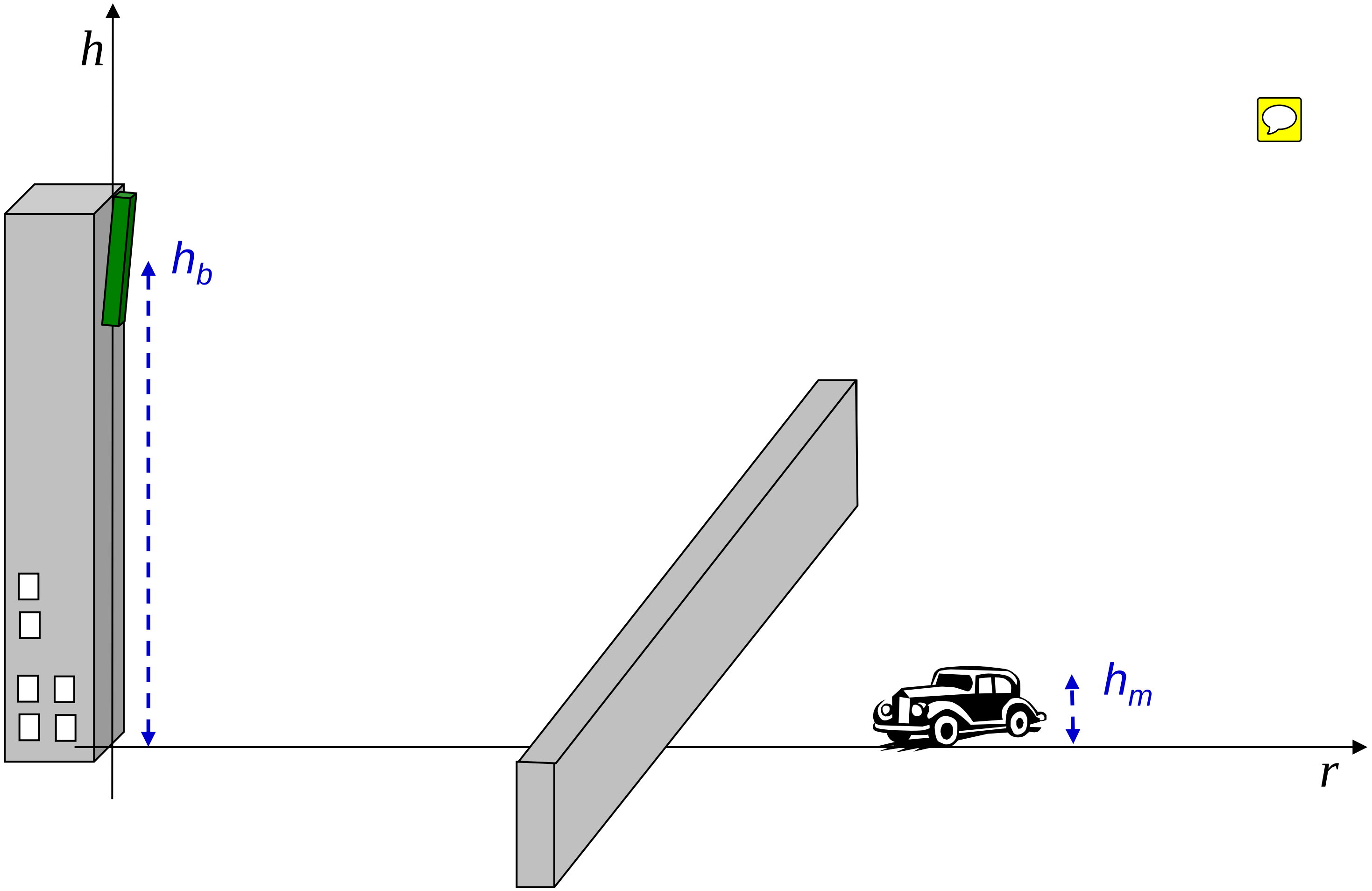
Chapter 8 Macrocells

- Prediction of path loss at any point in a large cell
- Various methods
  - Empirical
  - Physical
  - Some comparison
- Planning tools

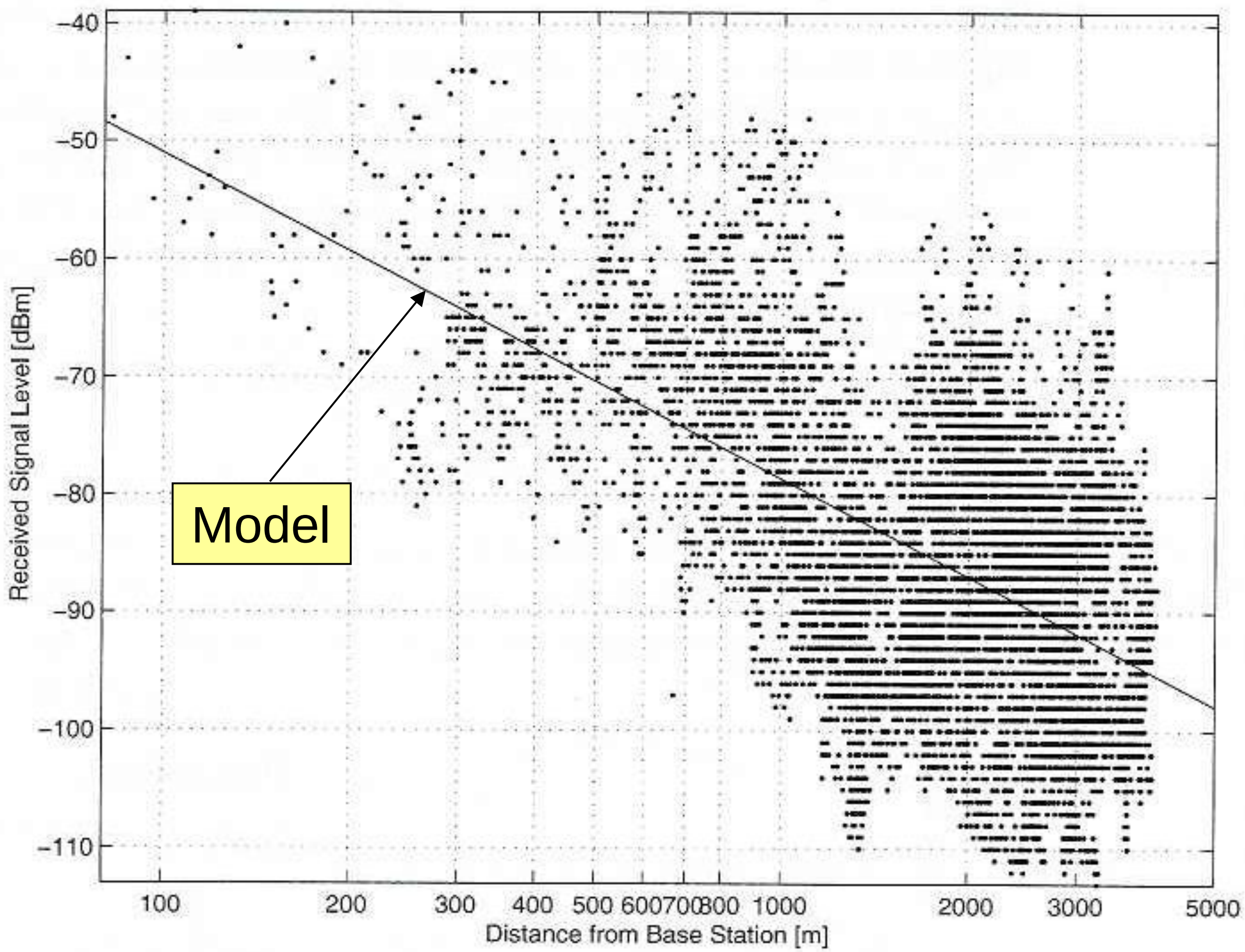
Empirical loss model

- In Chapter 5: free space loss and plane earth loss
- In Chapter 6: diffraction loss or obstruction
- Complex methods may not be practical to use since detailed knowledge of terrain, buildings, and vegetation is required
- Empirical models are an alternative using a large number of measurements and fitting an appropriate function through these
- Parameters from environment, frequency, and antenna heights
- Introduces local mean which is the average of a number of measurements within a small area (10-50 m) taking out fast fading

Geometry defining parameters



Example empirical model



Simple empirical modelling

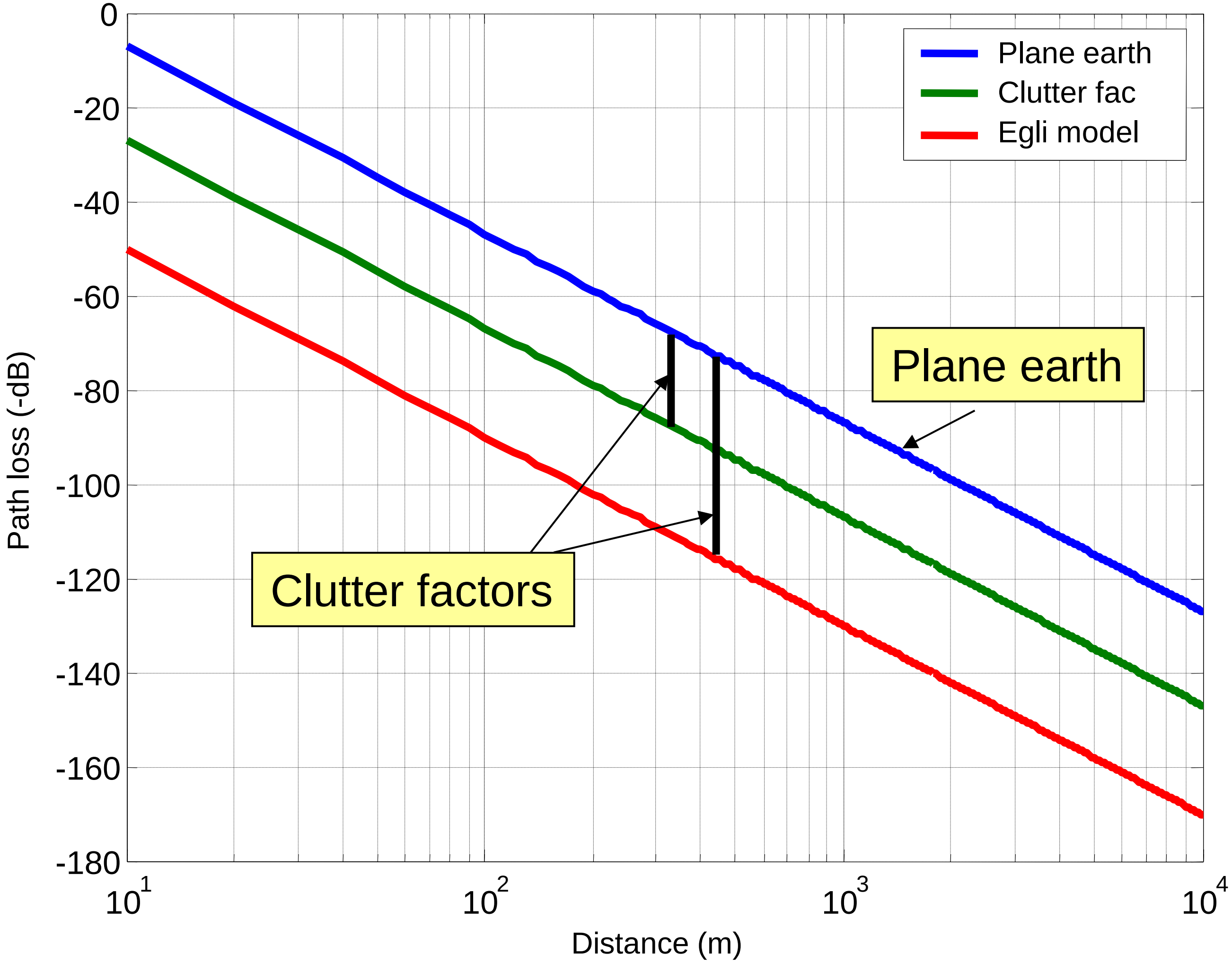
Power-law model

$$\frac{P_R}{P_T} = \frac{1}{L} = \frac{k}{r^n}$$

$$L = 10n\log r + K$$

$$L = 10n\log\left(\frac{r}{r_{ref}}\right) + L_{ref}$$

Clutter factor model



Okumura-Hata model

- Empirical prediction method developed by Okumura using 200 MHz to 2 GHz data from the Tokyo region
- Method provided as a series of graphs
- Hata has approximated these and three areas are used
  - Urban $L_{dB} = A + B\log R - E$
  - Suburban $L_{dB} = A + B\log R - C$
  - Open $L_{dB} = A + B\log R - D$

  where

  A, B, C, D, and E takes values according to frequency and heights of base station and mobile

  Valid for 150 MHz < f < 1500 MHz, 30 m < h_b < 200 m, 1 m < h_m < 10 m, and R > 1 km.

