A New Methodology for the Design of High Speed Wireless Communication Systems Based on Experimental Results

Tim Gallagher
University of Kansas
July 21, 1998

Presentation Outline

- Introduction
- Background
- Description of Measurement System and Experimental Procedure
- Results
- Conclusions

Introduction

- Broadband wireless: WLL & WLAN
- Bit Error Rate vs. Packet Error Rate: WATM
- Line-of-sight, Obstructed and All location cases
- Carrier frequency: U-NII band
- Characterizing the channel

Introduction: Characterizing the Channel

- Wireless system propagation anomalies
  - Multipath dispersion
    - Multiple versions of the transmitted signal with various phases and amplitudes add at the receiver
    - Motion implies short-term fading
  - Shadowing
    - Channel is not uniform in all directions
    - Variation in long-term average power

Background

- Better way to determine percent coverage area than by assuming a Rayleigh channel
  - BER vs. PER
  - Received power - log-normal
  - Theoretical fading model - Rician distribution
  - K distribution - log-normal
  - Using this information about the channel, can determine the percent coverage area

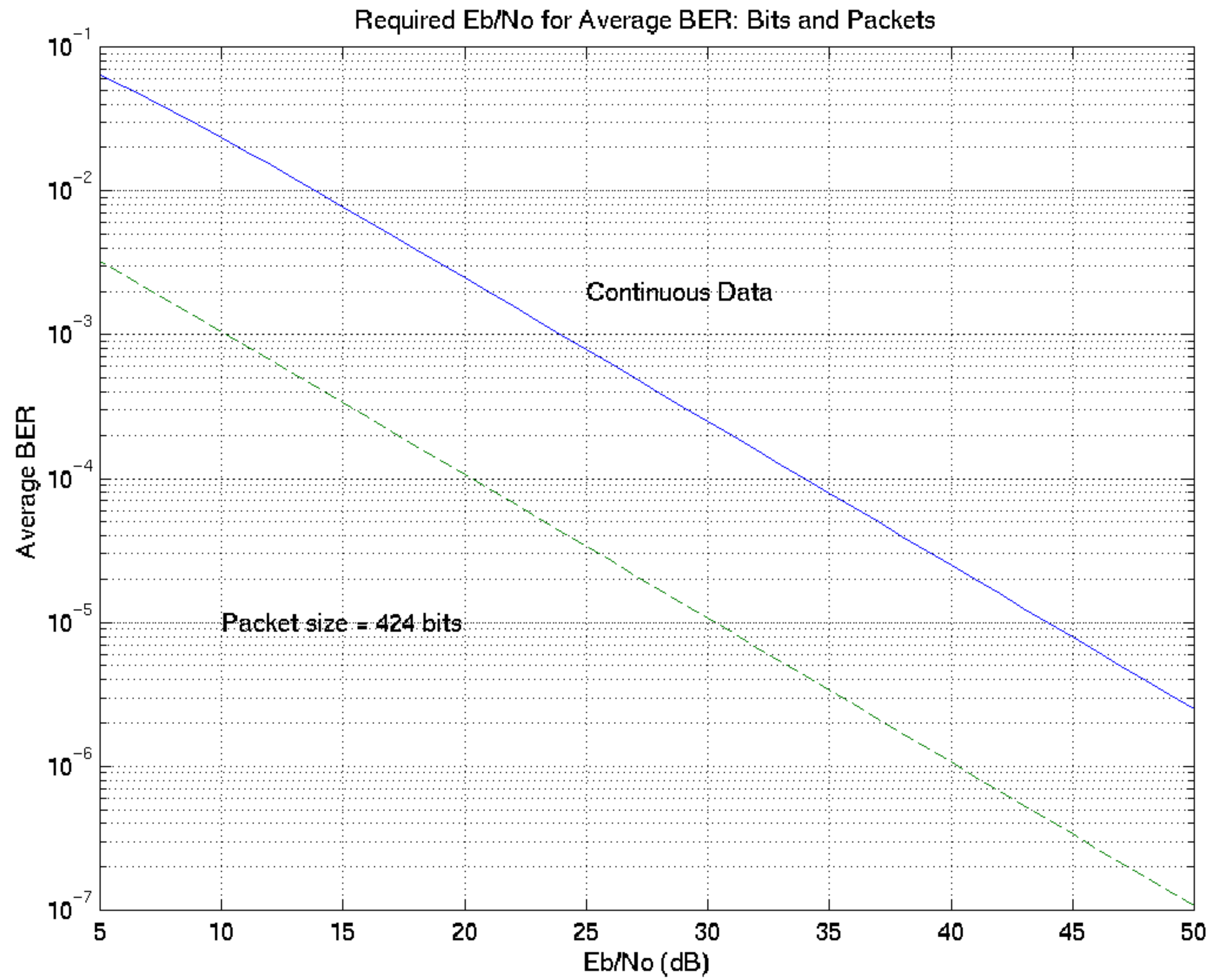
Background: Bit Error Rate (BER) vs. Packet Error Rate (PER)

- **Non-fading channel equivalent PER**

  $P[\text{At least 1 bit error in a N bit packet}] =$

  $$E_p(N) = 1 - [1 - E(\gamma)]^N$$

- **Fading channel - Errors are bursty**
  - **Can have more bit errors without increasing the PER, so we need less $\bar{\gamma}$**



Independent bit decisions in slow flat Rayleigh fading

Background: Received Power Distribution

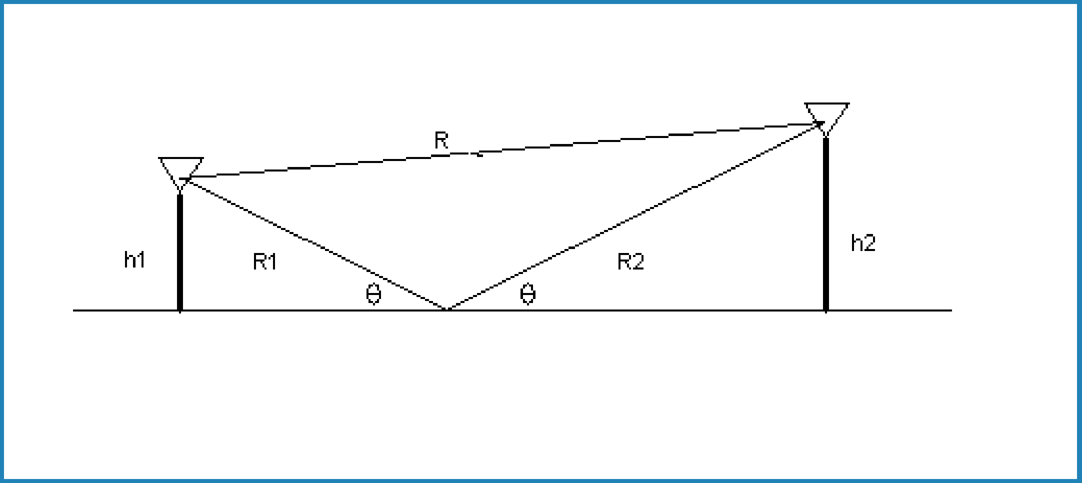
- Log-normal shadowing
  - Received signal is the product of many transmission factors -- In dB, it is the sum
  - Central Limit Theorem implies Gaussian
  - Cramer-von Mises goodness of fit test
- Received signal over distance
  - Power Law
  - Two-ray model

Background: Receive Power Distribution (cont.)

- **Power law**

$$l_s = \left(\frac{4\pi rf}{c}\right)^n \quad ; \quad L_s = n \cdot \log_{10}\left(\frac{4\pi rf}{c}\right)$$

- **Two-ray model**



Background: Fading Model

- Construct CDF from collected data
- Compare to a theoretical model
- Kolmogorov-Smirnoff goodness of fit test
- Fading model -- Rician distribution

Background: Fading Model (cont.)

