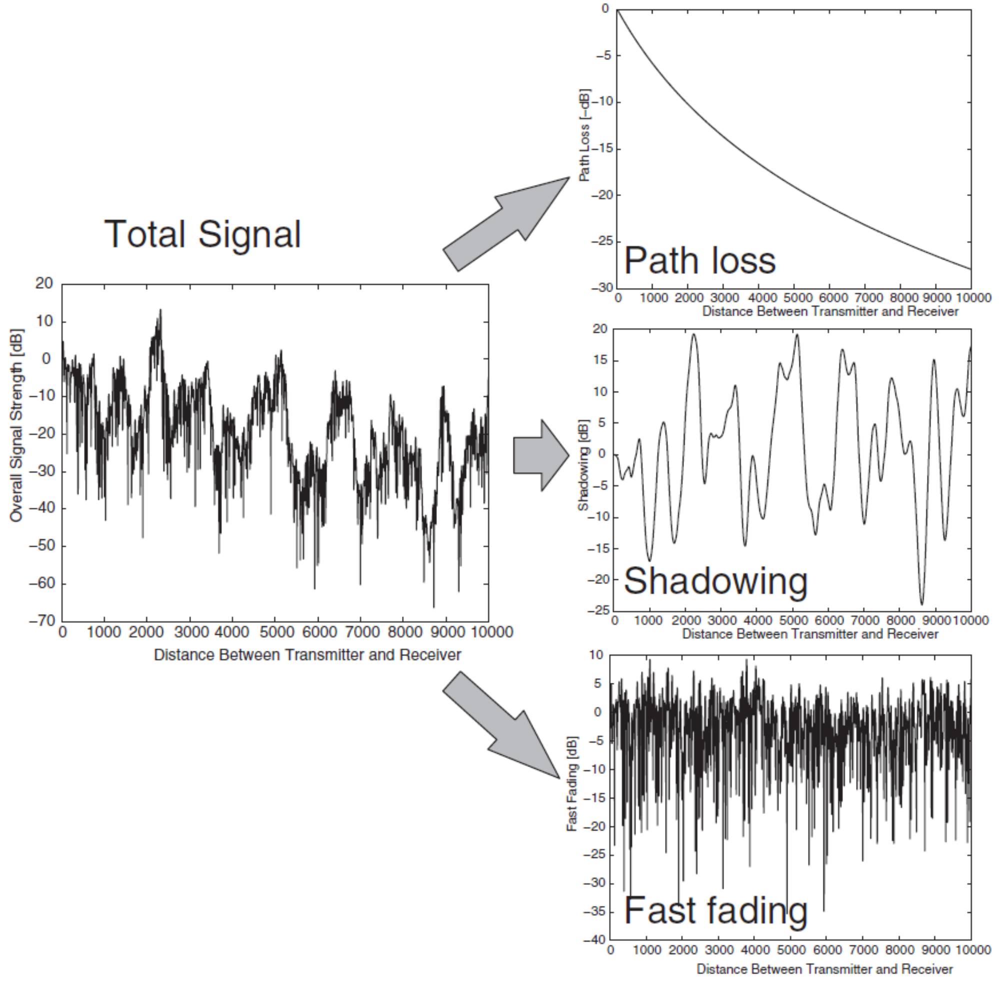
Project II

Narrowband Mobile Propagation Channel: Measurement and Modelling

Introduction

Narrowband UHF Mobile Propagation Channel

- Basic path loss (the mean for the given location)
  - (Semi-)Empirical models
  - (Semi-)Deterministic models
- Large-scale variations
  - Log-normal shadowing
- Small-scale variations
  - Rayleigh fading



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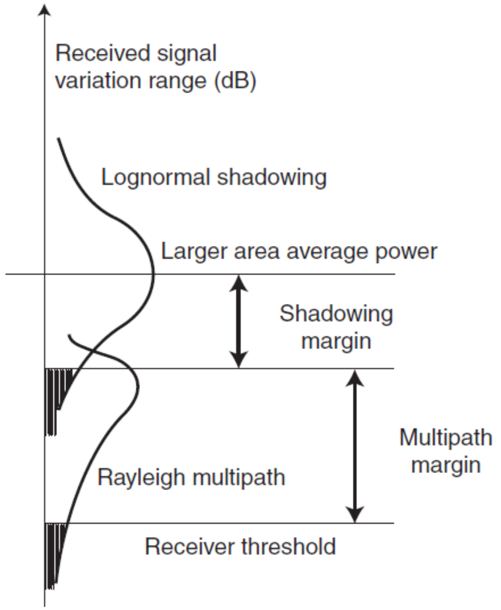