COST 231 Hata model

- Extending the Okumura Hata model to cover the 1.5 GHz to 2 GHz band
- Medium to small cities

$$L_{dB} = F + B\log R - E + G$$

where

$$F = 46.3 + 33.9\log f - 13.82h_b$$

and

$G = 0$ for medium sized cities and suburban areas and 3 dB for metropolitan areas

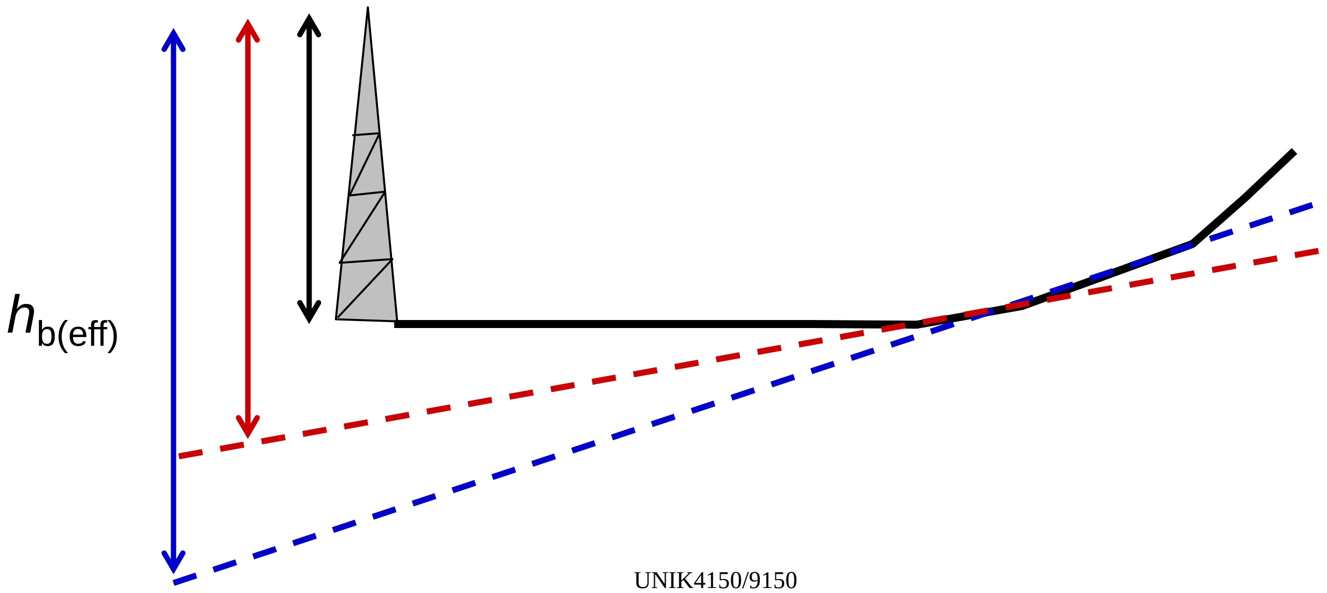
Lee model

- The Lee model is a power law model with parameters taken from measurements
- Simplified

  $L = 10n\log R - 20\log h_{b(eff)} - P_0 - 10\log h_m + 29$

  where

  n and P_0 are given from measurements, n in the range from 2 to 5 and P_0 from –85 to 45, and an effective base station antenna height

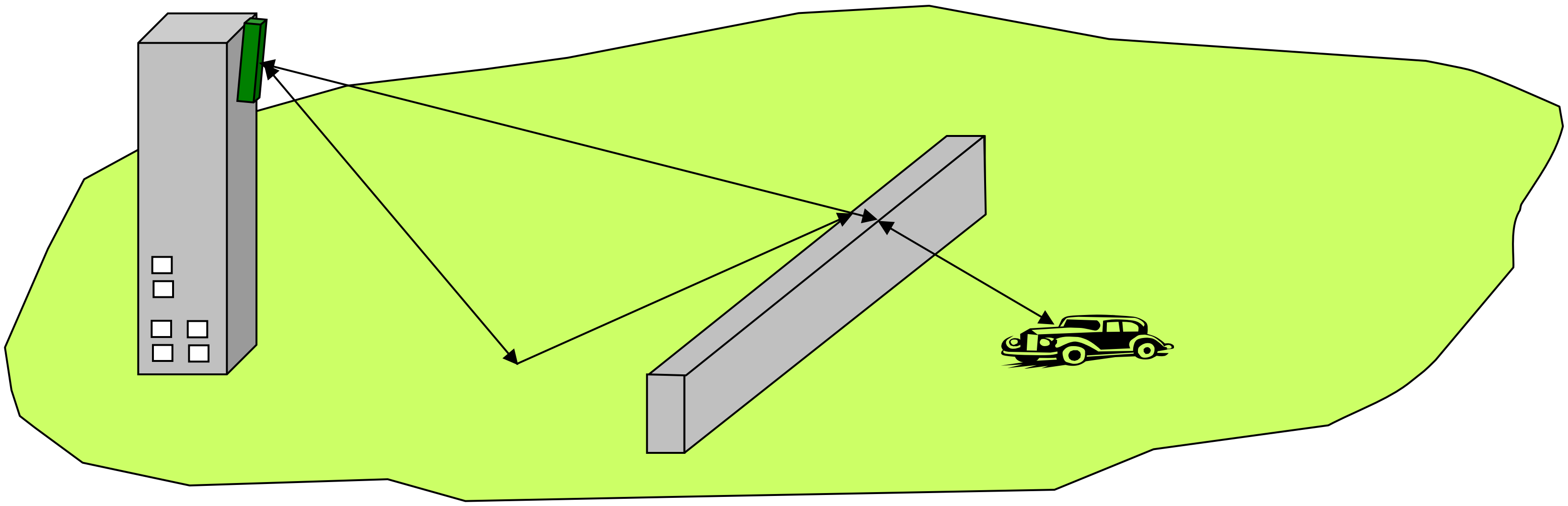


Empirical models problems

- Parameter ranges limited - poor for extrapolation
- Subjective classification
- No physical insight

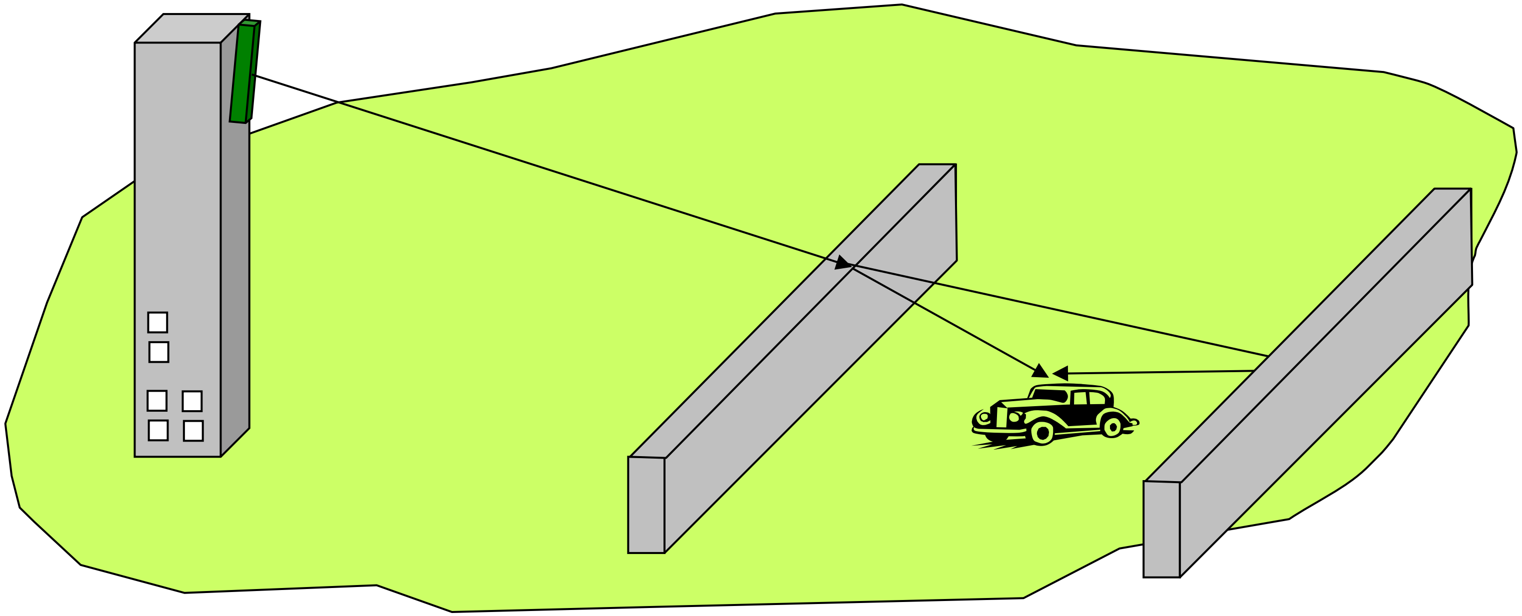
Hence examine physical (deterministic) models

Plane earth and single diffraction (Allsebrook and Parson model)



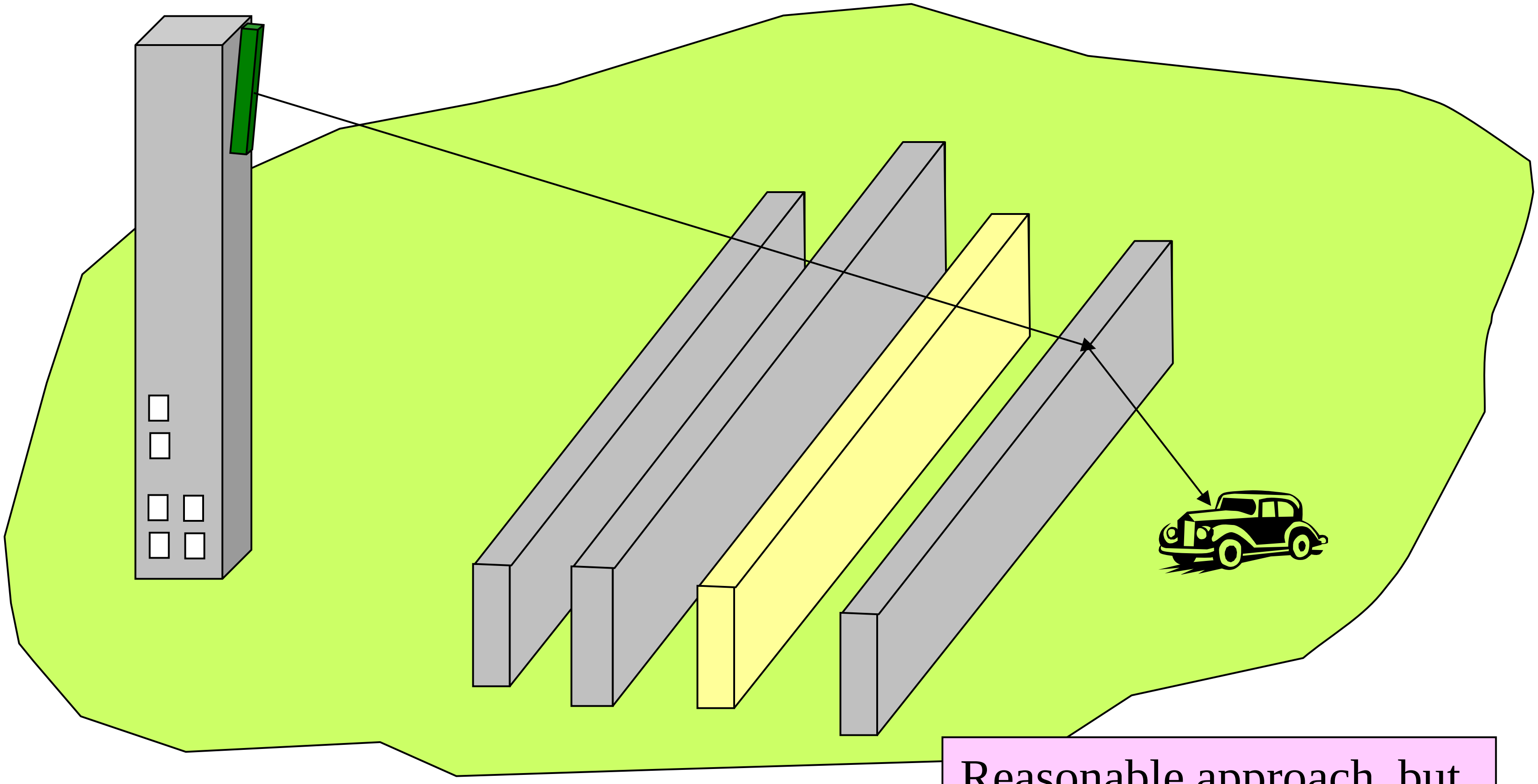
Better than empirical models as it takes geometry into account.

Single diffraction and reflection (Ikegami)



The model uses the free space path loss model, since base station height not used. This is problematic or questionable.