- **Rayleigh Distribution**

$$f(r) = \frac{r}{\sigma^2}\exp\left(-\frac{r^2}{2\sigma^2}\right) \quad \text{for } 0 \le r \le \infty$$

$$0 \quad \text{for r} < 0$$

- **Rician Distribution:** $K \equiv \frac{A^2}{2\sigma^2}$

$$f(r) = \frac{r}{\sigma^2}\exp\left(-\frac{(r^2 - A^2)}{2\sigma^2}\right) I_0\left(\frac{Ar}{\sigma^2}\right) \quad \text{for } A \ge 0, r \ge 0$$

$$0 \quad \text{for r} < 0$$

Background: Distribution of K

- K is specular-to-random ratio

$$K \equiv \frac{A^2}{2\sigma^2}$$

$$K(dB) = 10\log_{10}\left(A^2\right) - 10\log_{10}\left(2\sigma^2\right)$$

- A^2 and σ^2 should be log-normally distributed
- K(dB) should be normally distributed
  - Cramer-von Mises goodness of fit test

Background: Percent Coverage Area

- Determine required received signal level
  - link equation (function of K)
- Determine K and received power correlation
- Develop formula for percent coverage area

Background: Percent Coverage Area (cont.)

- Link equation

$$\left(\frac{C}{N_o}\right)_{\text{Required}} = \left(\frac{C}{N_o}\right)_{\text{Available}}$$

$$\frac{E_b}{N_o} + R_d + M = ERP - L_s - k + G_r - T_s$$

$$\Pr_{req}(K) = ERP - L_s = \frac{E_b}{N_o}(K) + R_d + M + k - G_r + T_s$$

Background: Percent Coverage Area (cont.)

- **K and Pr Correlation**

$$K \equiv \frac{A^2}{2\sigma^2} = \frac{P_{specular}}{P_{random}}$$

$$P_{receive} = P_{specular} + P_{random}$$

$$P_{receive} = P_{random}(1 + K) = P_{specular}\left(1 + \frac{1}{K}\right)$$

Background: Percent Coverage Area (cont.)

- **Development of Percent Coverage Area Formula**
  - **Bivariate Gaussian pdf**

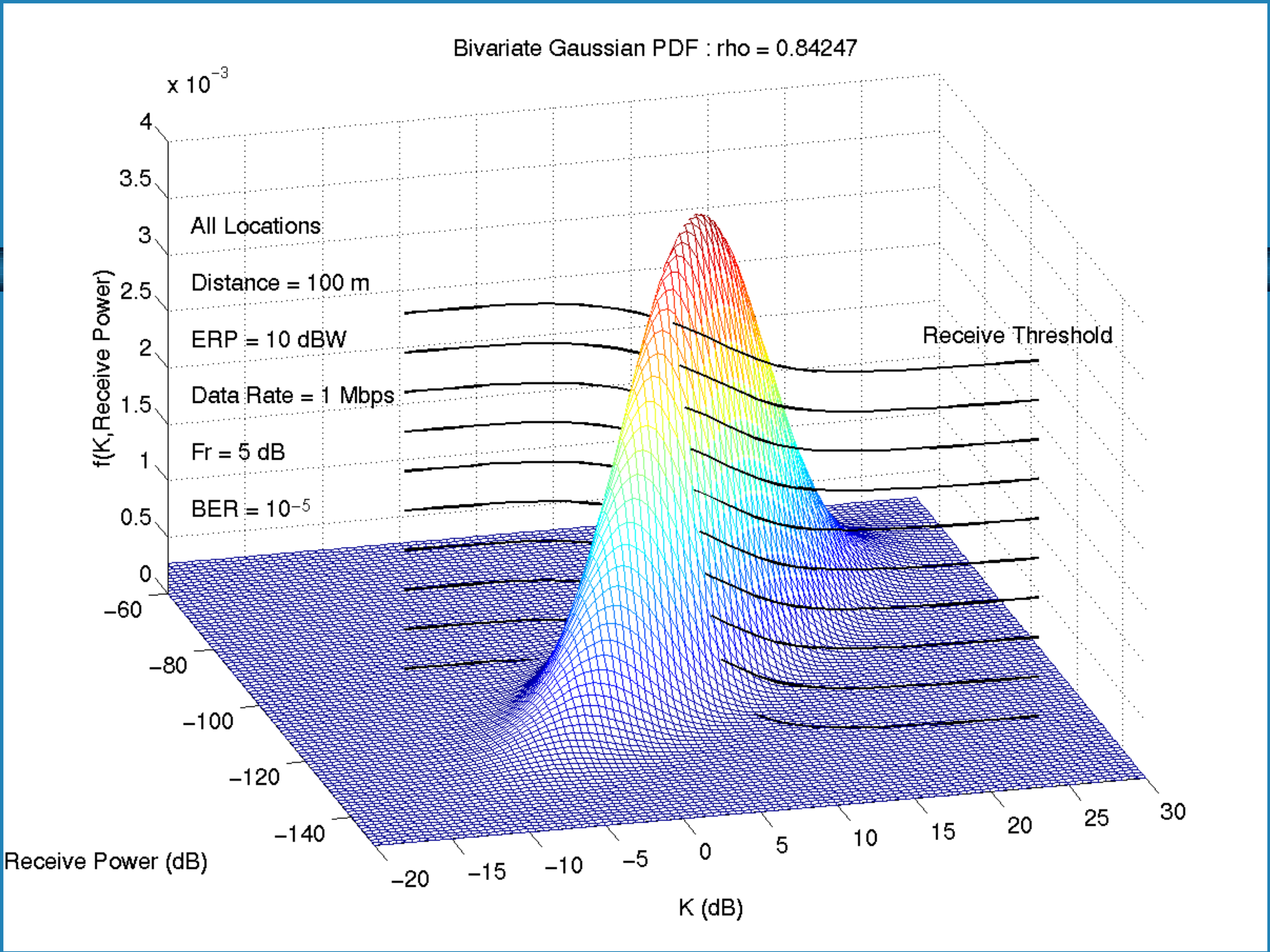
$$f_{\mathrm{Pr},K}(\mathrm{Pr},K)=\frac{1}{2\pi\sigma_{\mathrm{Pr}}\sigma_K\sqrt{1-\rho^2}}\cdot$$

$$\exp\left\{\frac{-1}{2\left(1-\rho^2\right)}\cdot\left[\left(\frac{\mathrm{Pr}-\mu_{\mathrm{Pr}}}{\sigma_{\mathrm{Pr}}}\right)^2+\left(\frac{K-\mu_K}{\sigma_K}\right)^2-\left(\frac{2\rho\left(\mathrm{Pr}-\mu_{\mathrm{Pr}}\right)\left(K-\mu_K\right)}{\sigma_{\mathrm{Pr}}\sigma_K}\right)\right]\right\}$$

Background: Percent Coverage Area (cont.)

- Development of Percent Coverage Area Formula
  - Want probability that Pr > Pr_{req}(K) for a specific distance
  - Integrate joint pdf over all K and from Pr_{req}(K) to infinity

$$P\left[close\,link\right]_{r_j} = \int_{-\infty}^{\infty} \int_{\Pr_{req}(K)}^{\infty} f_{\Pr,K}\left(\Pr, K\right) d\Pr\, dK$$



Bivariate Gaussian pdf with received signal power threshold

Background: Percent Coverage Area (cont.)

- **Percent Coverage Area Formula**

$$P[close\ link]_{r_j} \cong \int_{\mu_K-3\sigma_K}^{\mu_K+3\sigma_K} \int_{\Pr_{req}(K)}^{\mu_{\Pr}+3\sigma_{\Pr}} f_{\Pr,K}(\Pr,K)\, d\Pr\, dK$$

$$\int_a^b f(x)\,dx = \lim_{\Delta x\to 0} \sum_{i=1}^{n} f(c_i)\Delta x$$

$$P[close\ link]_{r_j} \cong \lim_{\Delta K\to 0} \sum_{i=1}^{n} \int_{\Pr_{req}(K_i)}^{\mu_{\Pr}+3\sigma_{\Pr}} f(\Pr, K=K_i)\, d\Pr\, \Delta K$$

$$P[close\ link]_{r_j} \cong \Delta K \sum_{i=1}^{n} \int_{\Pr_{req}(K_i)}^{\mu_{\Pr}+3\sigma_{\Pr}} f(\Pr, K=K_i)\, d\Pr$$

Background: Percent Coverage Area (cont.)