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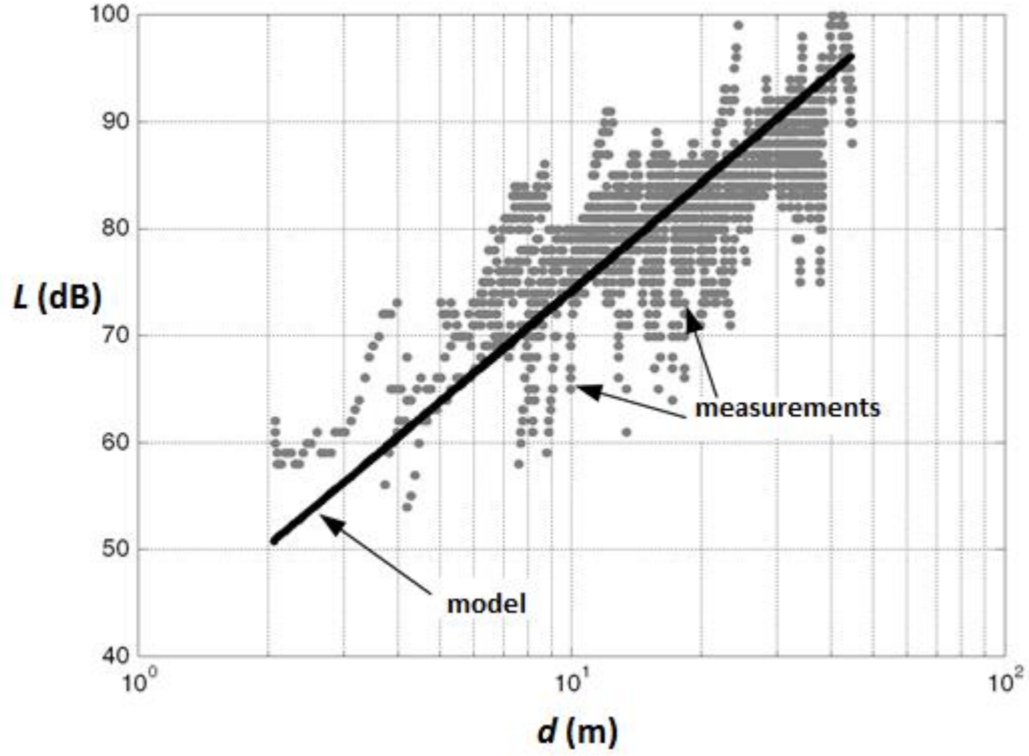
Mean Path Loss - Basic Empirical Model
(Log-distance Model, One Slope Model)



Environment	*n* (-)
Free space	2.0
suburban	2.5 – 4.0
dense urban	3.0 – 5.0
indoor – LOS	1.6 – 1.8
indoor – NLOS	3.0 – 6.0

$$\overline{L(d)} = \overline{L_1(d_1)} + 10n\log(\frac{d}{d_1})$$

$$P_p \approx \frac{1}{d^n}$$

Log-normal Shadowing

- **Long-term / Large-scale** variations from the **mean** due to **shadowing**
- Log-normal shadowing = measured signal levels **in dB** it the given area shows **normal** (Gaussian) distribution about the mean

$$L(d) = \overline{L(d)} + X_\sigma = \overline{L_1(d_1)} + 10n\log(\frac{d}{d_1}) + X_\sigma$$

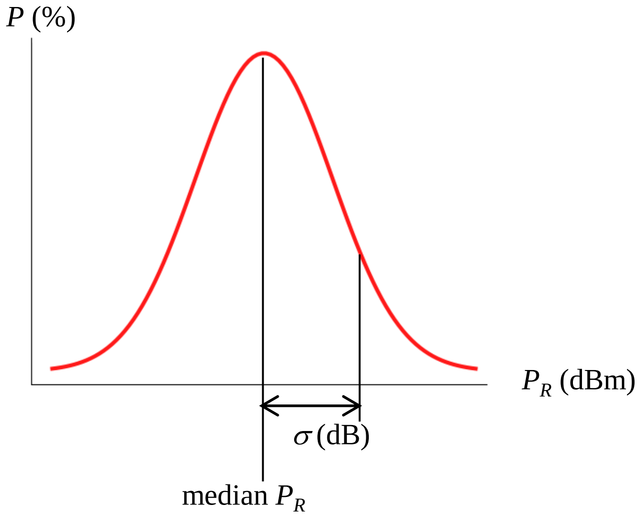
$$L(d,p) = \overline{L(d)} + L_{ln}(\sigma, p)$$

X_σ - zero-mean Gaussian distributed random variable in dB with standard deviation σ (dB); σ is given by the environment (urban ~8 dB, rural ~4 dB);
L_{ln} – value of X_σ for probability of p (%)

- Received power

$$P_R(d) = P_0 - L(d)$$

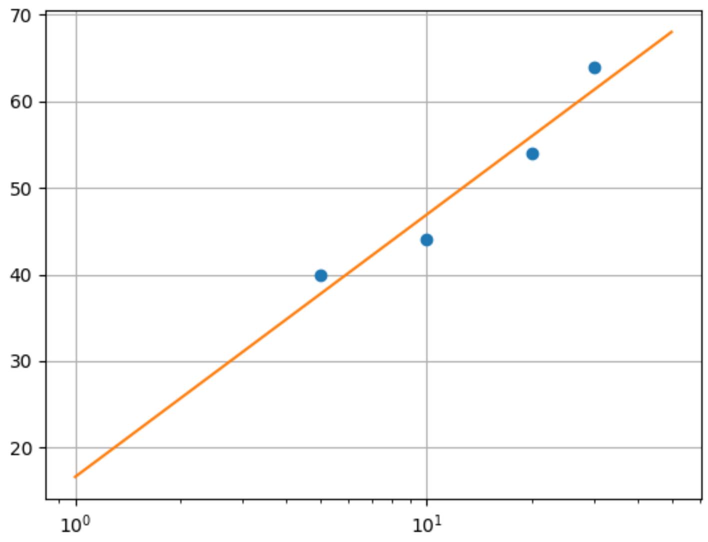
$$P[P_R(d) > \gamma] = Q(\frac{\gamma - \overline{P_R(d)}}{\sigma})$$



Example (not real and PRIMITIVE!)