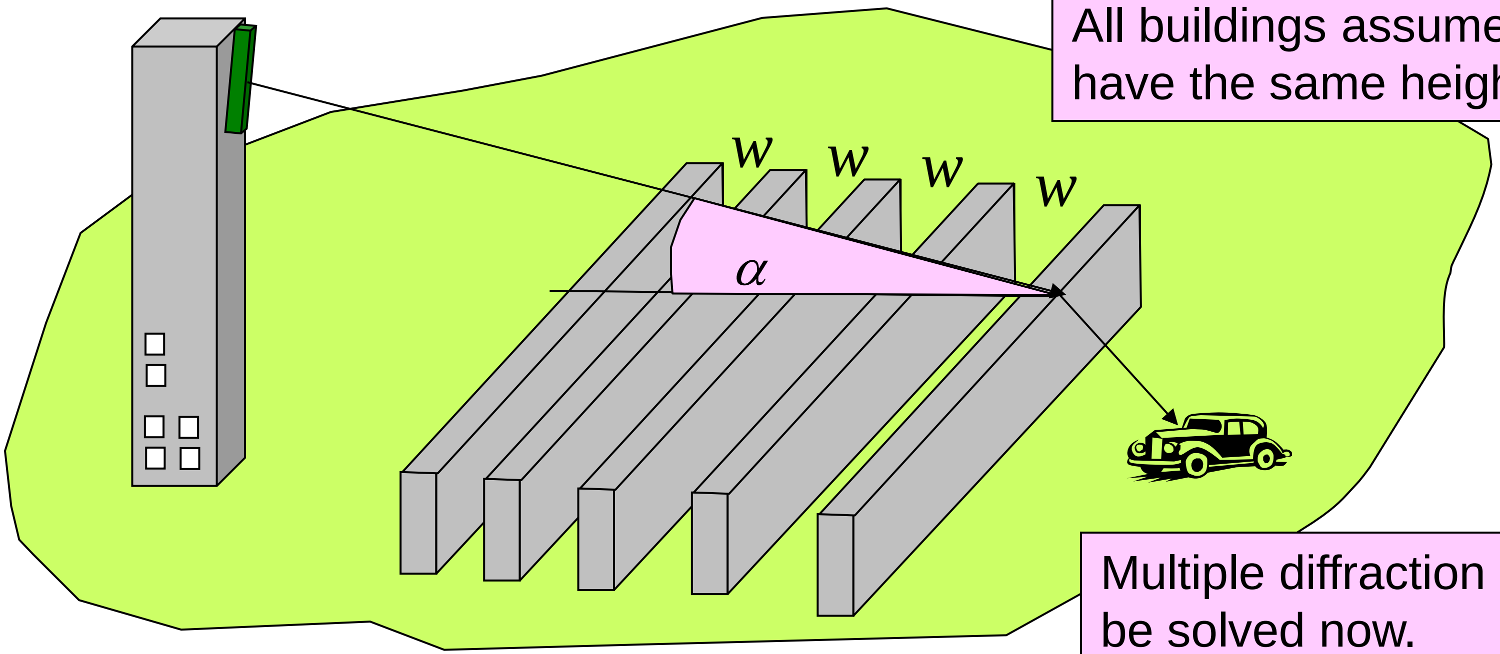
Multiple diffraction



Reasonable approach, but complex calculations

Flat edge model

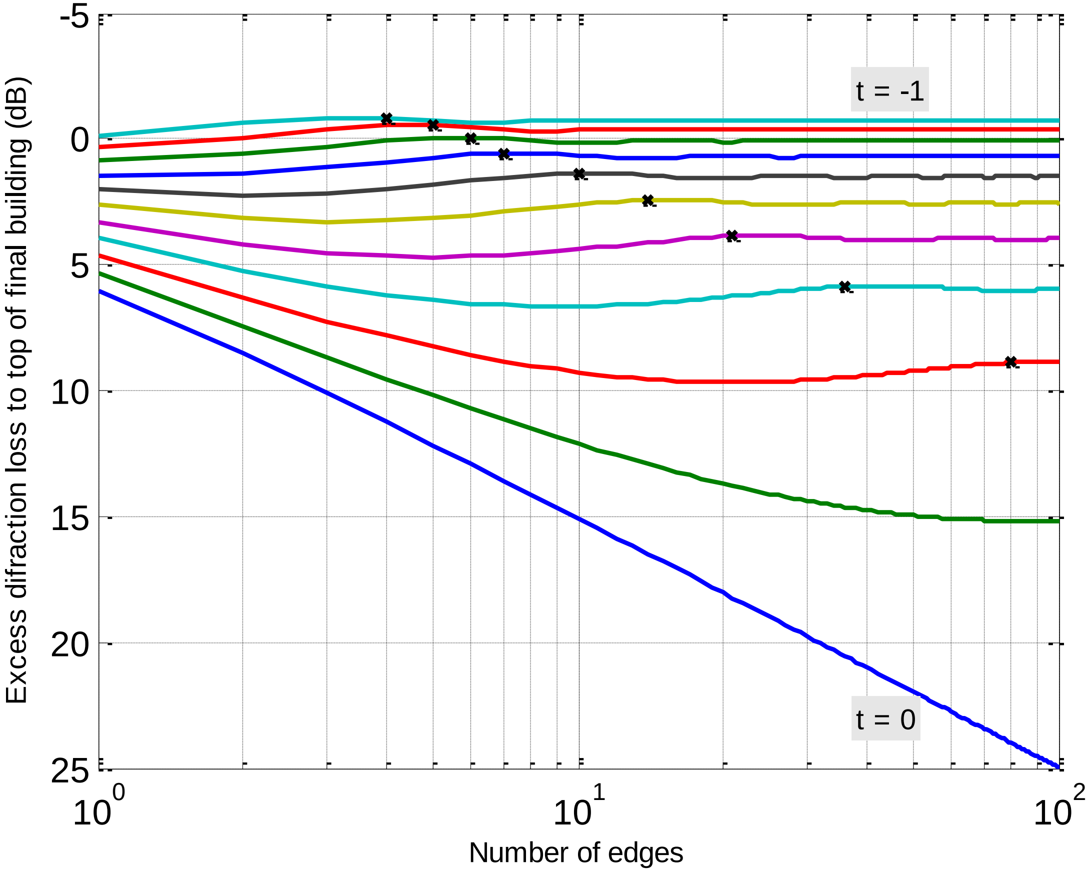
All buildings assumed to have the same height



Multiple diffraction integral can be solved now.

$$L_{ex}=\overbrace{L_{n-1}(t)}^{\text{Rooftop}}\overbrace{L_{ke}}^{\text{Knife-edge}} \quad \text{where} \quad t=-\alpha\sqrt{\frac{\pi w}{\lambda}}$$

Flat edge model excess diffraction loss to top of last building

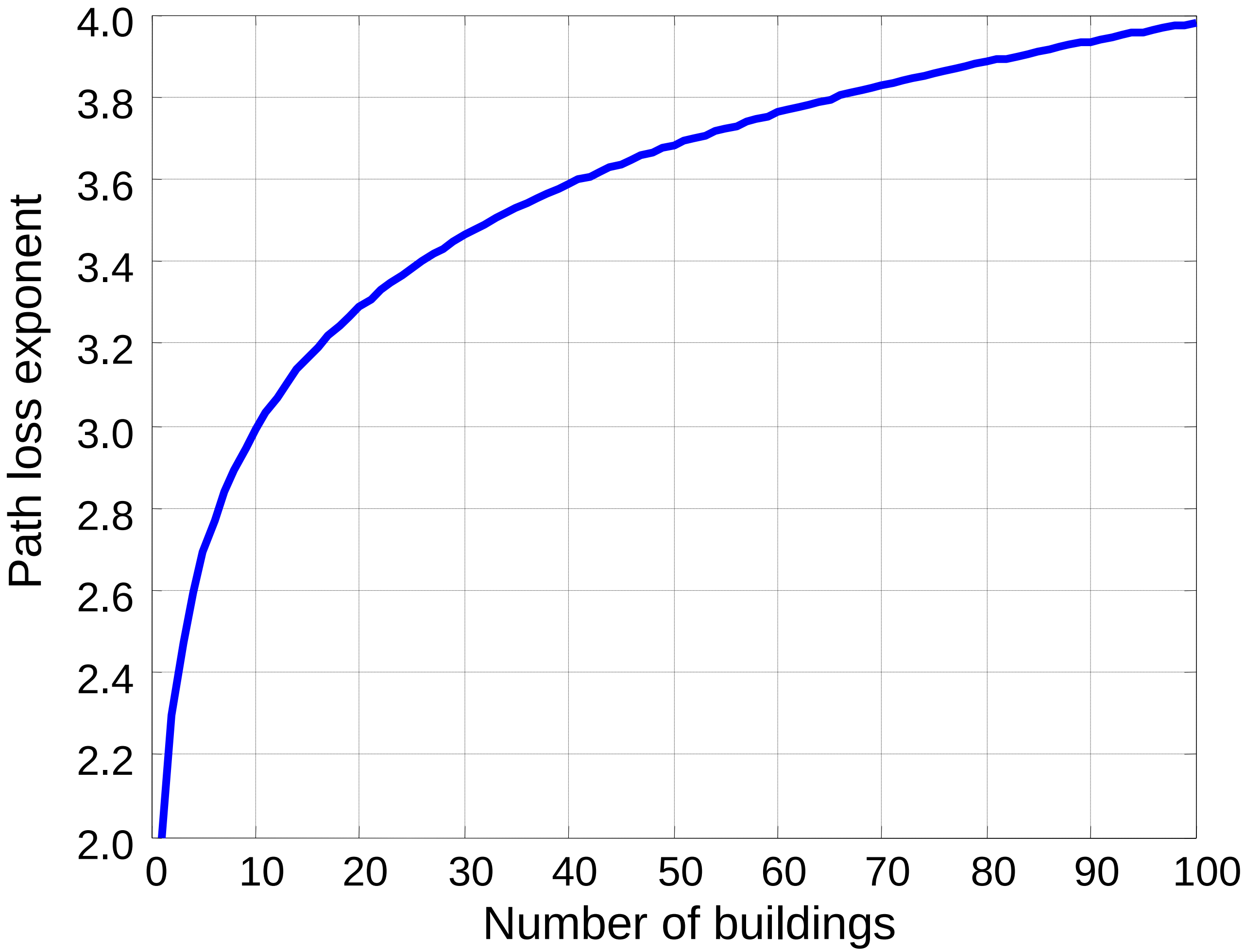


Loss settled after a number of buildings, more the smaller α is. Settled when building fill the first Fresnel zone, marked with x. The parameter *t* varies from -1 to 0 in 0.1 steps.

Approximation: $L_n(t) = -(c_1+c_2\log n)\log(-t)-(c_3+c_4\log n)$ dB

where c_1=3.29, c_2=9.9, c_3=0.77, and $\underline{c}_4$=0.26.

Path loss exponent for the flat edge model



Path loss exponent given from a simplified approximation to the flat edge model. The exponent approaches 4 for large number of buildings, the same as observed in measurements.

Walfisch-Bertoni model

Limiting case for the flat edge model when number of buildings $n > n_s$ gives amplitude ($n_s \approx \pi/t^2$ and $0.003 \leq t \leq 0.4$)

$$A_{settled}(t) \approx 0.1\left(\frac{\alpha}{0.03}\sqrt{\frac{w}{\lambda}}\right)^{0.9} = 0.1\left(\frac{-t}{0.03}\right)^{0.9}$$

where t becomes, for large ranges,

$$t = -\alpha\sqrt{\frac{\pi w}{\lambda}} \approx -\frac{h_b - h_m}{r}\sqrt{\frac{\pi w}{\lambda}}$$

This results in $L_{settled} \propto r^{-1.8}$.
Free space loss is proportional to r^{-2}, hence total propagation loss proportional to $r^{-3.8}$ close to r^{-4}.

Empirical versus physical

- Empirical advantages
  - Simple to compute
  - Accurate for similar environments
- Empirical disadvantages
  - Subject to shadowing ‘error’
  - Poor extrapolation
  - Classification problem
  - Poor use of geographic data

- Physical advantages
  - High accuracy
  - Point-by-point results
  - Wide parameter range
- Physical disadvantages
  - Complex computation
  - Expensive input data
  - Hard to generalise

Software tools

- Many commercial planning tools available
- Permit prediction of:
  - Area coverage
  - Interference
  - Automated frequency plans
  - Other network management issues
- Mostly based on empirical path loss models, plus terrain diffraction loss (?)

