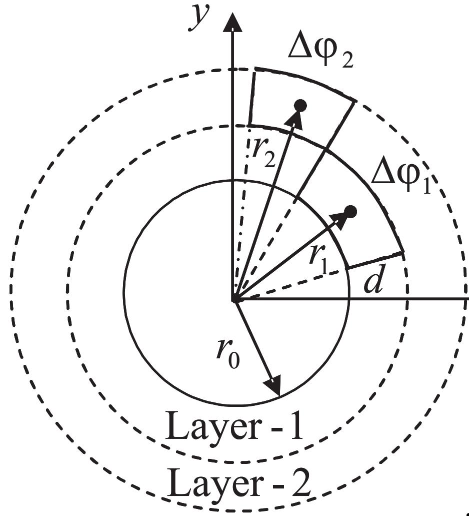
Matic, Harada, Prasad [1998]: $\alpha = 0.78 - 2.54$ (LOS, Omni - Dir)

Moraitis, Constantinou [2002]: $\alpha = 1.75$ (LOS Corridors < 44 m, Omni)

New Shadow Model

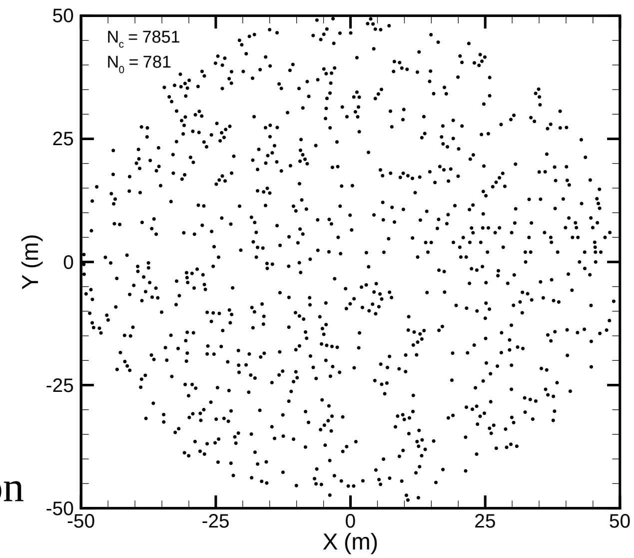
- **Log-normal model** $P_{rec}(r_a) = 20\log\frac{4\pi r_a}{\lambda} + \langle L_{ex}(r_a)\rangle + \sigma(r_a)\,X_n$
- **LOS and NLOS, larger ranges**
- **Random (uniform) locations of non-reflective obstacles**
  - **Circular Polarization**
- **Random (Gaussian) distribution of obstacle loss**
- **Diffraction loss ignored, propagation in a 2D plane**
- **Input Parameters:**
  - **mean obstacle loss, dB**
  - **Standard deviation of obstacle loss, dB**
  - **Obstacle spatial density**
- **Output Parameters:**
  - **Mean path loss versus distance**
  - **Standard deviation of path loss versus distance**
  - **Angular correlation of path loss versus distance**

New Shadow Model



$$\Delta\varphi_k = \frac{d}{r_k}$$

$$L_k = \frac{2\pi}{\Delta\varphi_k}$$



r_0 = initial radius of obstacle-free region

r_a = distance from transmitter

d = subcell size containing an obstacle

μ_L = mean loss of obstacle, dB

σ_L = standard deviation of obstacle loss, dB

N_c = Total number of subcells in region

N_0 = Total number of obstacles in region

p_0 = Obstacle density = N_0 / N_c

Mean Loss & Equivalent Path Loss Exponent

$$\langle L_{ex}(r_a)\rangle = \mu_L p_0 N_a, \quad N_a = \frac{r_a - r_0}{d}, \quad n_0 = \frac{r_0}{d}$$