- Measurement (distance [m], path loss[dB]):
  [(5, 40), (10, 44), (20, 54), (30, 64)]
- Fitting $\overline{L(d)} = \overline{L_1(d_1)} + 10n\log\left(\frac{d}{d_1}\right)$ for d_1 = 1 m:
  L_1 = 16.6 dB; **n = 3.0**
- Calculating standard deviation σ:
  σ^2 = {(37.8 – 40)^2 + (46.9 – 44)^2 + (56.0 – 54)^2 + (61.3 – 64)^2} / 4 = 6.1 => **σ =2.5 dB**

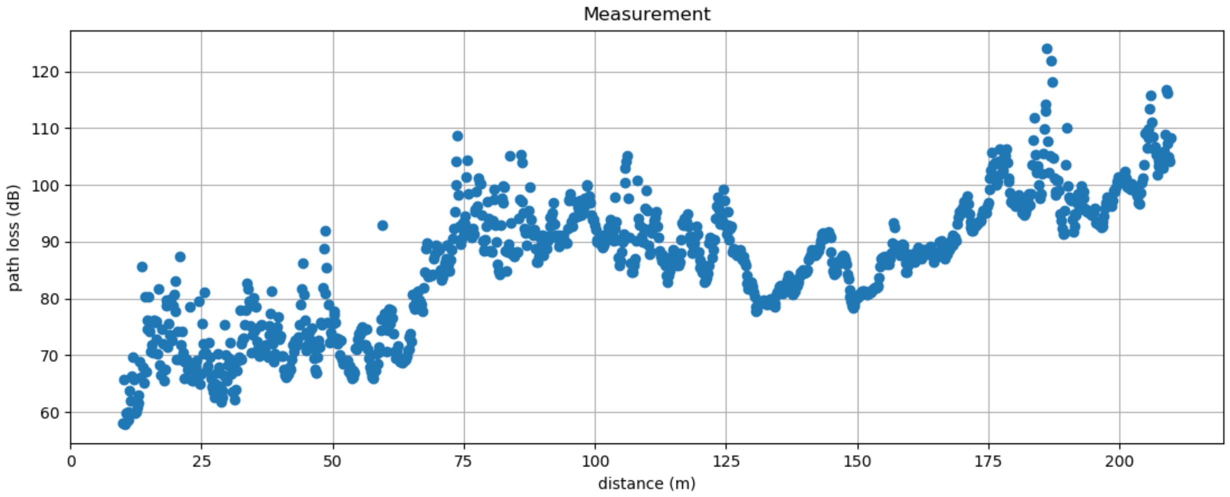
Distance (m)	Measured (dB)	Predicted (dB)	Error (dB)
5	40	37.8	-2.2
10	44	46.9	2.9
20	54	56.0	2.0
30	64	61.3	-2.7



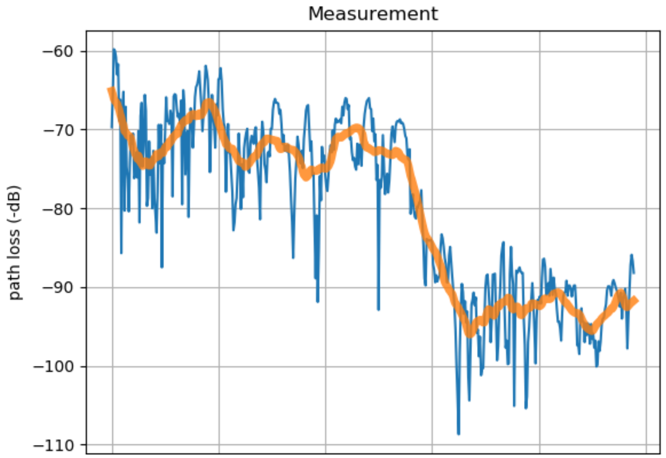
$$L(d) = \overline{L(d)} + X_\sigma = 16.6 + 30\log(d) + X_{2.5} \qquad [\text{dB, m, dB}]$$

Example I

- Calculation of measured path loss vs. distance from the link budget and geometry



- If fast fading present (dynamic scene, speed) apply filtering first

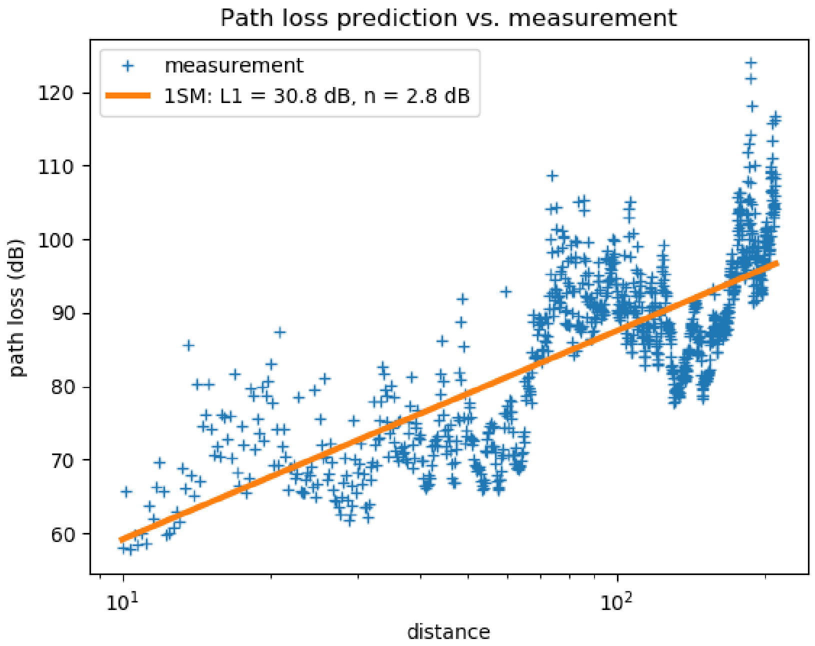


Note the path loss given in – dB
and the difference between realtive path loss
and received signal strengths (RSS) in dB

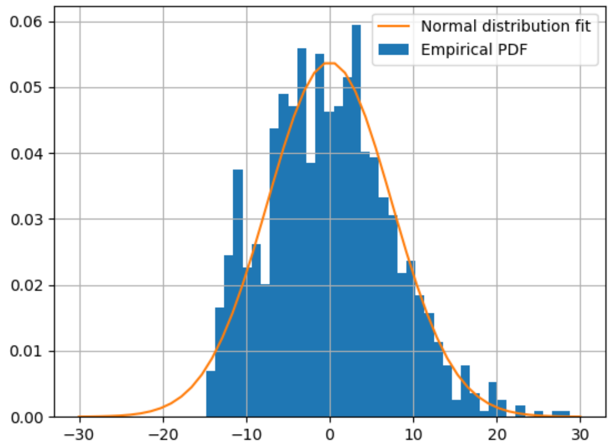
Example I (contd.)