- **Percent Coverage Area Formula**

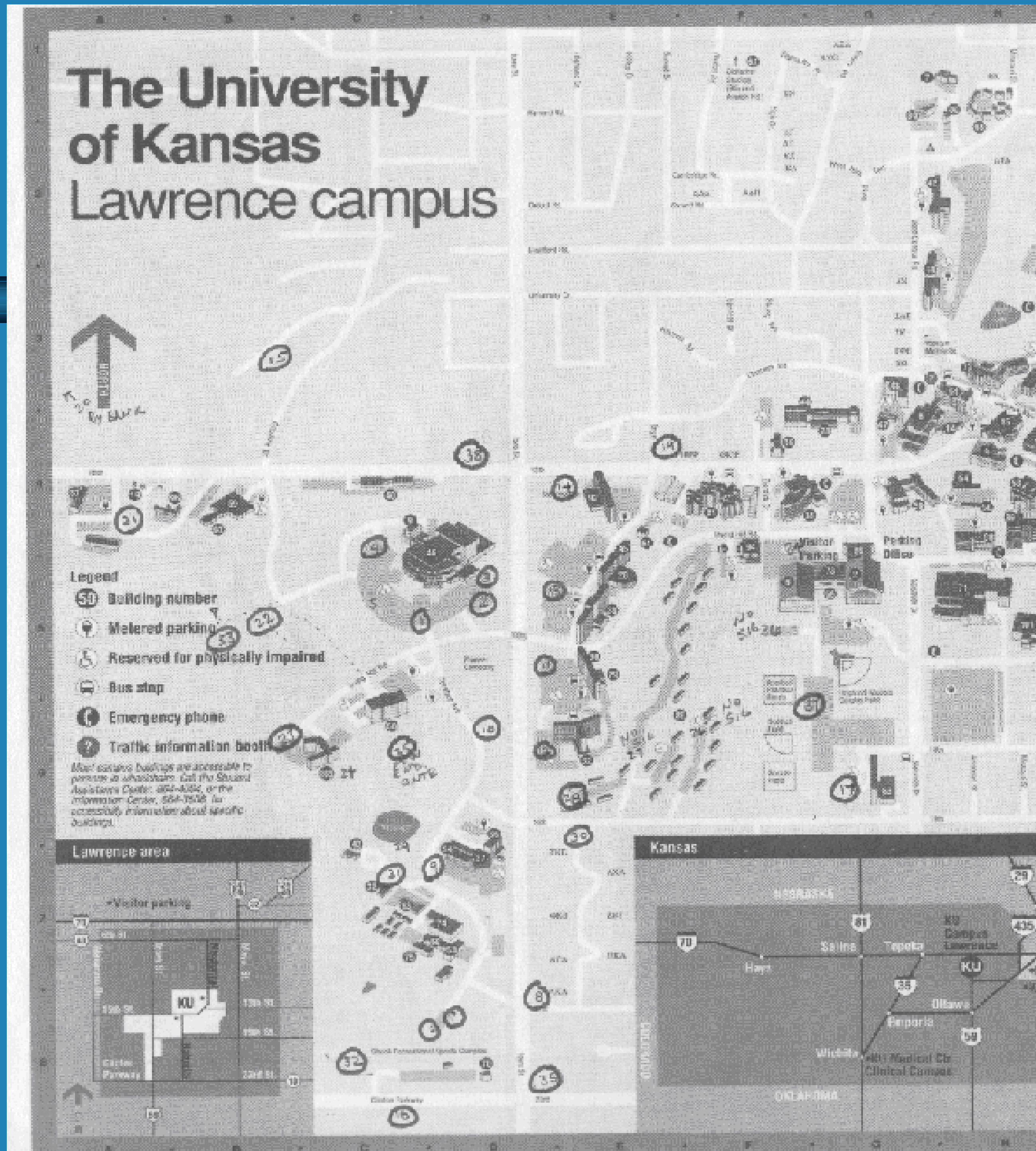
$$Fractional\ Coverage = \frac{1}{\pi R^2}\int_0^{2\pi}\int_0^{R} P[close\ link]_{r_j}\ r\ dr\ d\theta$$

$$= \frac{2\pi}{\pi R^2}\int_0^{R} P[close\ link]_{r_j}\ r\ dr$$

$$= \frac{2}{R^2}\lim_{\Delta r\to 0}\sum_{j=1}^{n} P[close\ link]_{r_j}\left[\frac{1}{2}\left(r_j + r_{j-1}\right)\right]\Delta r \qquad ; \qquad r_0 = 0,\ r_n = R$$

$$Fractional\ Coverage \cong \frac{1}{R^2}\sum_{j=1}^{n} P[close\ link]_{r_j}\left(r_j + r_{j-1}\right)\left(r_j - r_{j-1}\right)$$

$$Percent\ Coverage \cong 100\cdot\sum_{j=1}^{n} P[close\ link]_{r_j}\frac{\left(r_j^2 - r_{j-1}^2\right)}{R^2}$$

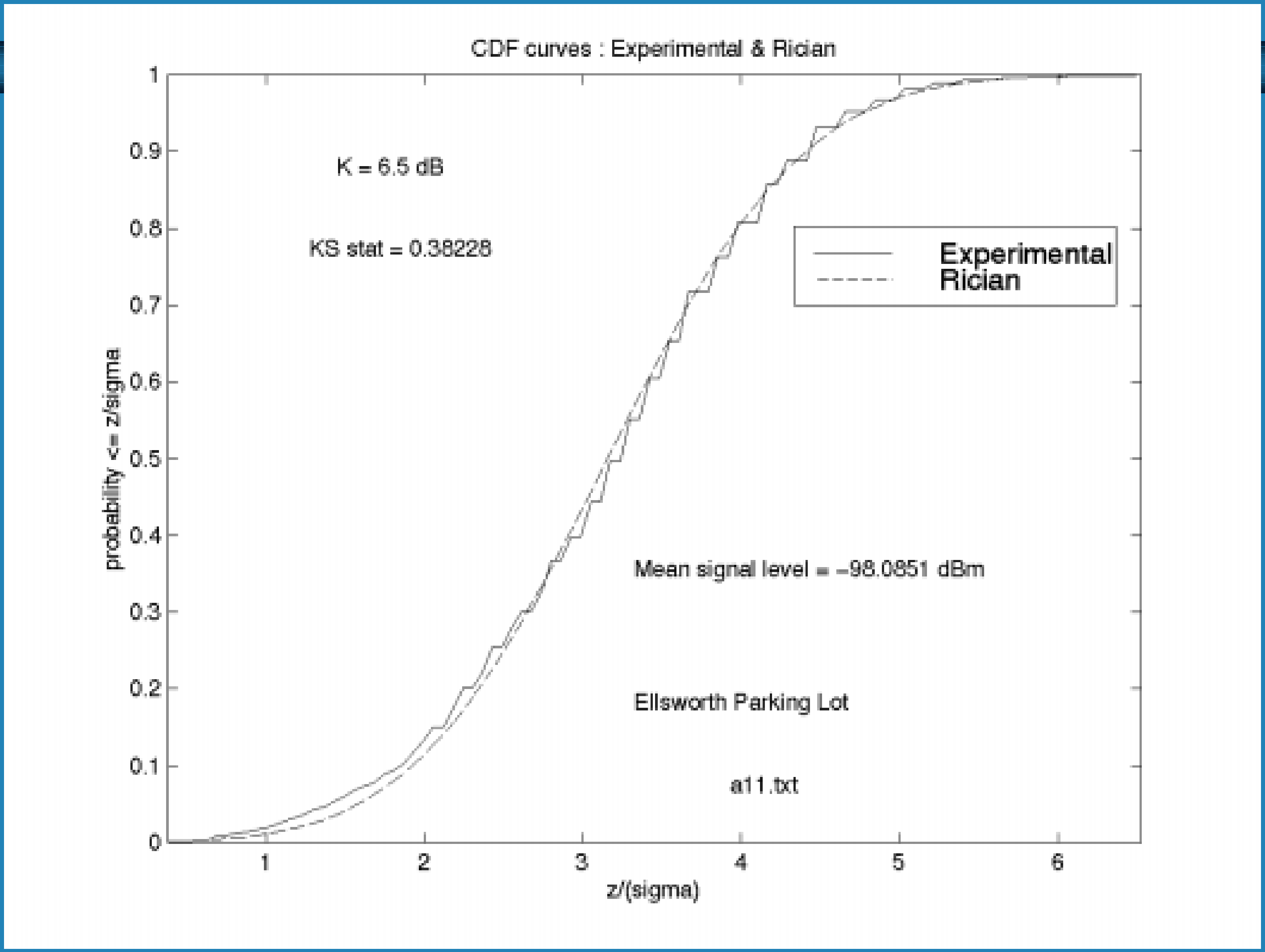


The University
of Kansas
Lawrence campus
Legend
Building number
Metered parking
Reserved for physically impaired
Bus stop
Emergency phone
Traffic information booth
Visitor Parking
Parking Office
Lawrence area
Visitor parking
KU
Kansas
NEBRASKA
Hays
Salina
Topeka
Ottawa
Emporia
Wichita
OKLAHOMA