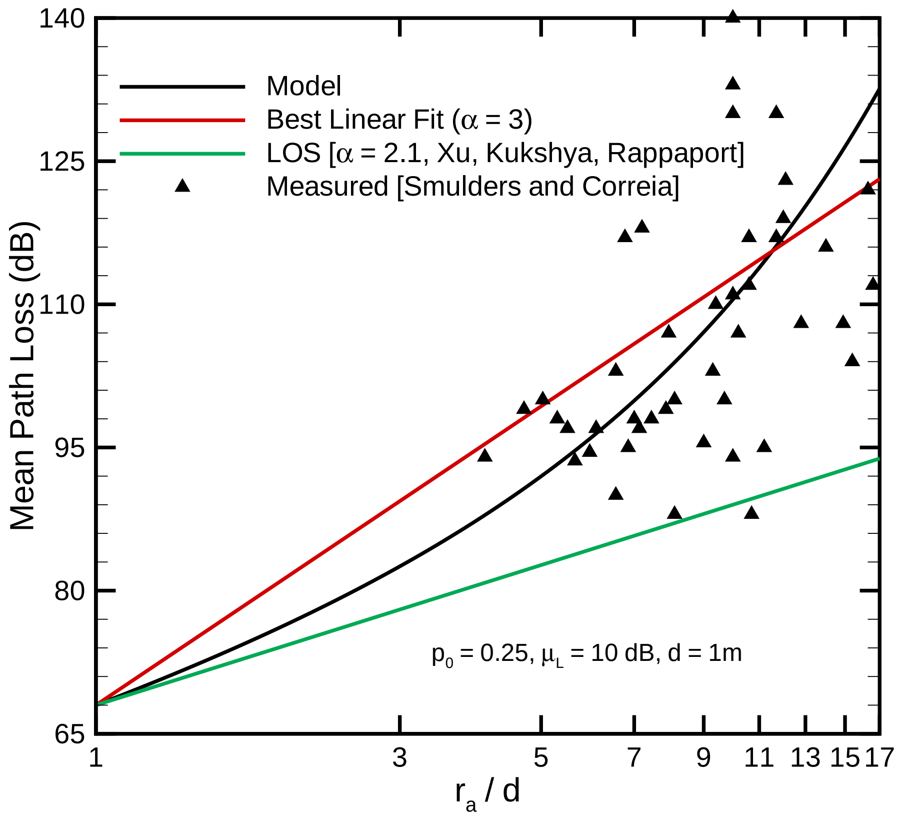
Mean excess loss increases lineary with distance and not logarithmically as in the previous models.

Least square linear fit to model produces an equivalent path - loss exponent model :

$$\alpha(r_a) = 2 + \frac{\mu_L p_0}{10} \frac{\sum_{n_a=1}^{N_a}(n_a - n_0)\log(n_a)}{\sum_{n_a=1}^{N_a}[\log(n_a)]^2}$$

= Equivalent path loss exponent for total mean loss in a cell of radius r_a.