- Fit the one slope empirical model

$$\overline{L(d)} = 30.8 + 28\log(d) \quad \text{[dB, m]}$$



- Calculate prediction error



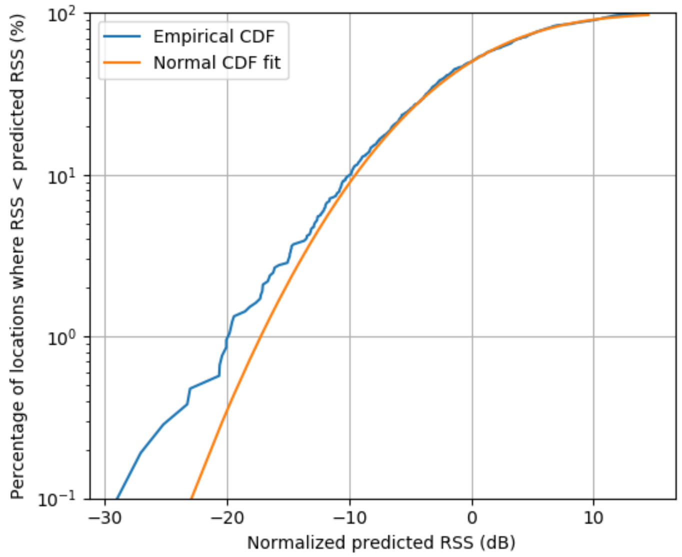
σ =7.4 dB

$$L(d) = \overline{L(d)} + X_\sigma = 30.8 + 28\log(d) + X_{7.4} \quad \text{[dB, m, dB]}$$

- Provide CDF and required predictions, e.g.:

a) predicted path loss at *d* = 100 m

b) max distance where *L* < 80 dB fo 90% locations



Example I (contd.)

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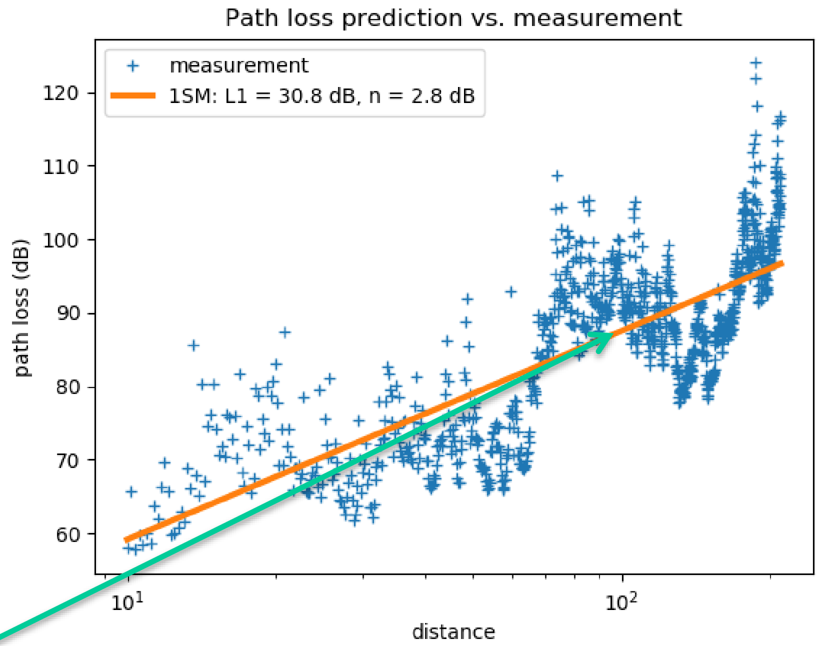
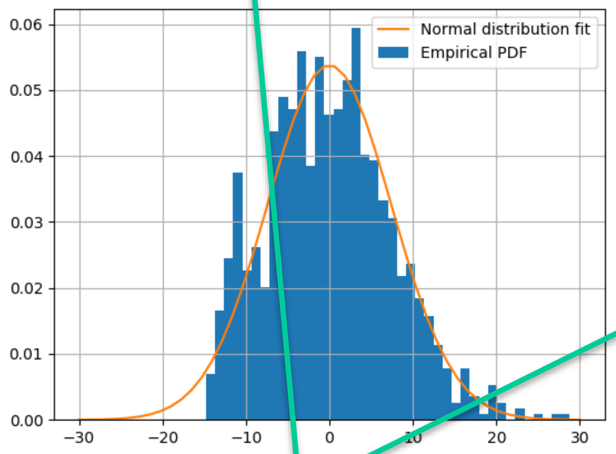
$$\overline{L(d)} = 30.8 + 28\log(d) \quad [\text{dB, m}]$$



- Calculate prediction error



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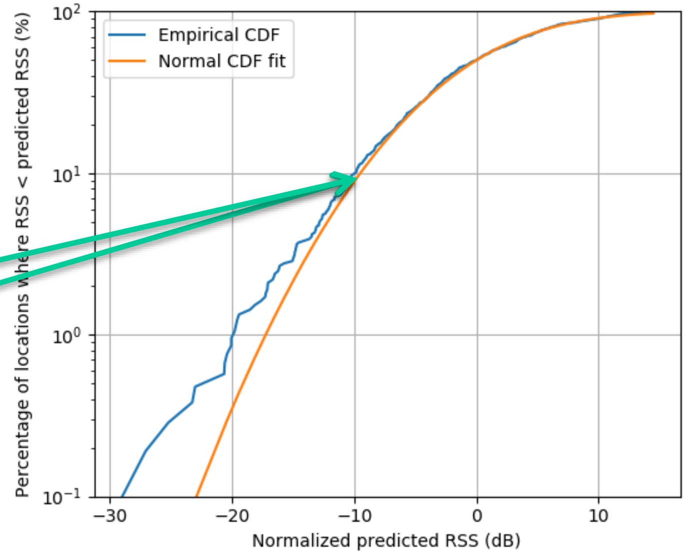
$$L(d) = \overline{L(d)} + X_\sigma = 30.8 + 28\log(d) + X_{7.4} \quad [\text{dB, m, dB}]$$