Conclusion

- Path Loss models required to predict macrocell coverage
- Empirical models give fast, cheap predictions
- Physical models, based on multiple rooftop diffraction for greater accuracy
- Coverage and interference can be controlled by antenna pattern shaping

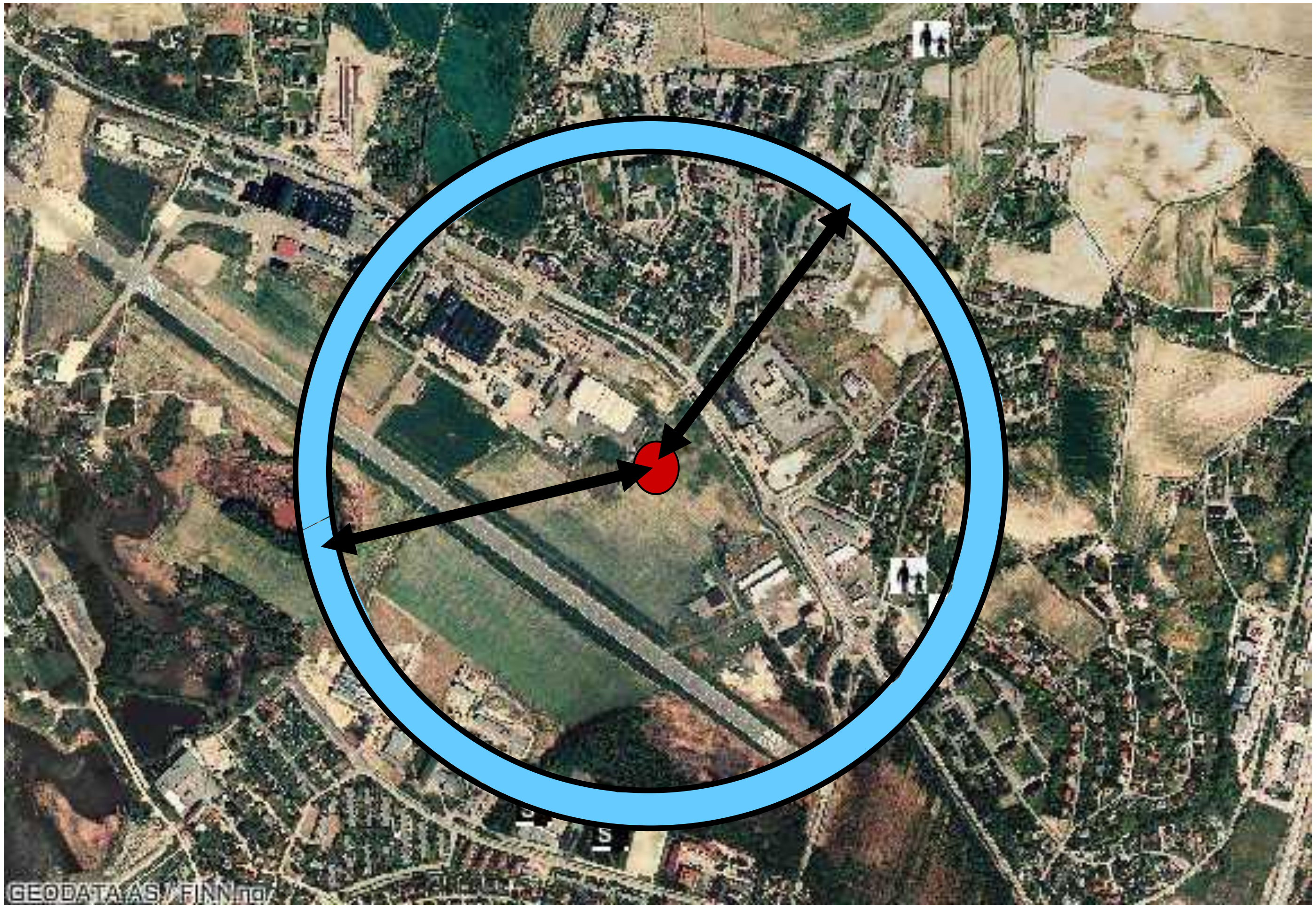
Path loss roughly as $$\frac{P_R}{P_T} = \frac{1}{L} = k\,\frac{h_m h_b^2}{r^4 f_c^2}$$

where *k* is a constant appropriate to the environment

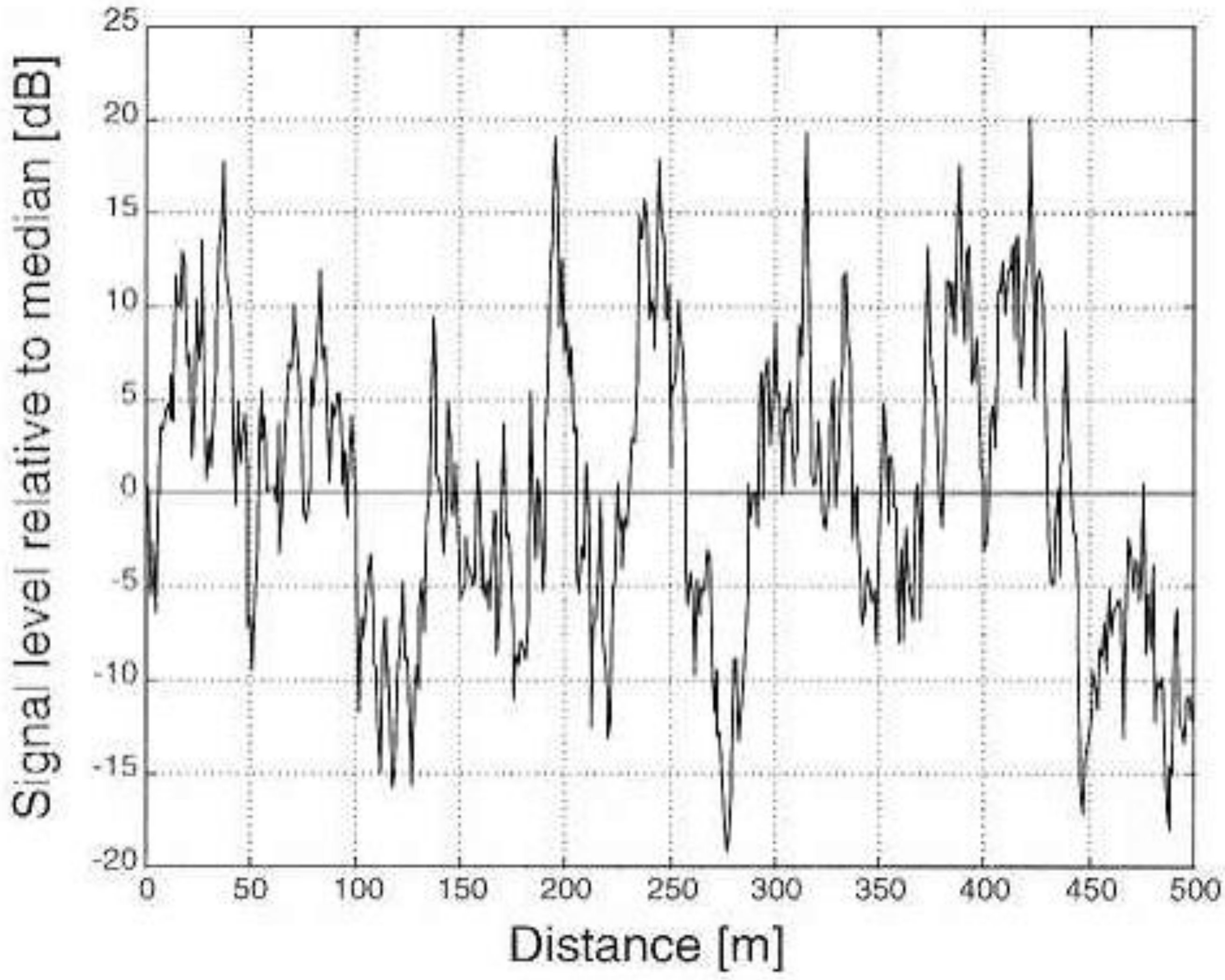
Chapter 9 Shadowing

- Source of shadowing
- Shadowing statistics
- Impact of shadowing on cell size and system availability
  - At cell edge
  - Over cell area
- Measured shadowing variability
- Shadowing correlations
  - Serial (auto) correlation
  - Site-to-site (cross) correlation

Same distance to the base station, but different paths



Typical example signal variation



Signal variation

- Signal and noise vary with location (and time also!)
- Necessary to use statistical representation for a number of applications, e.g., dimensioning
- System requirements are obviously a key, but independently the local features and climate have a crucial impact
- Different statistical distributions
  - Normal and log-normal, i.e., the logarithmic value is normal
  - Rayleigh
  - Rice-Nakagami
  - and a quite a few more

Statistics basics

The *probability* that random variable *x* is in the interval (*a*,*b*) where *p*(*x*) is the *probability density function* (pdf):

$$\Pr(a < x < b) = \int_{x=a}^{b} p(x)dx$$

By definition of probability:

$$\int_{x=-\infty}^{\infty} p(x)dx = 1$$

The *cumulative distribution function* (cdf):

$$\Pr(-\infty < x < a) = \int_{x=-\infty}^{a} p(x)dx = P(a)$$

The *expectation* of some function of random *x*:

$$E[f(x)] = \int_{x=-\infty}^{\infty} f(x)p(x)dx$$

The mean μ of a random variable *x* is:

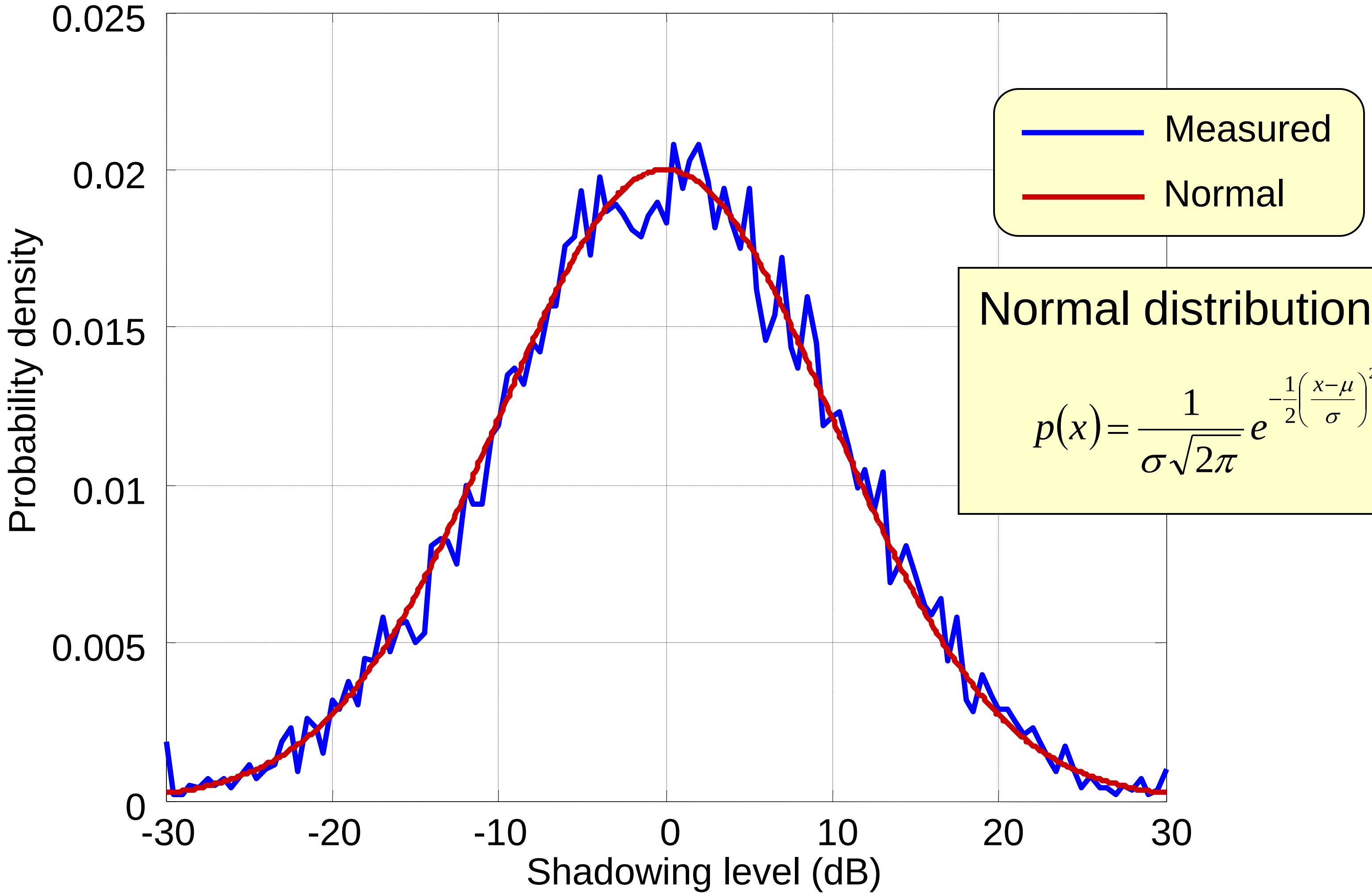
$$\mu = E[x] = \int_{x=-\infty}^{\infty} xp(x)dx$$

The *standard deviation* σ or variance σ^2 :

$$\sigma^2 = E\left[(x - E[x])^2\right] = E\left[x^2 - 2xE(x) + E^2(x)\right] = E\left[x^2\right] - E^2(x) = \int_{x=-\infty}^{\infty} x^2 p(x)dx$$

The *median* is the value *m* such that *P*(*m*)=1/2.