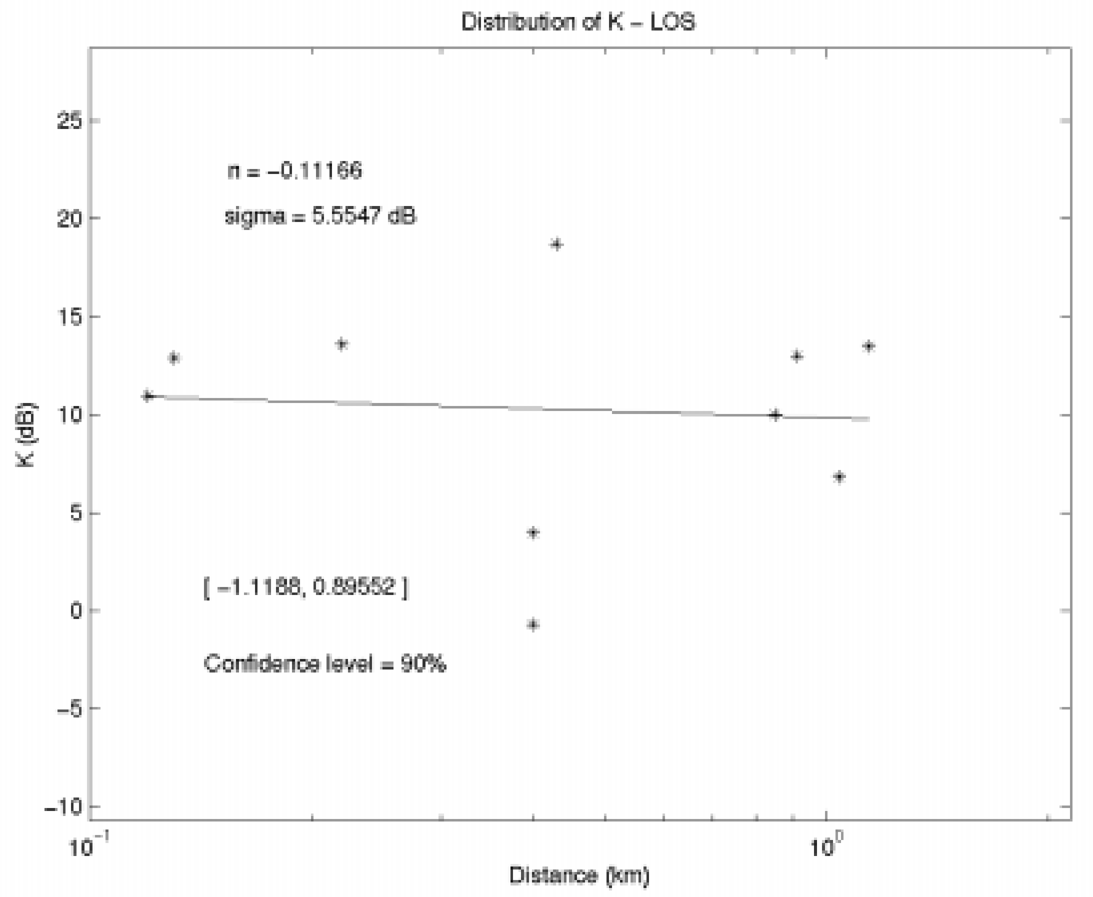
Measurement System and Experimental Procedure (cont.)

- Procedure
  - Determine fading for each location (K)
  - Determine average K over distance
    - test for normality
  - Determine path loss exponent
    - test for normality
  - Close link for average K and path loss
  - Determine correlation coefficient, K & Pr
  - Determine percent coverage area