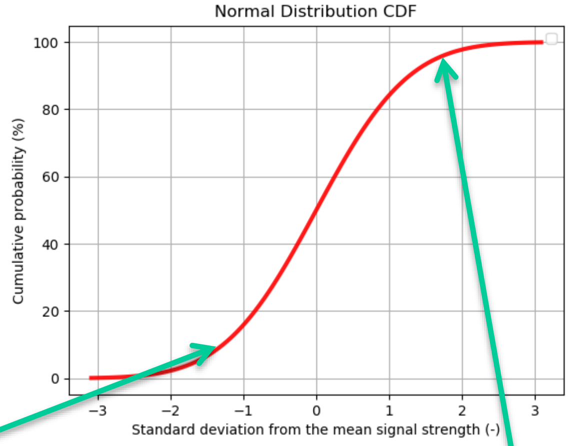
- Provide CDF and required predictions, e.g.:

a) predicted path loss at d = 100 m
mean = 86.8 dB; for 10% locations higher than 96 dB

b) max distance where L < 80 dB fo 90% locations
mean = 80 + 10 = 90 dB => d = 130 m

Example I (contd.)

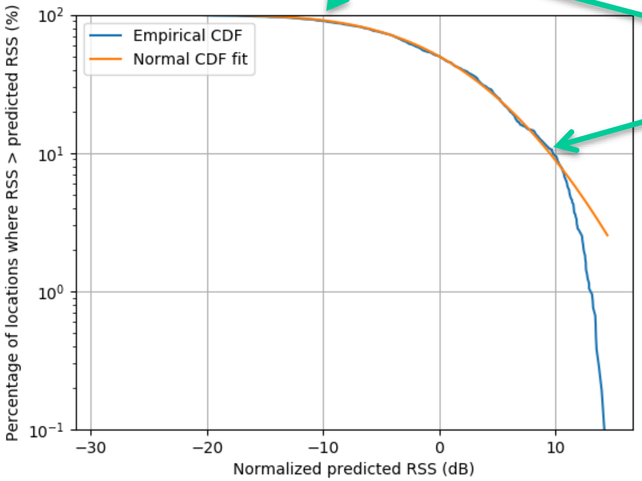
- Standard Gaussian distribution $m = 0$, $\sigma = 1$

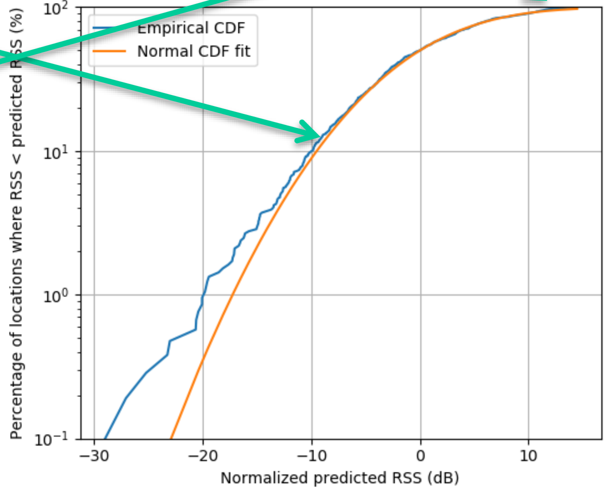


1%	-2.33
5%	-1.65
10%	-1.28
20%	-0.84
30%	-0.52
50%	0.00
70%	0.52
80%	0.84
90%	1.28
95%	1.65
99%	2.33

- $\sigma = 7.4$ dB

$L_M(7.4 \text{ dB}, 10\ \%) = -1.28 \times 7.4 \text{ dB} = -9.5 \text{ dB}$ $L_M(7.4 \text{ dB}, 95\ \%) = 1.65 \times 7.4 \text{ dB} = 12.2 \text{ dB}$