Probability density function of shadowing



Normal distribution:

$$p(x)=\frac{1}{\sigma\sqrt{2\pi}}e^{-\frac{1}{2}\left(\frac{x-\mu}{\sigma}\right)^2}$$

Shadowing follows a log-normal distribution

- Assume contributions to the path loss are multiplicative and independent:

$$A = A_1 \text{ x } A_2 \text{ x } A_3 \text{ x } \ldots. \text{ x } A_N$$

- In decibels:

$$L = L_1 + L_2 + L_3 + \ldots. + L_N$$

- If N is large, central limit theorem gives L normal, so A is lognormal

Total path loss: median plus shadowing

The path loss is a random variable

$$L = L_{50} + L_S$$

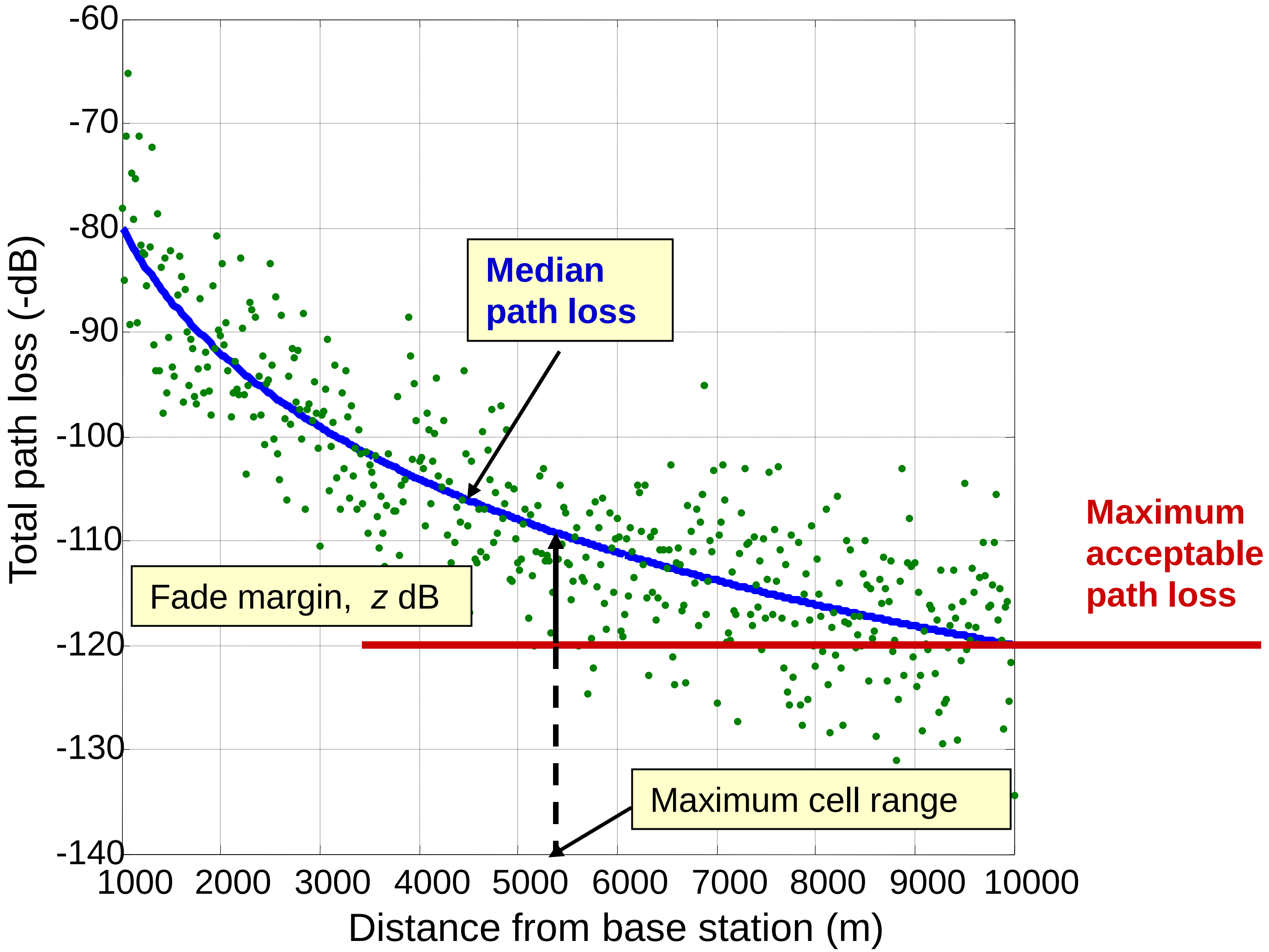
where

L_{50} is the level not exceeded at 50 % of locations at a given distance (Chapter 8) and

L_S is the shadowing component following a normal distribution with zero mean and standard deviation σ_L

$$p(L_S) = \frac{1}{\sigma_L \sqrt{2\pi}} e^{-\frac{L_S^2}{2\sigma_L^2}}$$

Cell range limited by shadowing



Total path loss: median plus shadowing

The probability that L_S increases the median by z dB or more is

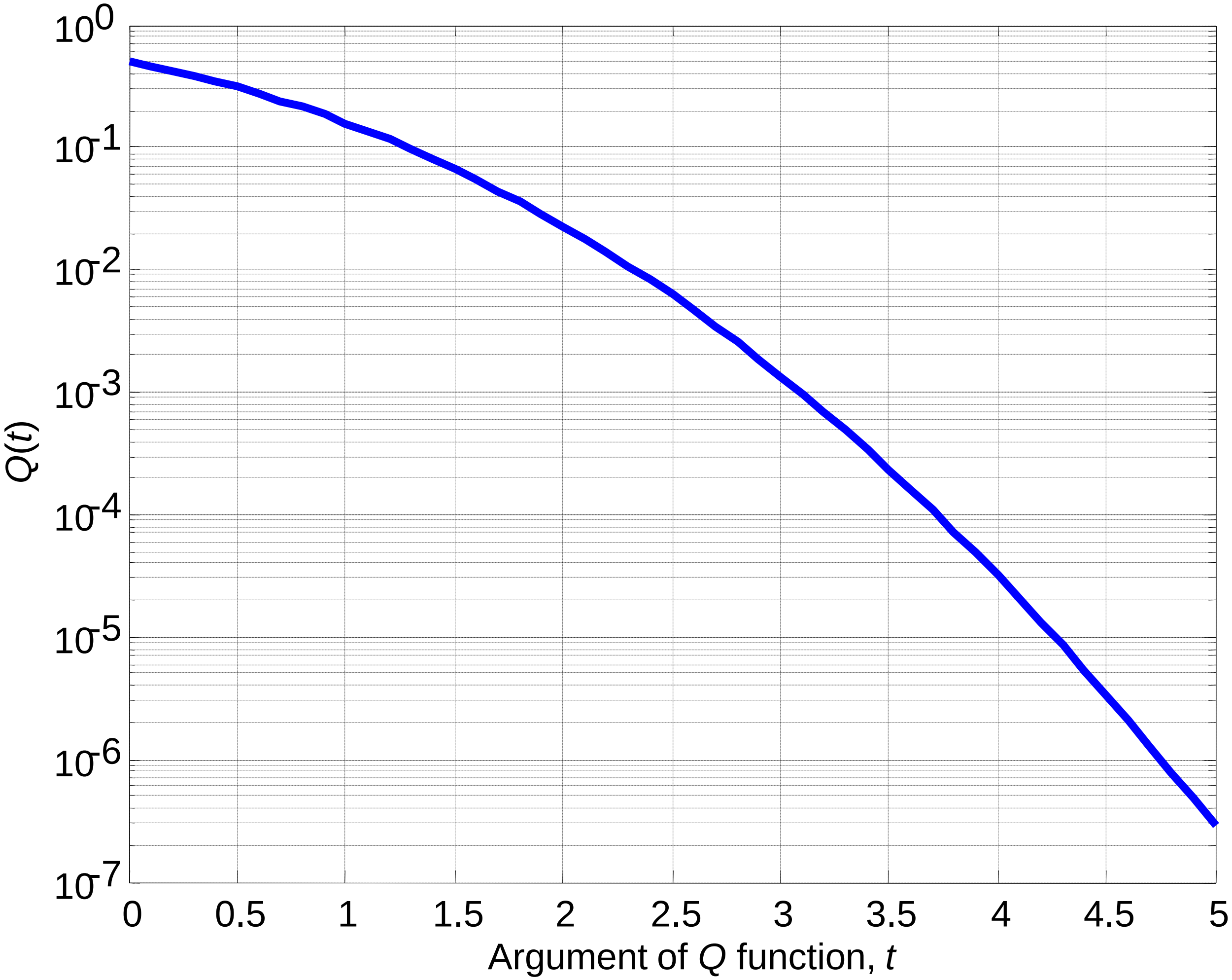
$$\Pr(L_S > z) = \int_{L_S=z}^{\infty} p(L_S)\, dL_S = \frac{1}{\sigma_L\sqrt{2\pi}} \int_{L_S=z}^{\infty} e^{-\frac{L_S^2}{2\sigma^2}}\, dL_S$$

$$\Pr(L_S > z) = \int_{x=\frac{z}{\sigma_L}}^{\infty} \frac{1}{\sqrt{2\pi}} e^{-\frac{x^2}{2}}\, dx = Q\left[\frac{z}{\sigma_L}\right]$$

Where Q is the complementary cumulative normal function

$$Q(t) = \frac{1}{\sqrt{2\pi}} \int_{x=t}^{\infty} e^{-\frac{x^2}{2}}\, dx = \frac{1}{2} erfc\left(\frac{t}{\sqrt{2}}\right)$$

The Q-function

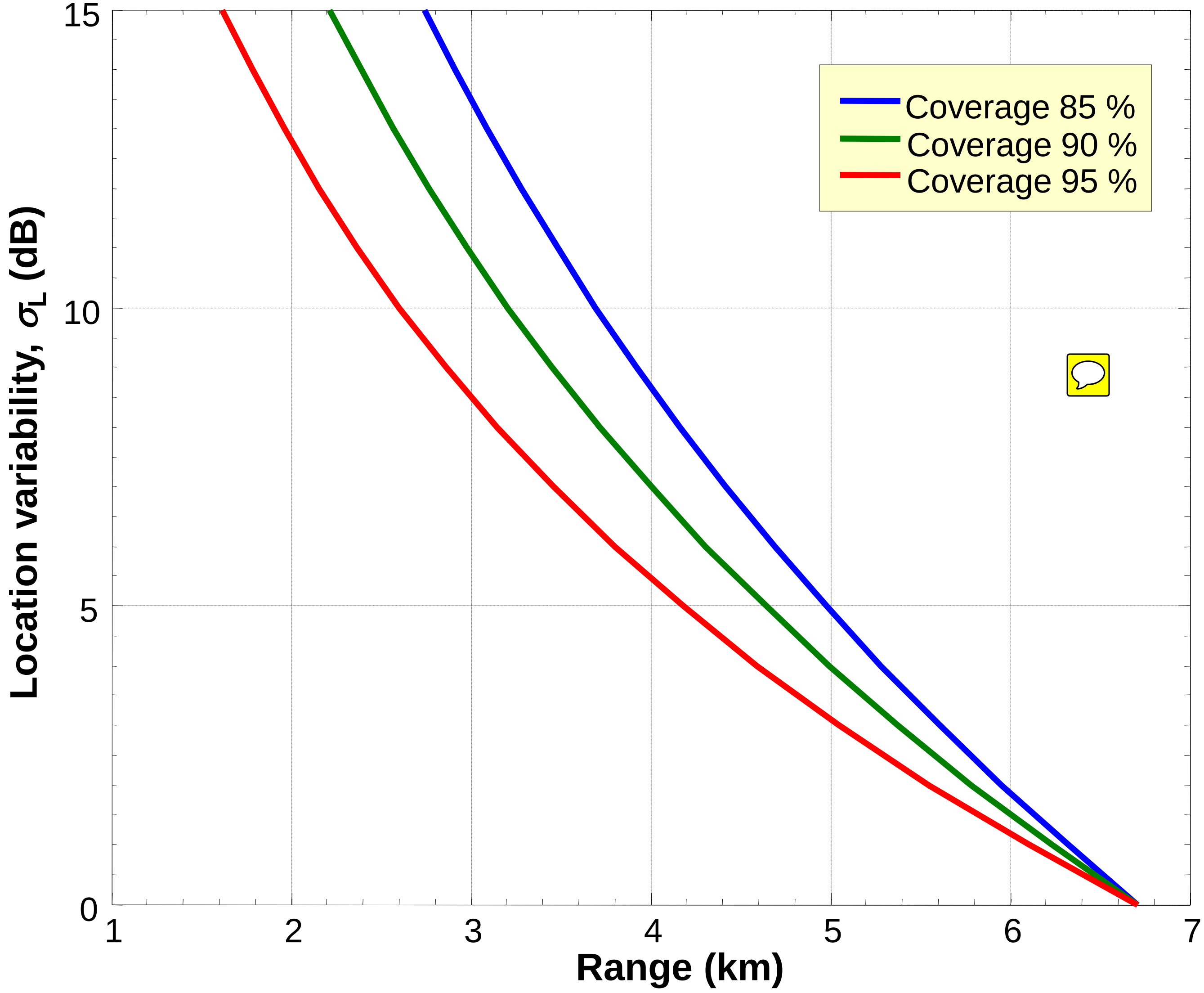


Use this to evaluate shadowing margin needed.