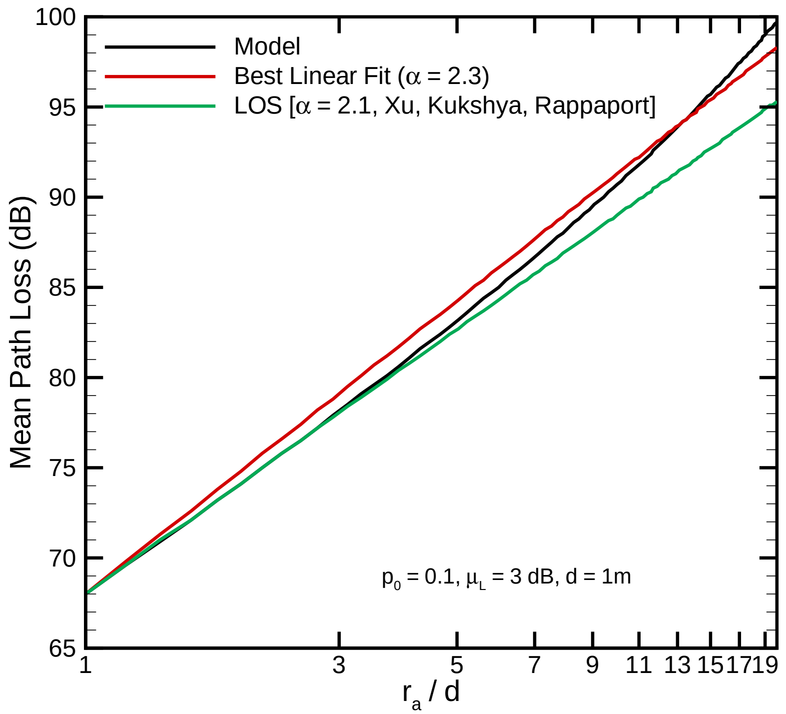
Measured and Model Mean Loss

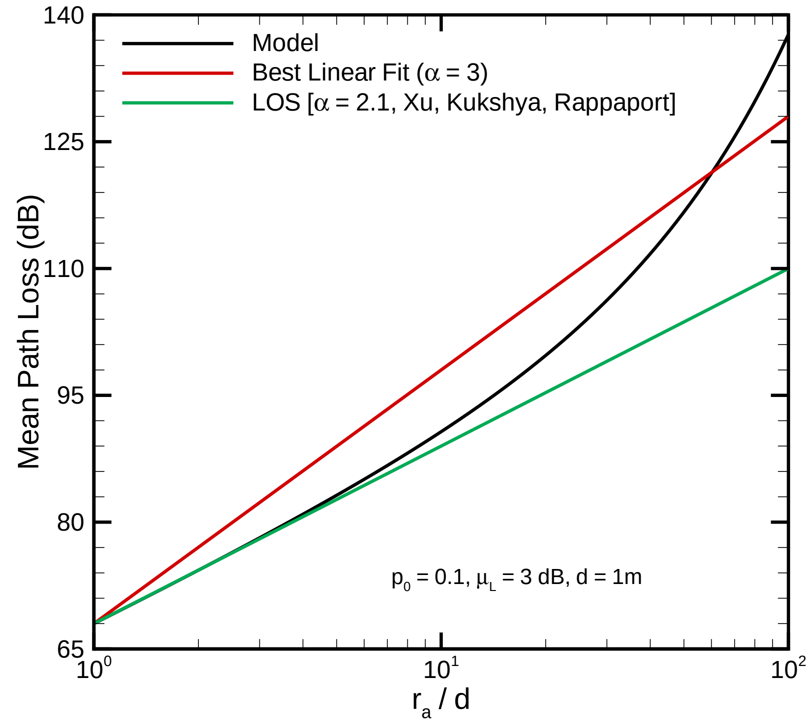


$$\text{STD Dev of Error} = \begin{cases} 12 \text{ dB with model} \\ 11.6 \text{ dB with linear fit} \end{cases}$$

$$p_0 \mu_L / d = 2.5 \,\text{dBm}^{-1}$$

Mean Loss & Equivalent Path Loss Exponent





$$p_0 \mu_L / d = 0.3\,\text{dBm}^{-1}$$

Variance & Angular Correlation of Loss

Variance $\sigma^2(r_a,\phi_a) = p_0 N_a \left[\sigma_L^2 + \mu_L^2 \frac{N_c^2 - N_0 N_c - N_a N_c + N_0 N_a}{N_c(N_c-1)} \right]$

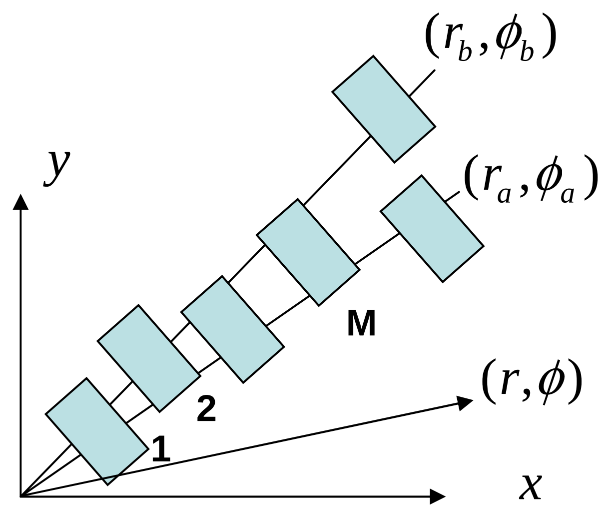
$$\sim p_0 N_a \left[\sigma_L^2 + \mu_L^2 (1-p_0) \right], \quad N_c \to \infty$$

Variance of loss increases linearly with distance from transmitter

Angular Correlation $\rho_{ab}(r_a,\phi_a;r_b,\phi_b) \sim \frac{M}{\sqrt{N_a N_b}}, \quad N_c \to \infty$