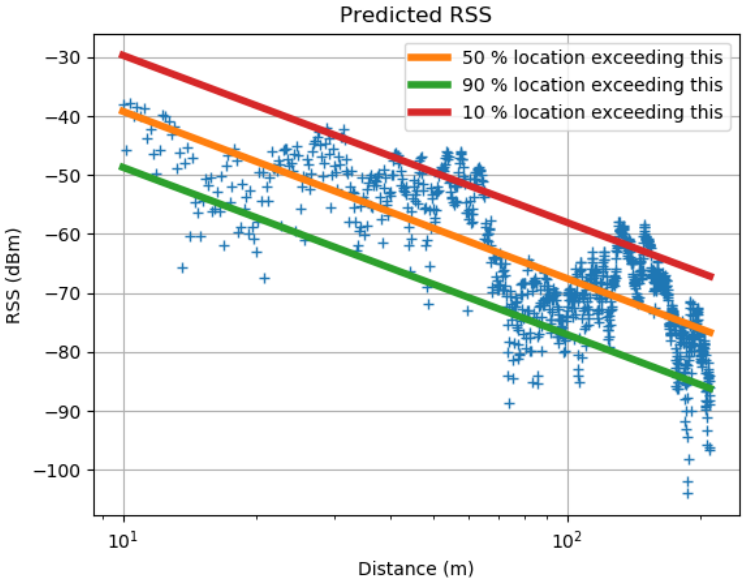


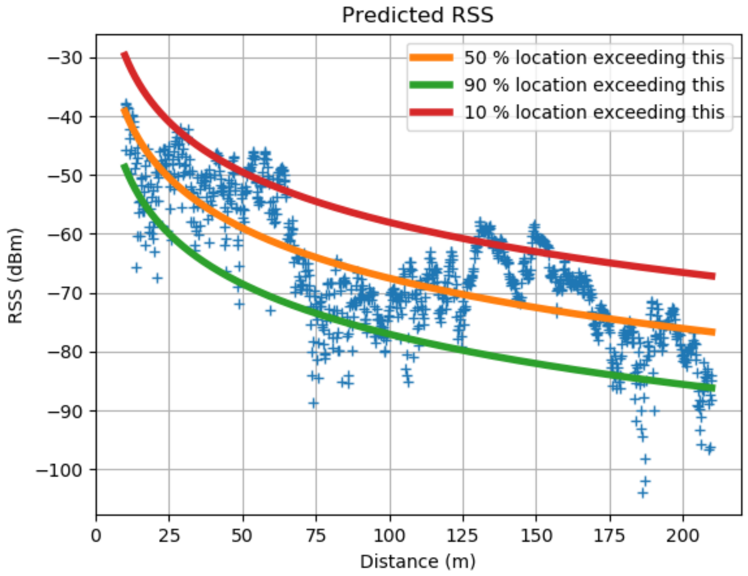
Example I (contd.)

$$L(d,p) = \overline{L(d)} + L_{ln}(\sigma,p) = 30.8 + 28\log(d) + L_{ln}(7.4,p) \qquad [\text{dB, m, \%, dB}]$$

$$P_R(d,p) = P_T + G_T + G_R - L_{sys} - L(d,p) \qquad [\text{dBm, m, \%, dBm, dB}]$$

$$P(P_R > x) = p = 10\%,\ 50\%,\ 90\%:$$





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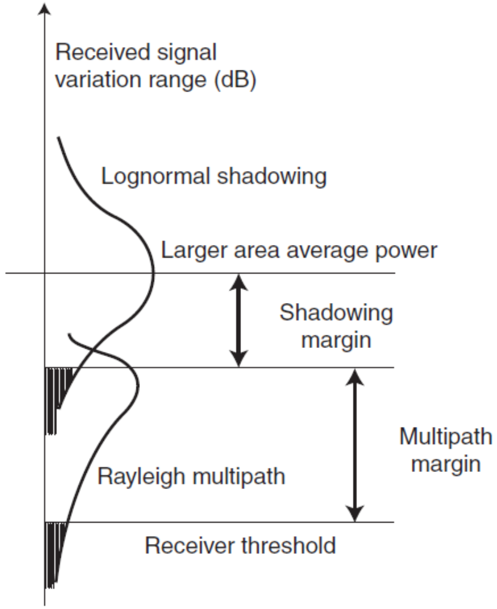
- **Small-scale variations**
  - **Rayleigh fading**



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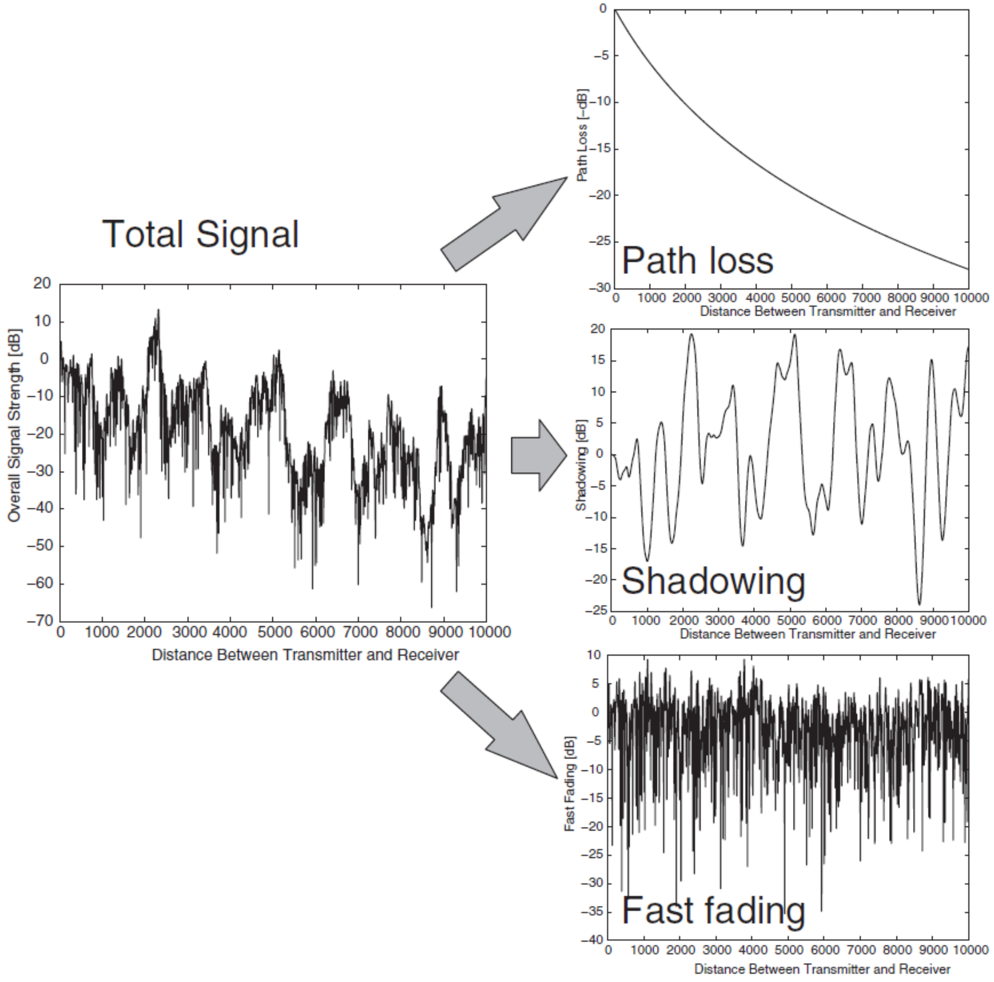