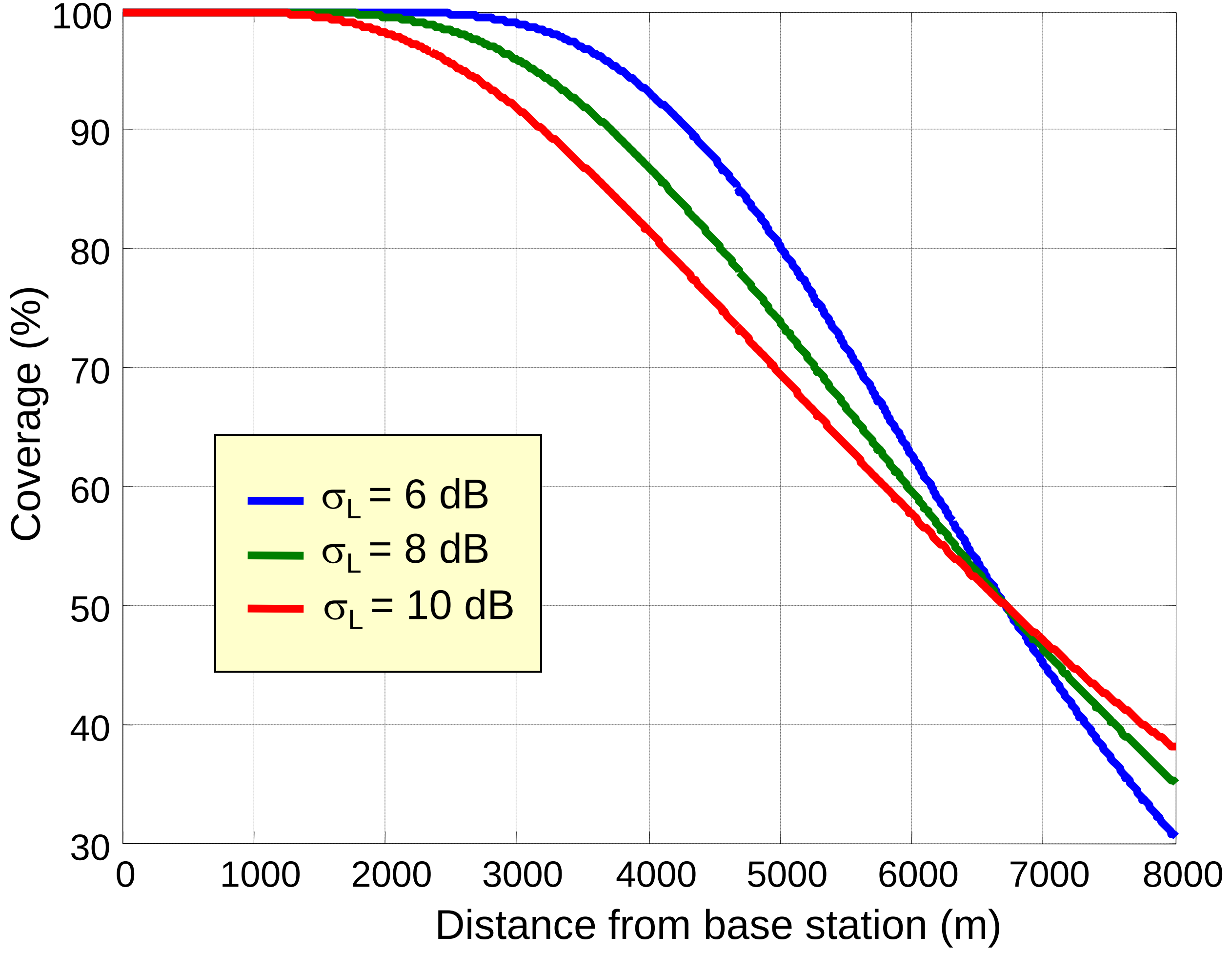
Example
What is the range of the system?

- Provide 90 % communications at the fringe of coverage
- Plane earth model
- Maximum acceptable path loss 140 dB
- Base station height 30 m
- User terminal height 1.5 m
- Clutter factor 20 dB
- Shadow location variability 6 dB or 8 dB

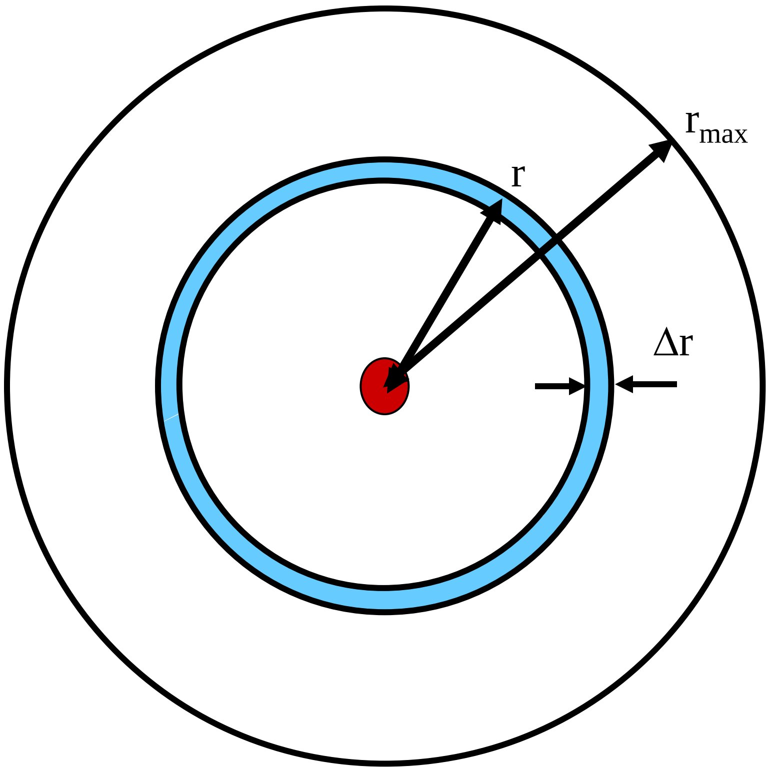
Example


15
10
5
0
1
2
3
4
5
6
7
Location variability, σ_L (dB)
Range (km)
Coverage 85 %
Coverage 90 %
Coverage 95 %

Coverage at the cell edge for varying shadowing, range, and a given fade margin

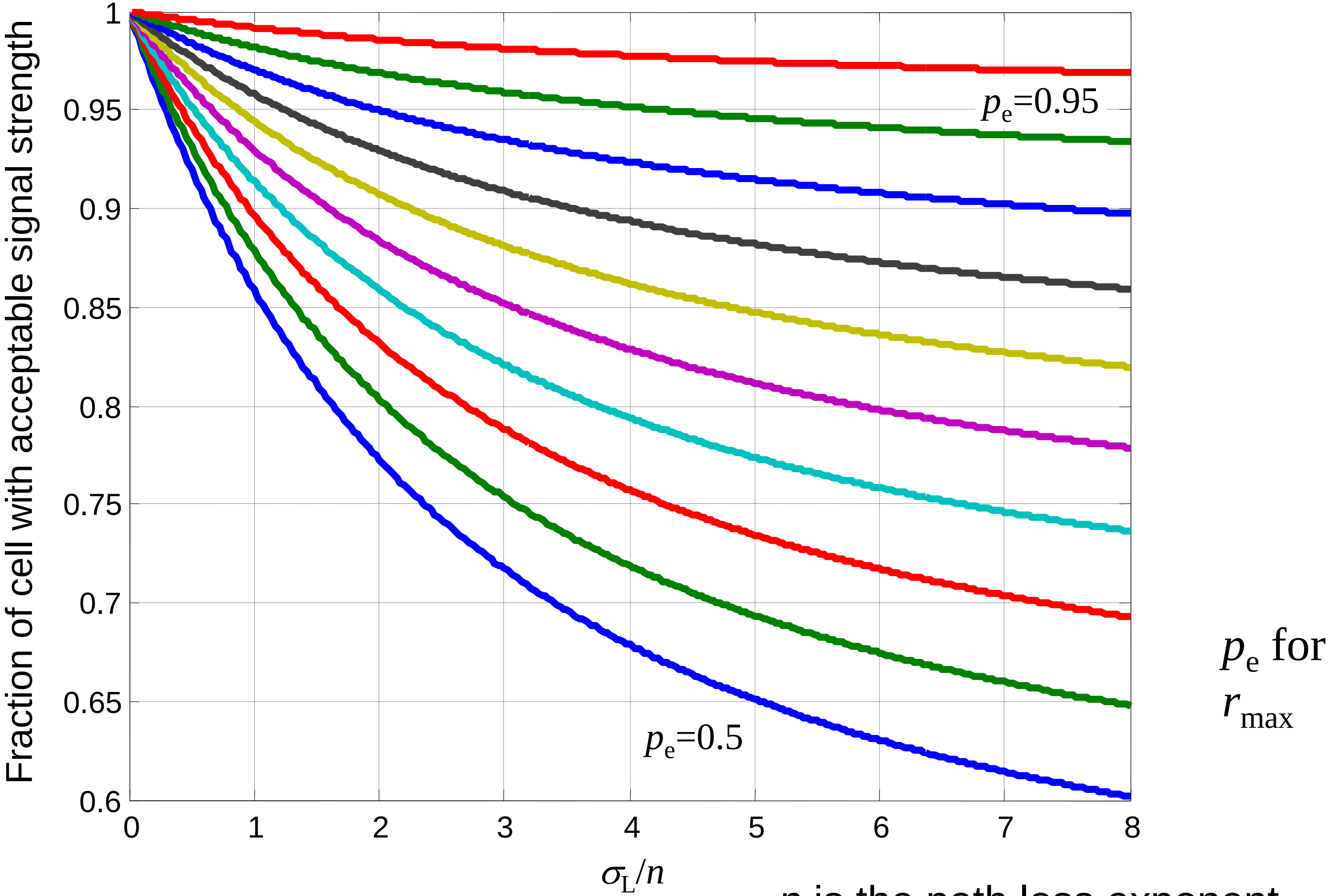


Coverage at the cell edge for varying shadowing, range, and a given fade margin



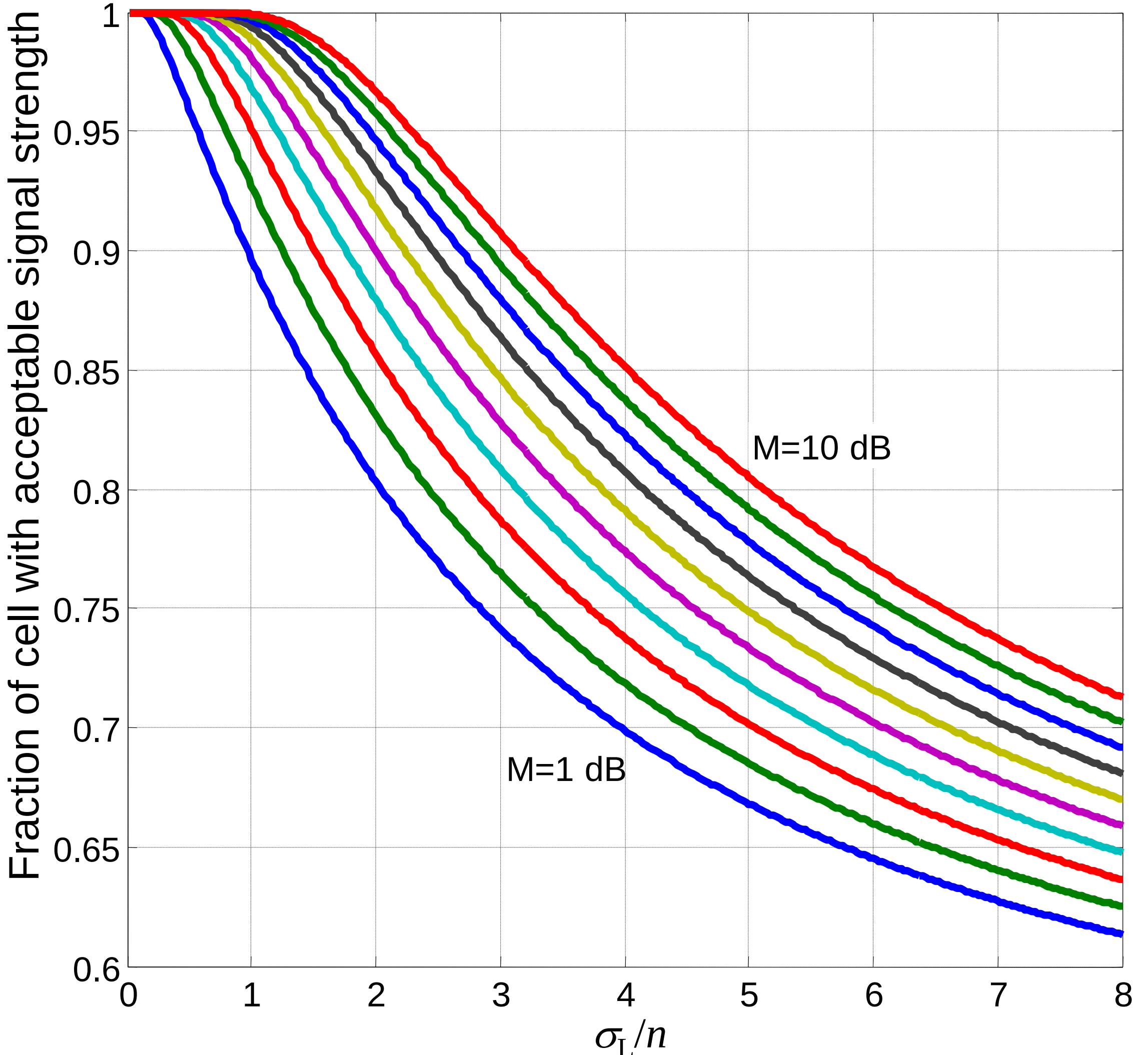
- Availability decreases with distance
- Compute at all distances and average
- Probability $p_e(r)$ for coverage in the ring