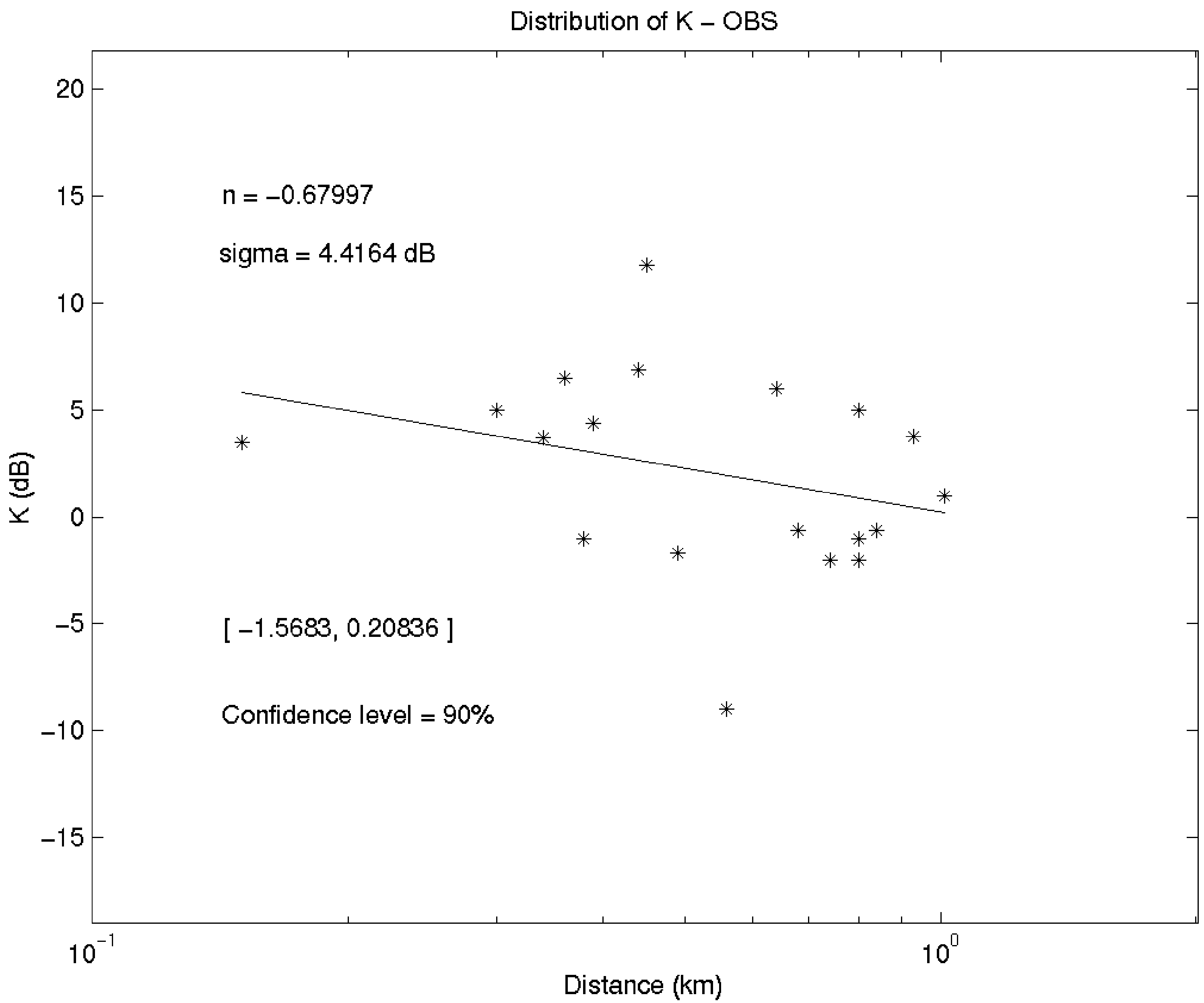
Results: Fading



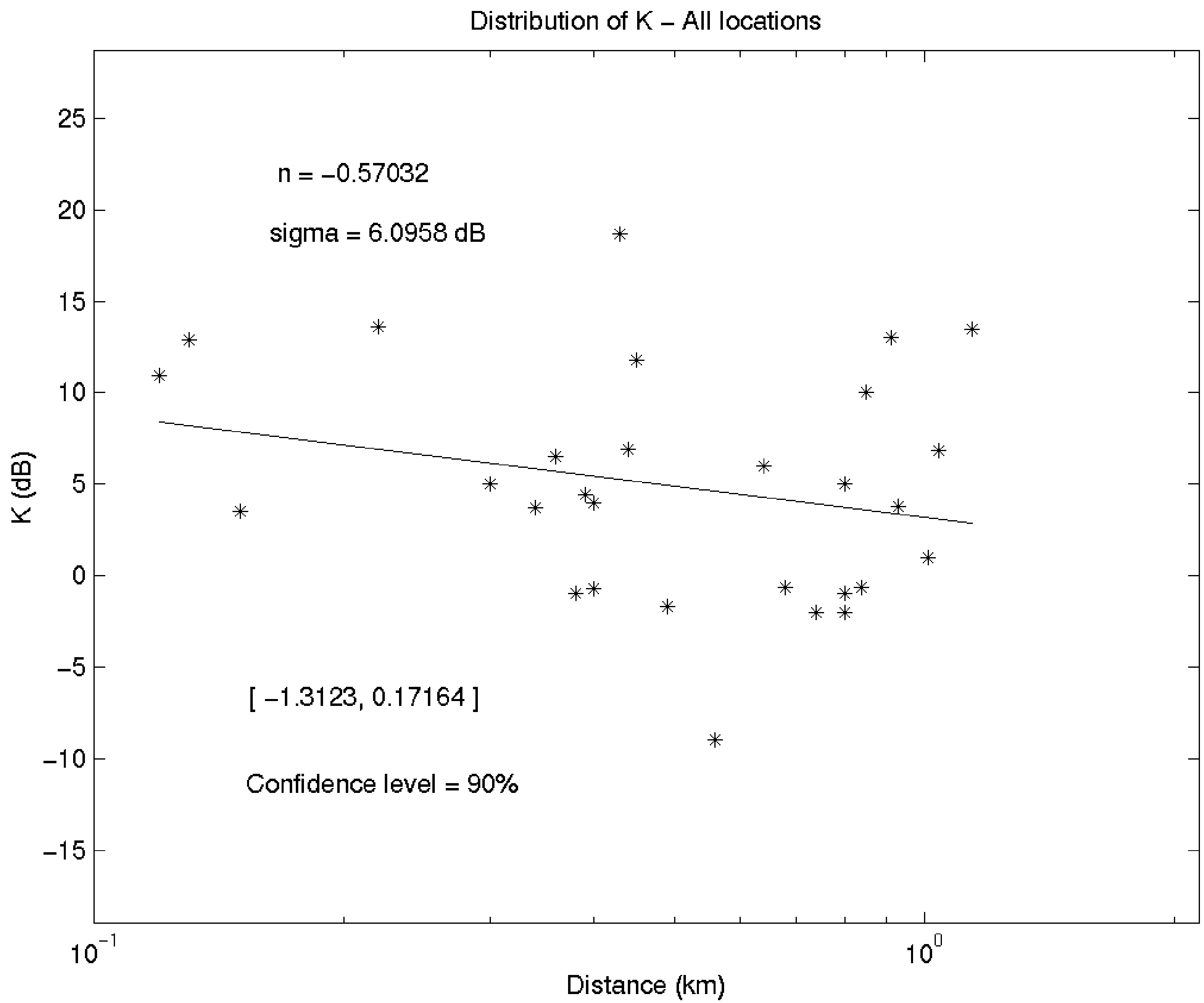
Results: Distribution of K



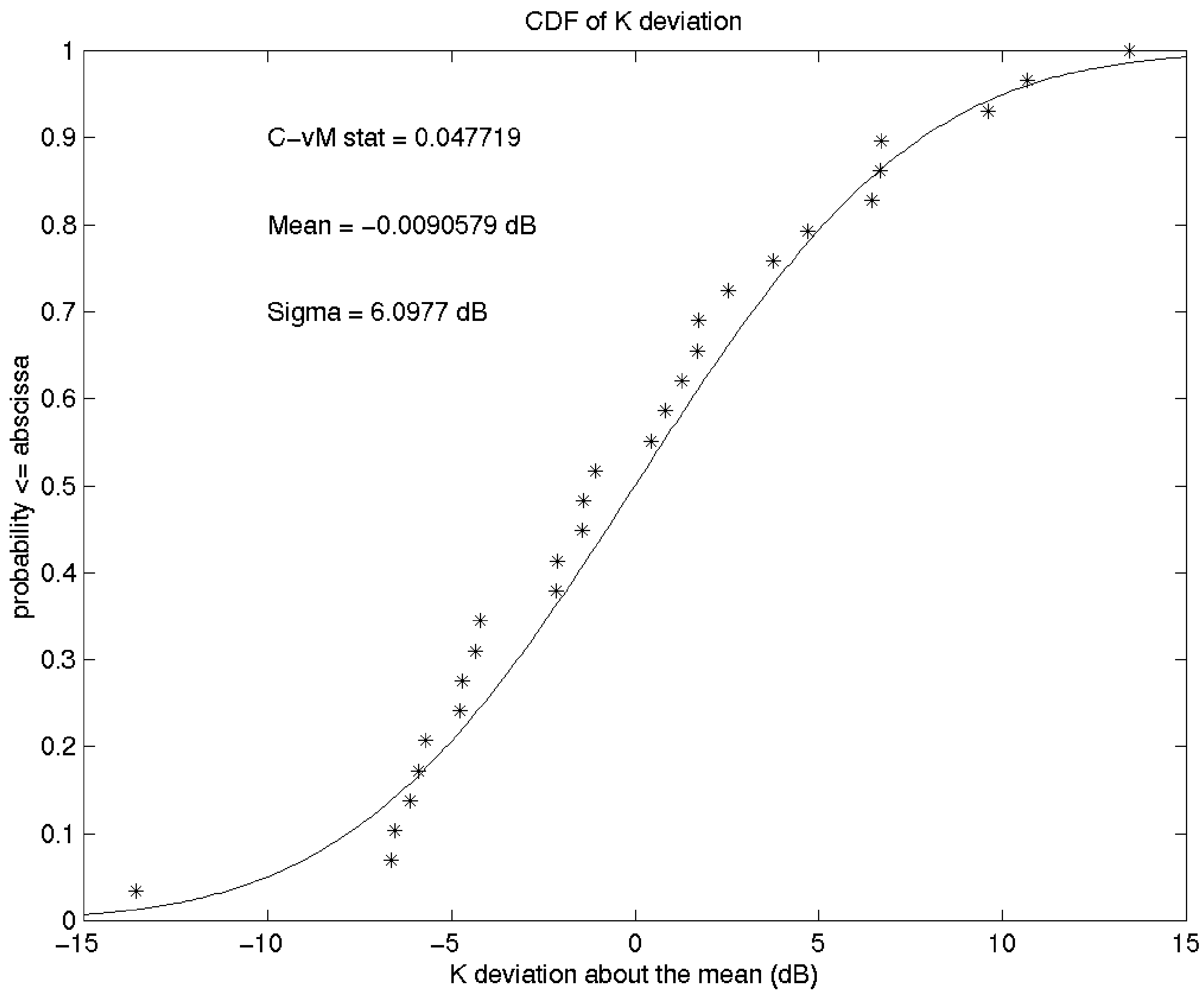
Distribution of K: LOS locations



Distribution of K: OBS locations



Distribution of K: All locations


CDF of K deviation
C–vM stat = 0.047719
Mean = –0.0090579 dB
Sigma = 6.0977 dB
probability <= abscissa
K deviation about the mean (dB)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
–15
–10
–5
0
5
10
15