$$N_a = \frac{r_a - r_0}{d}, \quad N_b = \frac{r_b - r_0}{d}$$

M = Number of layers with common cells. Depends on n_0 and $|\phi_a - \phi_b|$



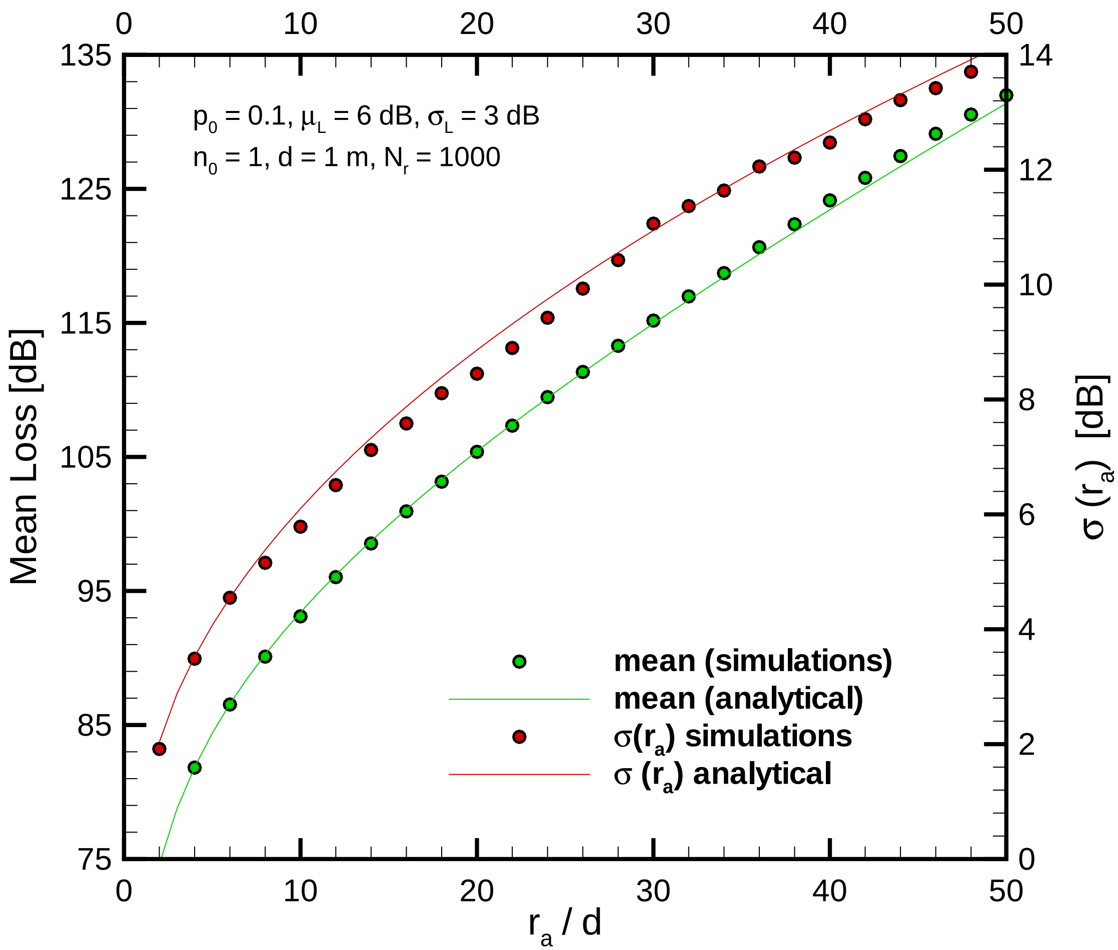
Angular Correlation of Shadow Loss

ρ_{ab} = correlation coefficient of the signal received two points (r_a, ϕ_{a}) and (r_b, ϕ_{b}) due to a transmitter placed at the origin.

= correlation coefficient of the signal received at the origin due to two transmitters at (r_a, ϕ_{a}) and (r_b, ϕ_{b}).

If the width of a typical obstacle is W and if the nearest distance of it to the receiver is d_0, then the correlation angle $\sim W/d_0$. For example, if $2W = d_0 = 1$ m, then correlation angle ≈ 0.5 radian

Comparison of Analytical vs Monte Monte Carlo Simulation



Sample Link Calculation

Uplink :

$P_T = 10\,\text{dBm},\ G_T = 10\,\text{dB}, H_T = 2\,\text{m}, \text{Pol.} = \text{Cir}$

$G_R = 22\,\text{dB}, H_R = 2\,\text{m}, \text{MDS} = -50\ \text{to} -60\,\text{dBm}, r_0 = 1\,\text{m}$

$p_0\mu_L / d = 6.5\,\text{dBm}^{-1}$ (Very high loss, home environment, Akeyama)

$$P_R = P_T + G_T + G_R - \left(68 + 20\log\frac{r_a}{r_0}\right) - \frac{p_0\mu_L}{d}(r_a - r_0) \geq MDS$$

$$\Rightarrow 20\log r_a + 6.5 r_a \leq 30.5\ \text{to}\ 40.5 \Rightarrow r_a \leq 3.2\,\text{m to}\ 4.3\,\text{m}$$

Conclusions

- New log-normal shadow fading model valid both for LOS and NLOS situations
  - Non-reflective obstacles
  - Diffraction effects ignored
  - Gaussian distribution of obstacle loss (mean and std. dev. of obstacle loss)
  - Uniform distribution of obstacle locations
  - Density of obstacles

- Mean excess loss in dB increases linearly with distance.

- Variance of loss increase linearly with distance.

- Angular correlation of loss increases linearly with number of common cells M.

- Model recovers previous shadow fading models for low loss.

References

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