Availability versus location variability



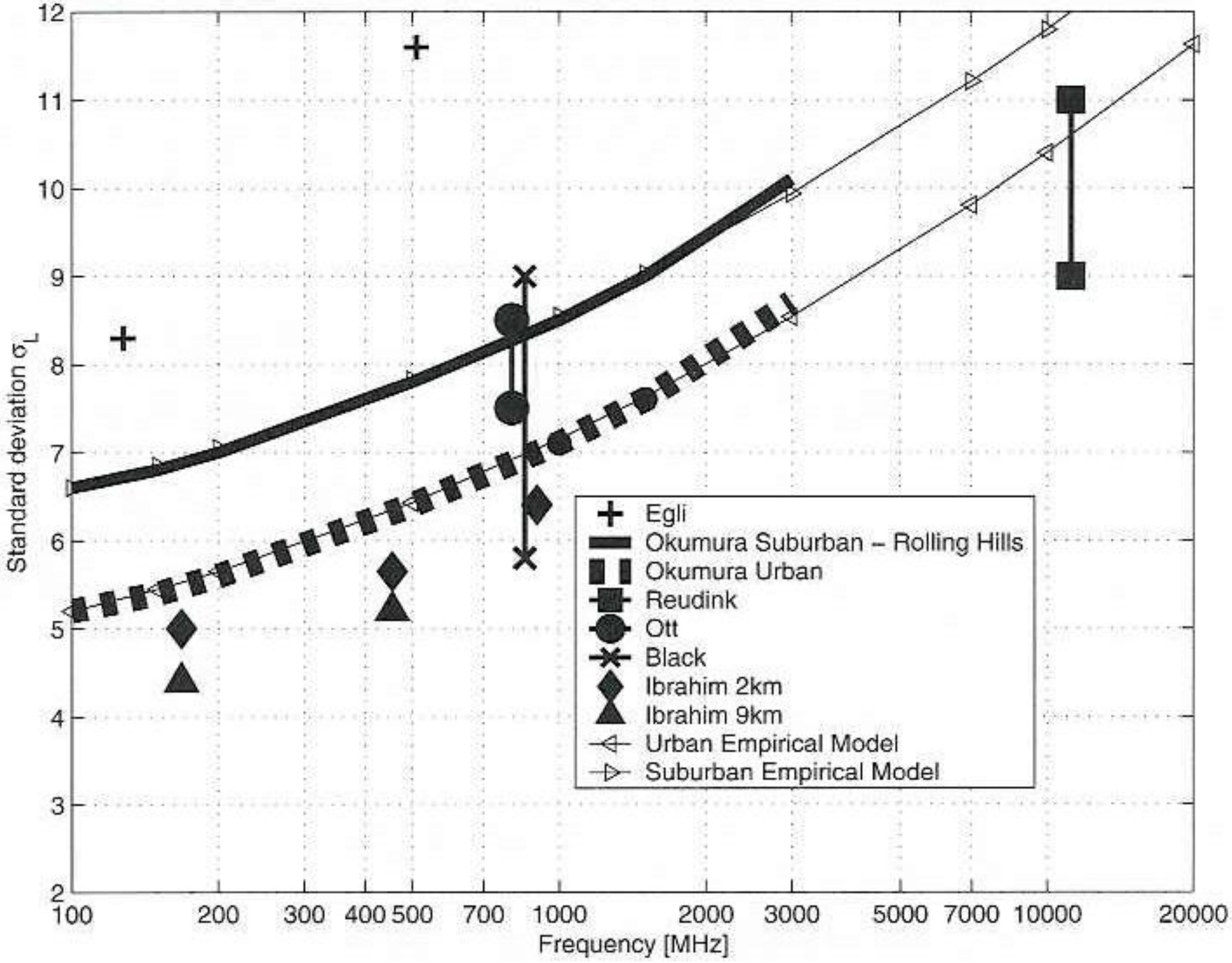
n is the path loss exponent

Cell area availability

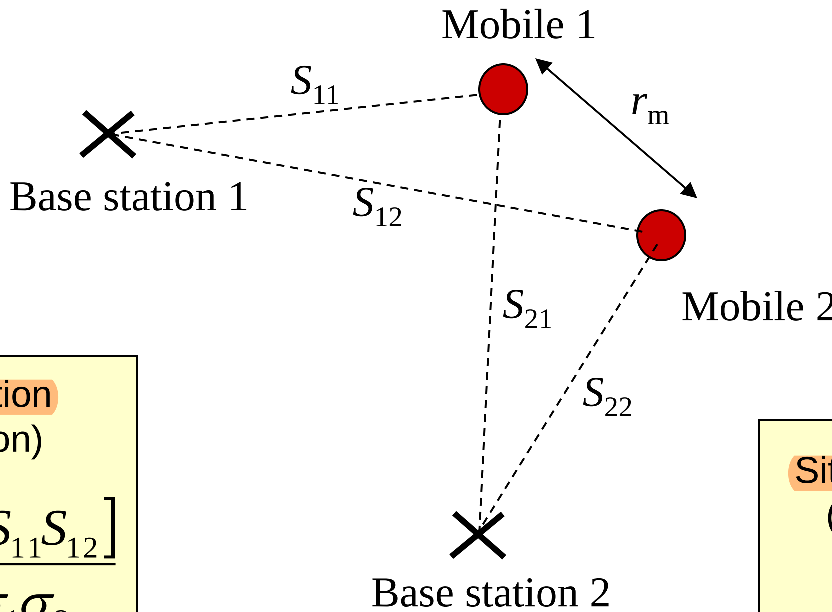


M is the fade margin

Location variability



Correlated shadowing



Serial correlation
(autocorrelation)

$$\rho_s(r_m) = \frac{E[S_{11}S_{12}]}{\sigma_1\sigma_2}$$

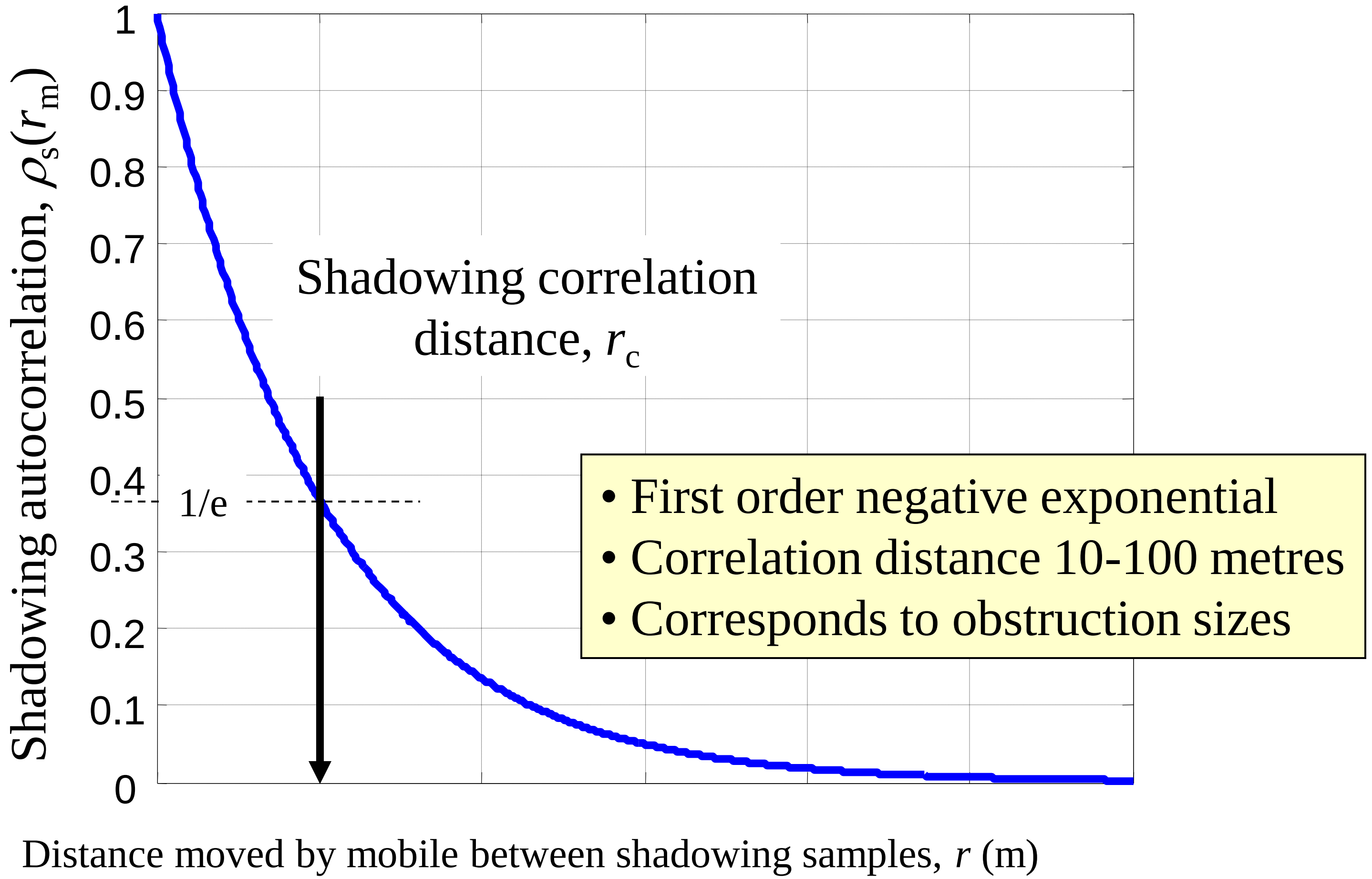
Site-to-site correlation
(cross-correlation)