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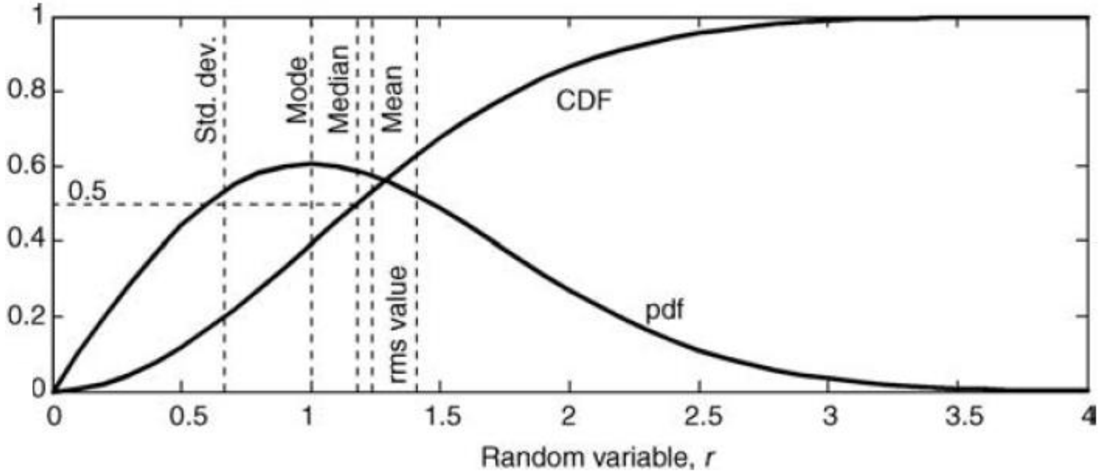
Rayleigh fading

$$r(t) = \sqrt{I(t)^2 + Q(t)^2}$$

$$p_R(r) = \frac{r}{\sigma^2} \mathrm{e}^{\frac{-r^2}{2\sigma^2}}$$

Mode	σ
Median	$\sigma\sqrt{2\ln 2} = 1.18\sigma$
Mean	$\sigma\sqrt{\pi/2} = 1.25\sigma$
RMS value	$\sigma\sqrt{2} = 1.41\sigma$
Standard deviation	$\sigma\sqrt{2 - \pi/2} = 0.655\sigma$



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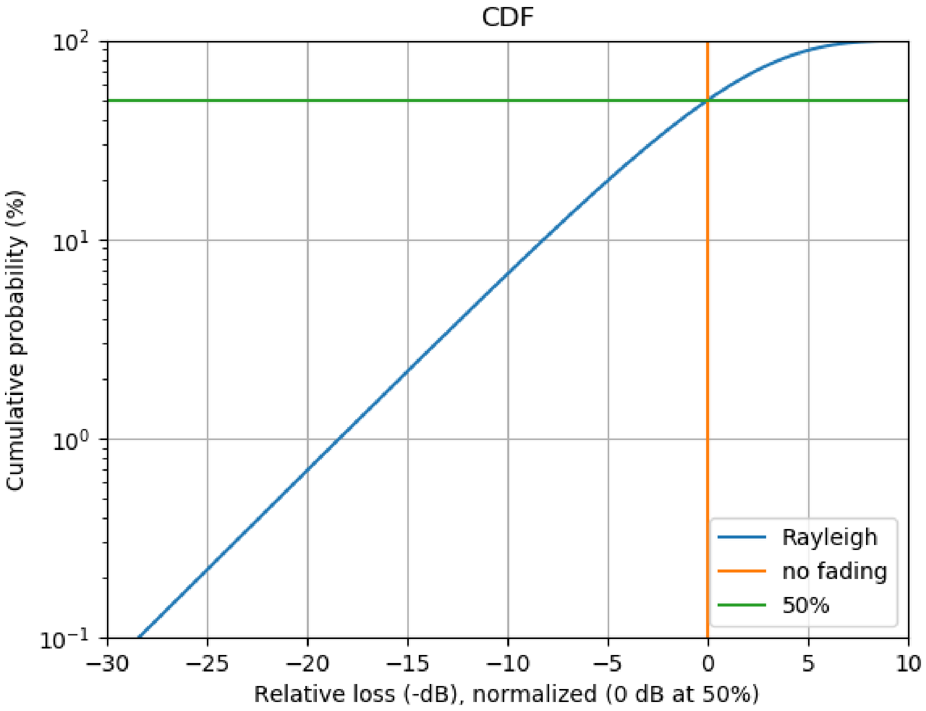
$$P[r \le R] = P_R(R) = 1 - \mathrm{e}^{\frac{-R^2}{2\sigma^2}}$$

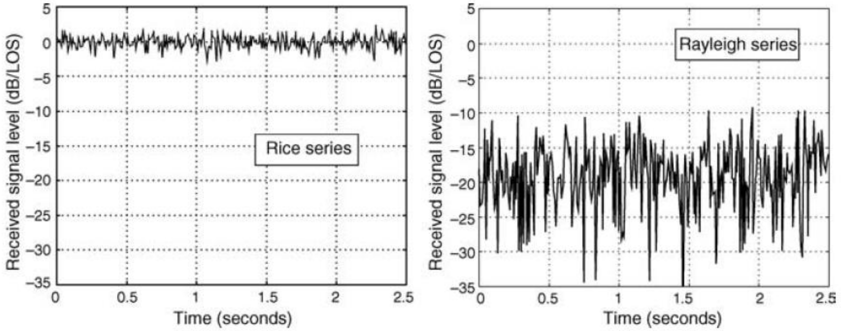
Note:
r(*t*) models *voltage* (V)
power (W) = *voltage*^{2} / (2 · 50 Ω)
power (dBm) = 10 log [power (W) / 10^{-3}]