Log-normal K

Results: Average Receive Power

- Log-normal shadowing
  - C-vM statistic = 0.049

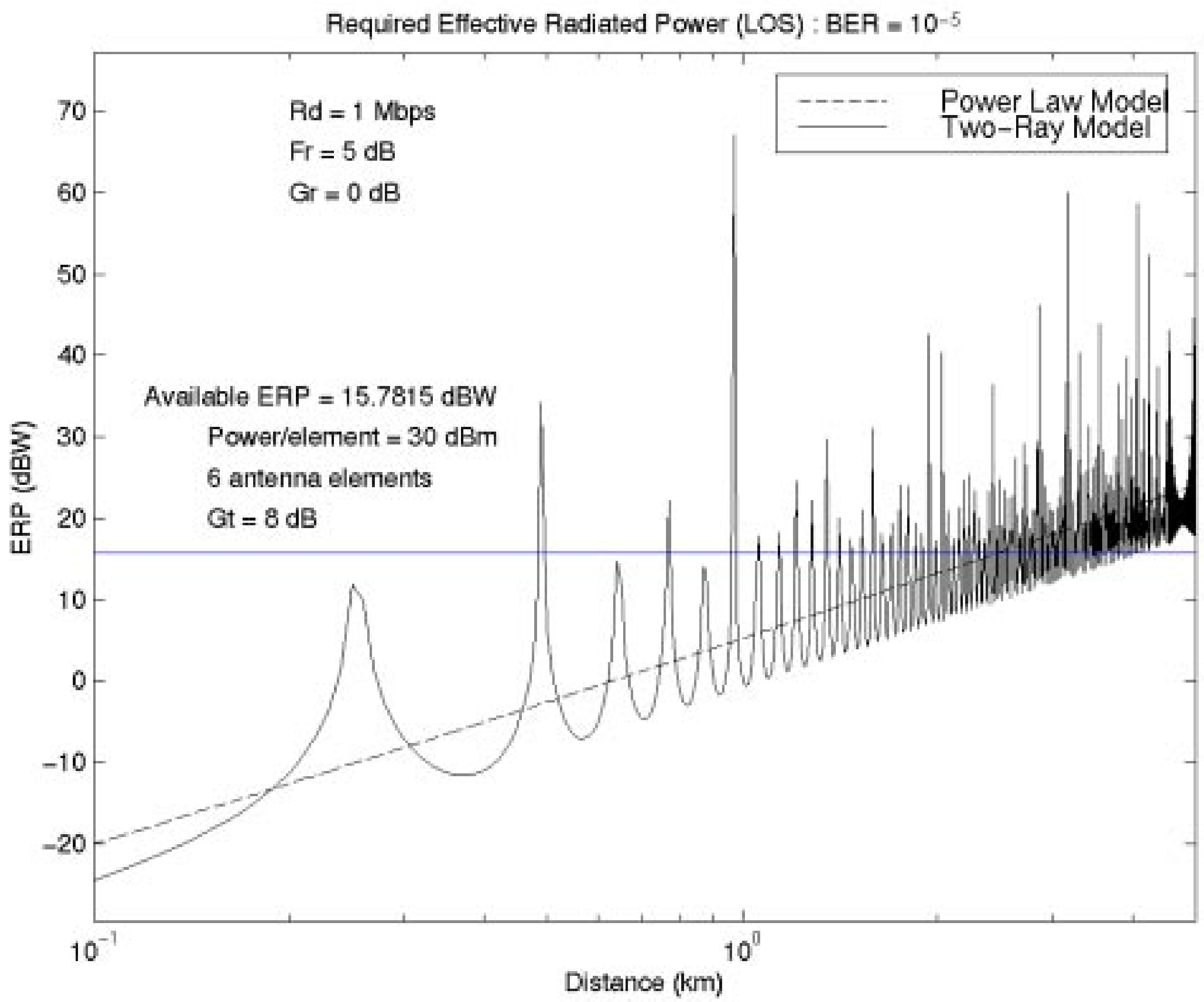
Location	Path loss exponent	Sigma (dB)
LOS	2.232	9.0272
OBS	3.8108	8.1661
ALL	3.422	12.4788

Results: Average Receive Power

- Two-ray model

Location	Power Law Sigma (dB)	Two-Ray Sigma (dB)
LOS – 2m	9.0272	8.205
LOS – 1m	9.0272	10.9284
OBS	8.1661	9.6151
ALL	12.4788	12.7121