$$\rho_s(r_m) = \frac{E[S_{11}S_{21}]}{\sigma_1\sigma_2}$$

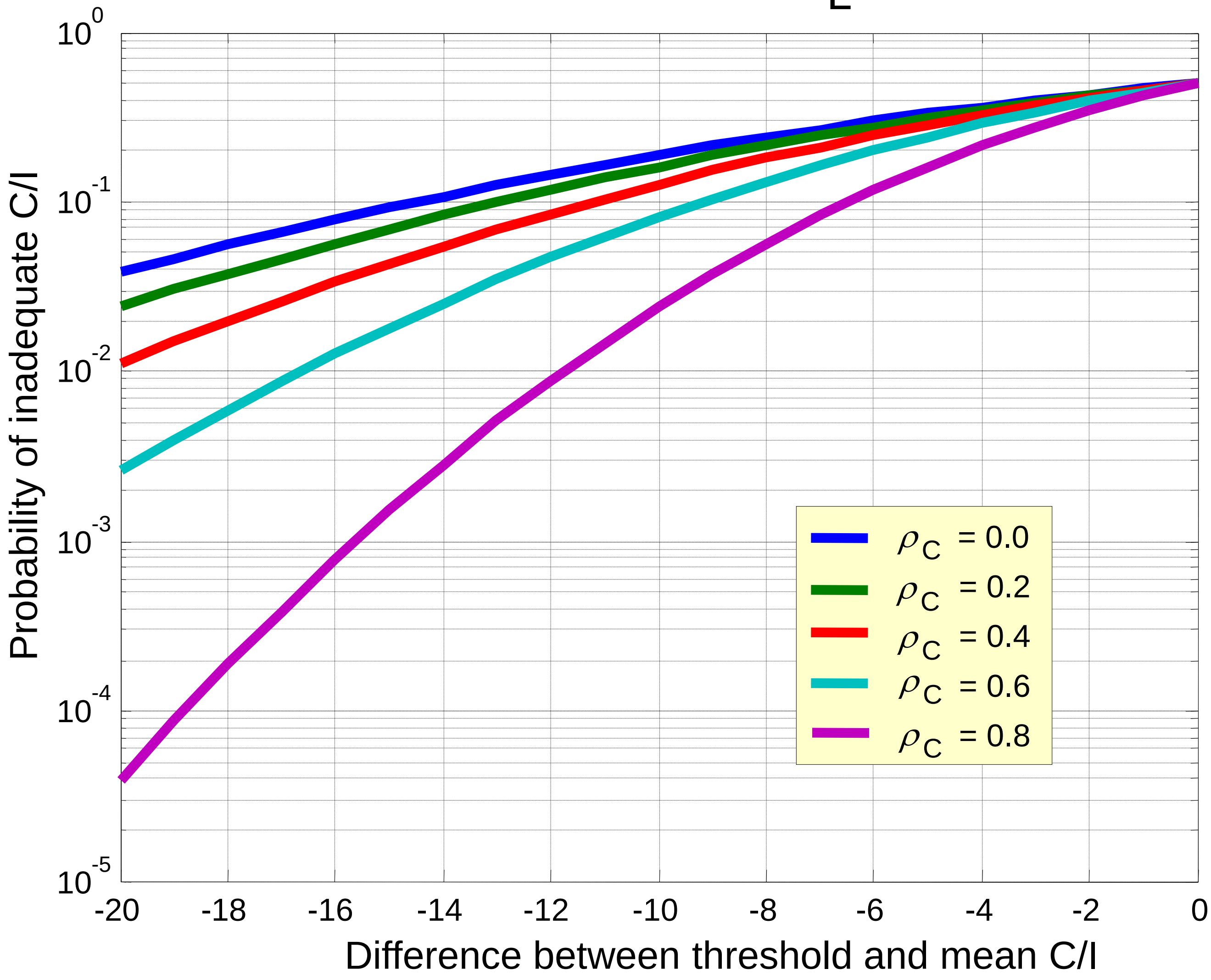
Impact of serial correlation (autocorrelation)

- Rate of power variation
- Affects power control
- Handover (handoff) measurements
- Automatic gain control in receivers

Typical autocorrelation function



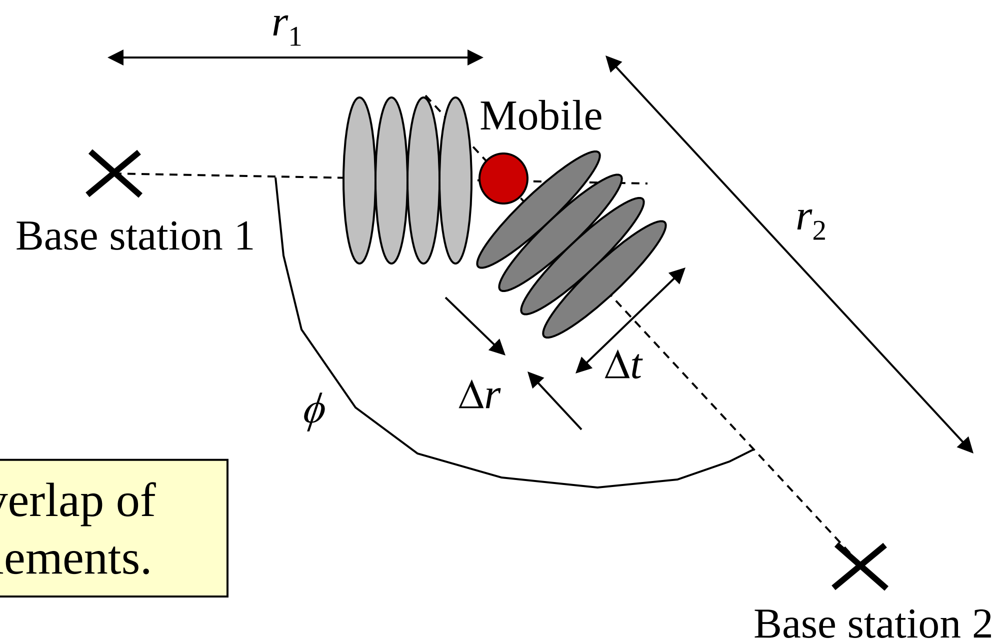
Impact of cross correlation on site-to-site interference for σ_L = 8 dB



Other impacts of shadowing cross correlation

- Sectorisation gain
- Soft handoff, site diversity, simulcast performance
- Handover algorithm performance
- Frequency planning
- Adaptive antenna performance

Physical model for cross correlation

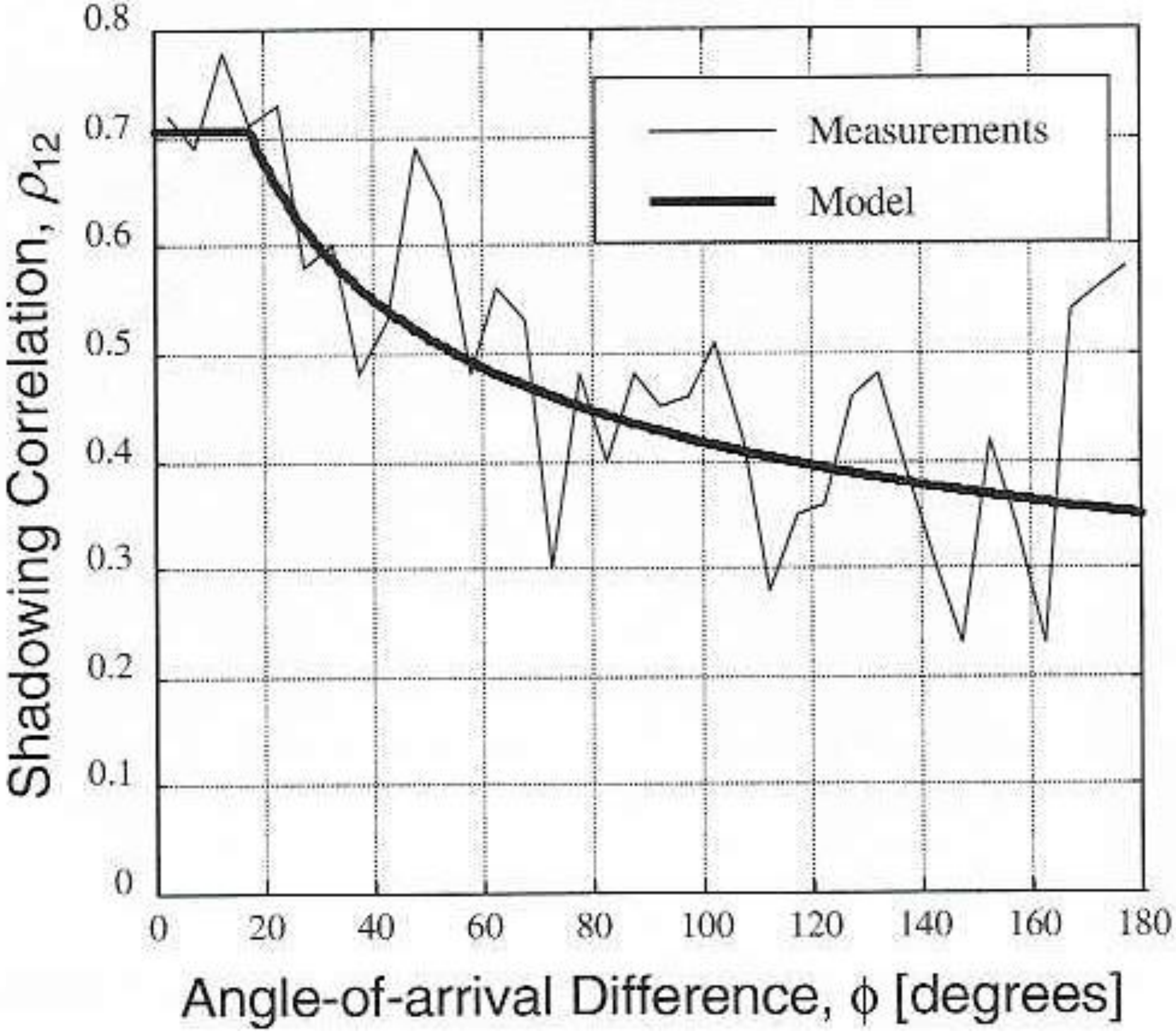


Correlation arises from overlap of independent shadowing elements.

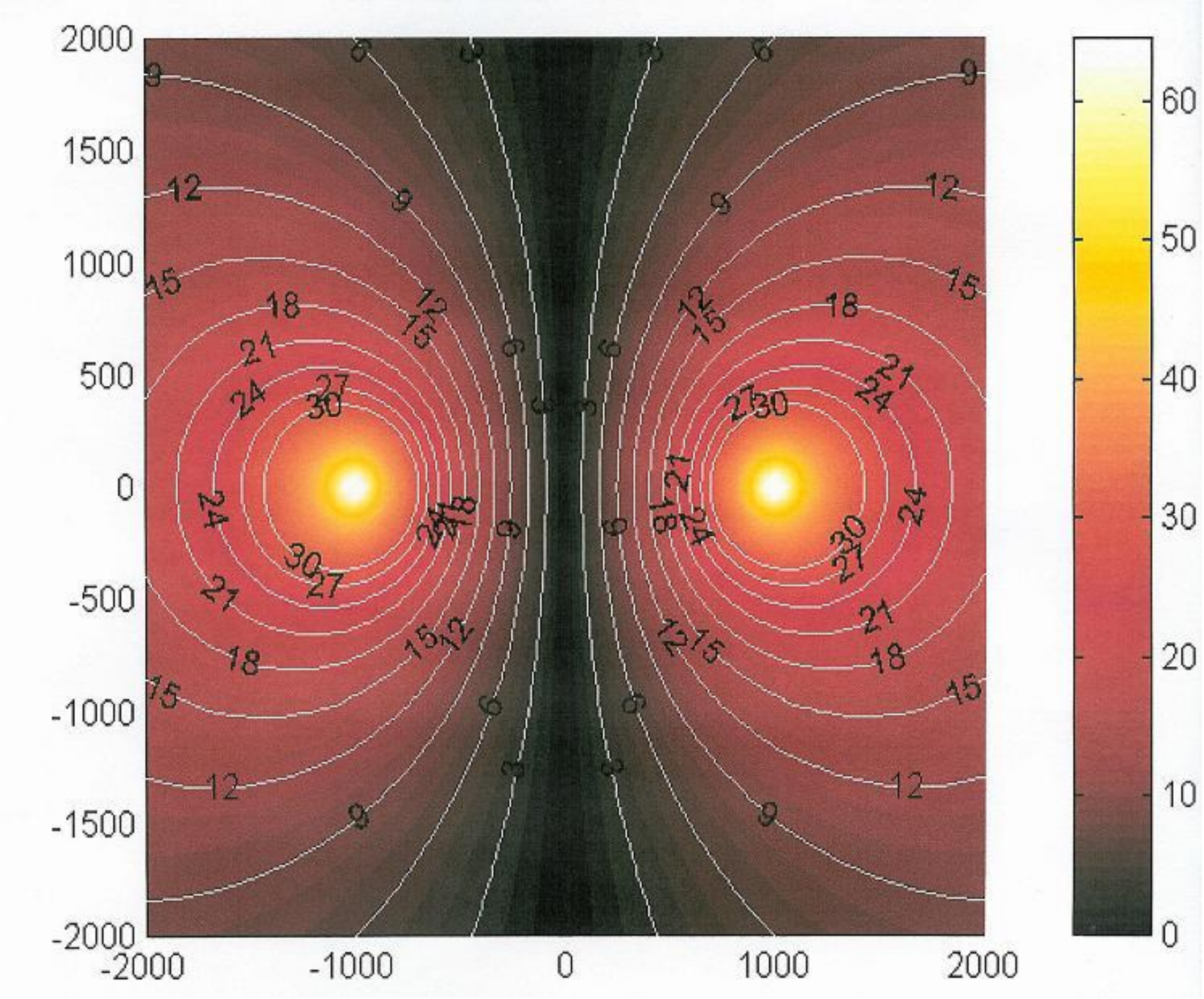
$$\rho_c = \begin{cases} \sqrt{\dfrac{r_1}{r_2}} & \text{for } 0 \le \phi < \phi_T \\ \dfrac{\phi_T}{\phi}\sqrt{\dfrac{r_1}{r_2}} & \text{for } \phi_T \le \phi < \pi \end{cases}$$

where $\phi_T = 2\sin^{-1}\dfrac{r_c}{2r_1}$

Comparison with measurements



Carrier-to-interference without shadowing



Conclusions

- Shadowing makes coverage prediction statistical (predict availability rather than signal level)
- Affects both coverage and capacity
- Can be predicted using simple statistics without specific knowledge of variability of path profiles
- Overall impact dependent on correlations