$$R_{dB} = 20\log_{10}(\frac{R}{R_{50}})$$



Rice channel

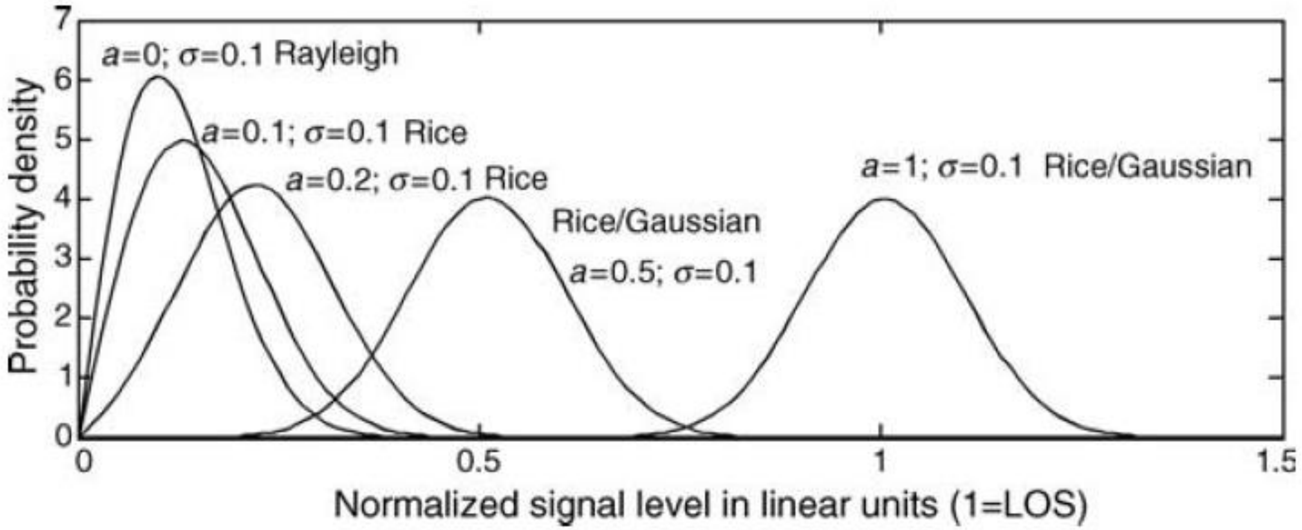
- Adding two components
  - Coherent LOS (constant power; path loss + shadowing)
  - Random multipath (Rayleigh distributed)



$$p_R(r) = \frac{r}{\sigma^2} \mathrm{e}^{-\frac{r^2+a^2}{2\sigma^2}} \mathrm{I}_0\left(\frac{ar}{\sigma^2}\right)$$

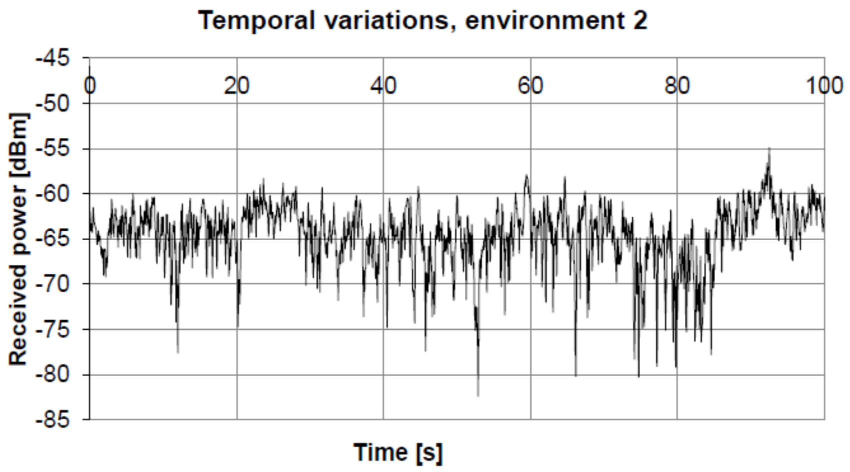
$$k = \frac{a^2}{2\sigma^2}, \quad K(\mathrm{dB}) = 10 \log(k)$$

r – magnitude of complex envelope
a – amplitued of the direct LOS signal
σ – mode of Rayleigh distribution when $a = 0$
$2\sigma^2$ – normalized average power of the multipath component
I_0 – modified Bessel f. of the first kind and zeroth order
k, K – Rice k-factor; Carier-to-Multipath ratio (C/M)

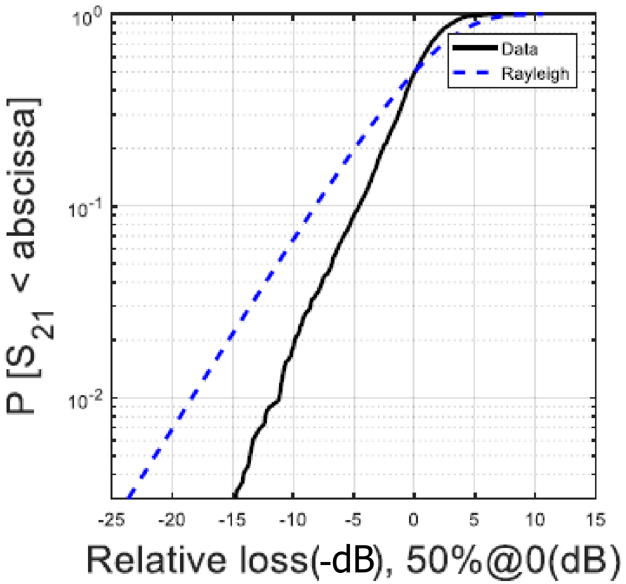


Illustrations from Modeling the Wireless Propagation Channel, © F. P. Fontan, P. M. Espineira, 2008

Example II



Minimum [dBm]	-82.5
Maximum [dBm]	-54.9
Median [dBm]	-64
Maximum fade [dB]	18.4



P **(%)**	***RSS*** **(dB)**
50	0
10	-5
1	-12

Illustrations from the SBS 2017 class, Group B presentation