Results: Closing the Link

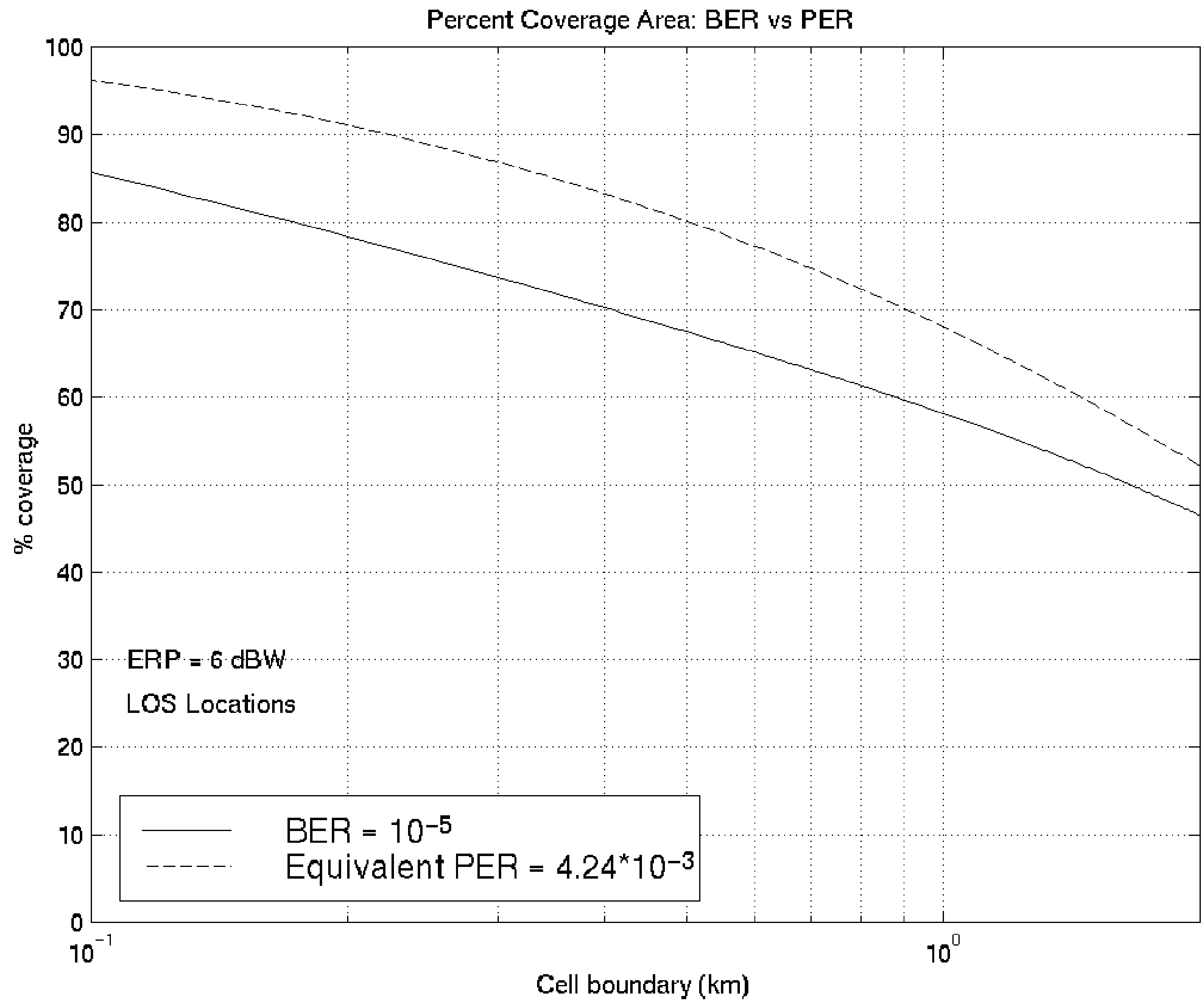


Results: Correlation Between K and Shadowing

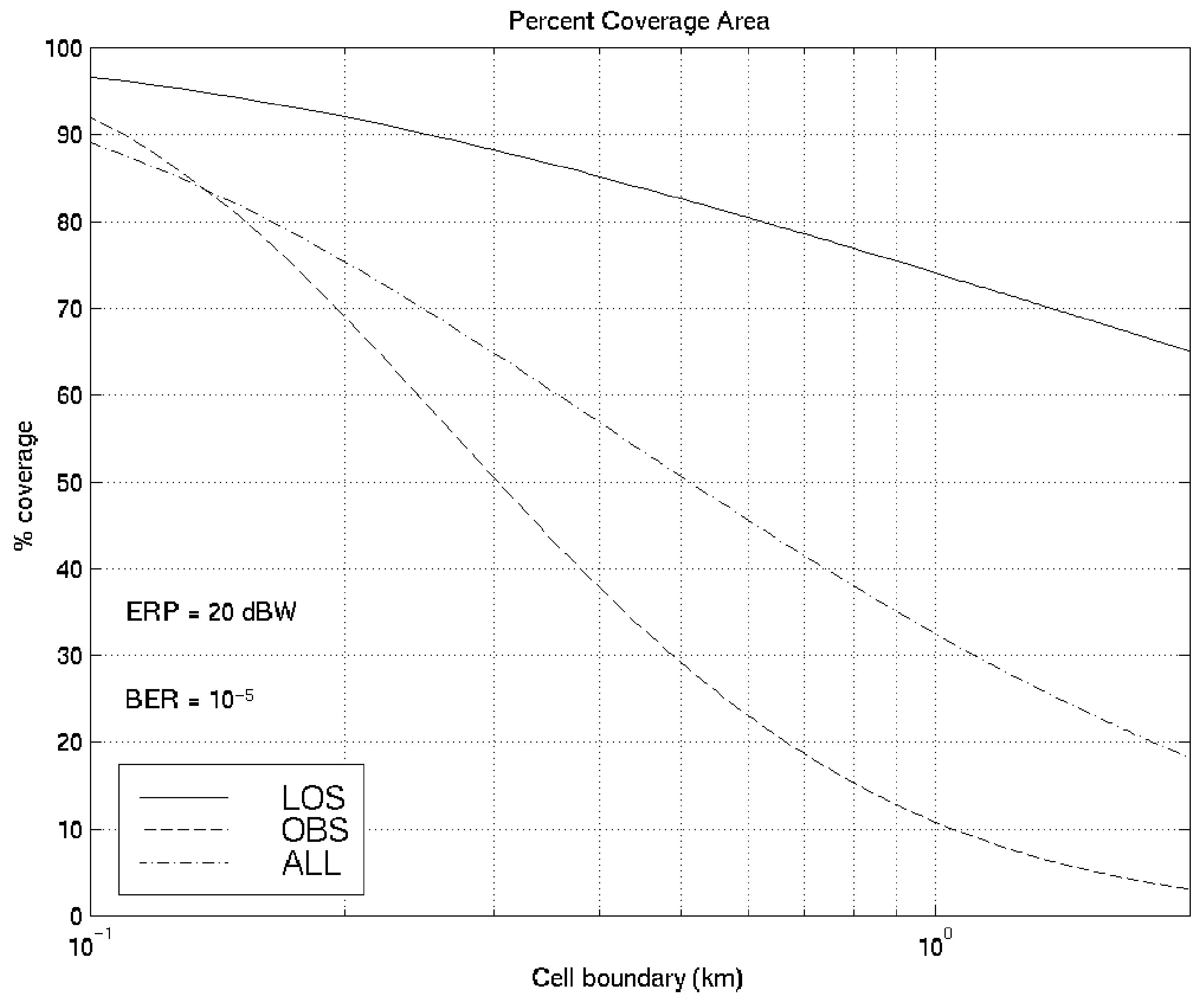
Location	Correlation Coefficient
LOS	-0.88327
OBS	-0.6622
ALL	-0.84247

Results: Percent Coverage Area

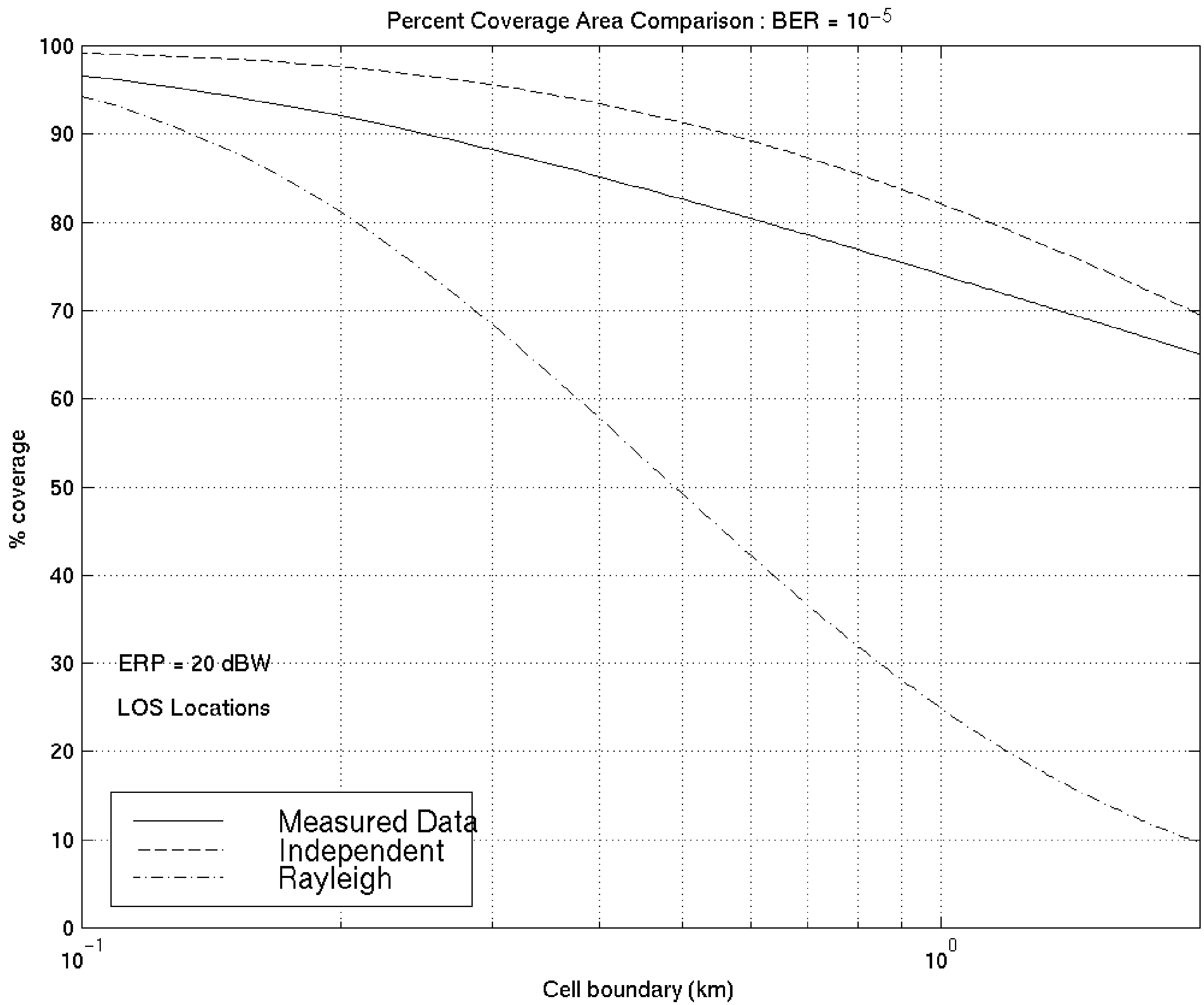
- BER vs. PER
- LOS, OBS, ALL comparison
- K and receive power joint distribution
  - Distance trade-off
  - Power trade-off
- ERP family of curves



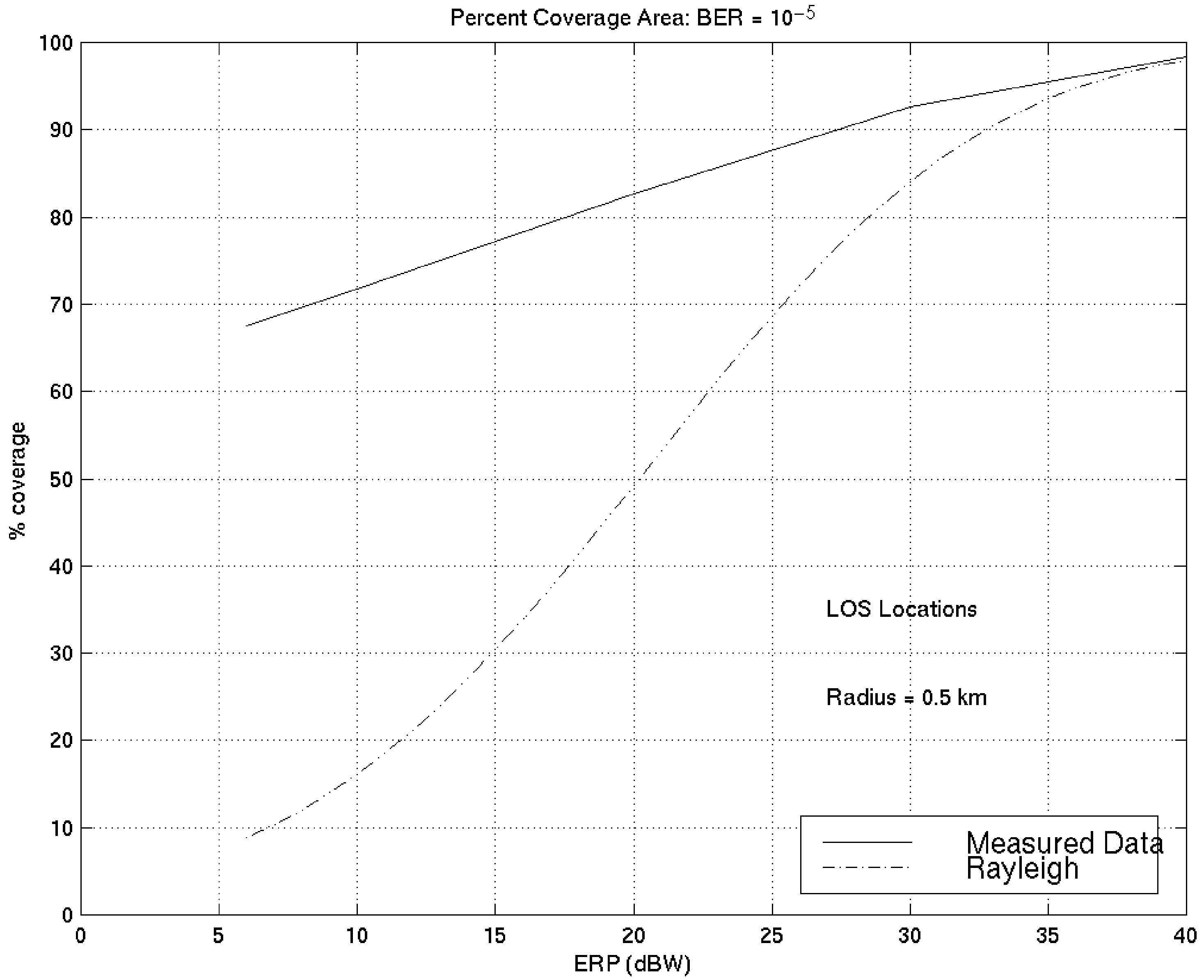
BER vs PER: Packet size = 424 bits



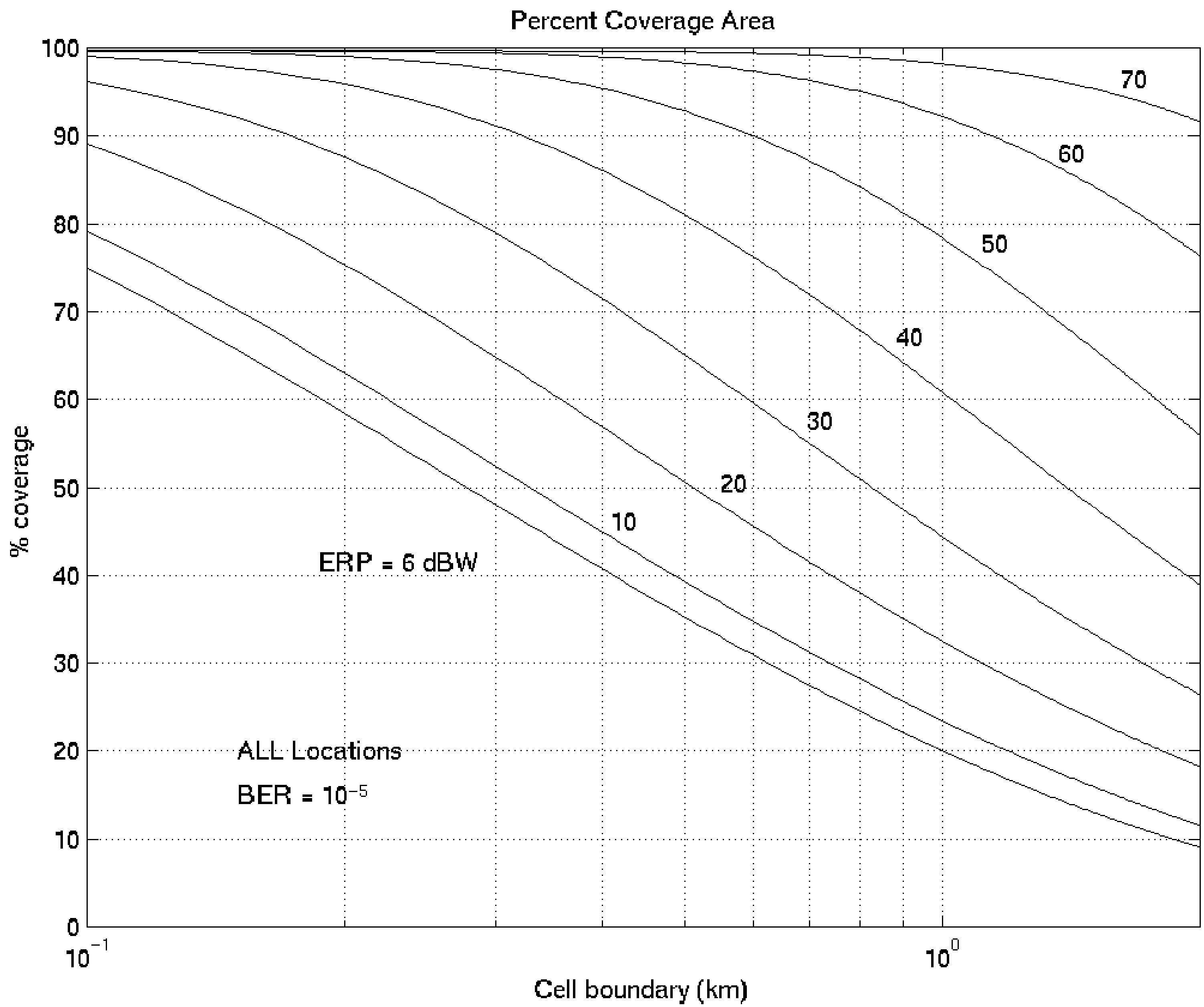
LOS, OBS and ALL comparison: BER = 10^{-5}, ERP = 20 dBW



Distance Trade-off: LOS locations, BER = 10^{-5}, ERP = 20 dBW



Power trade-off: LOS locations, BER = 10^{-5}, Cell radius = 500 m



ERP family of curves: All Locations, BER = 10^{-5}

Conclusions

- K is log-normal - as predicted
- Pr is log-normal - as expected
- Two-ray model is better for LOS, but sensitive
- PER better than BER -- as expected
- K and Pr correlated - as expected
- Use of real data better than Rayleigh assumption