**2-18.** Table 2.5 lists a set of empirical path loss measurements.

(a) Find the parameters of a simplified path-loss model plus log-normal shadowing that best fit this data.

(b) Find the path loss at 2 km based on this model.

(c) Find the outage probability at a distance $d$ assuming the received power at $d$ due to path loss alone is 10 dB above the required power for non-outage.

**Table 2.5:** Path-loss measurements for Problem 2-18

| Distance from transmitter | $P_r/P_t$ |
|---|---|
| 5 m | −60 dB |
| 25 m | −80 dB |
| 65 m | −105 dB |
| 110 m | −115 dB |
| 400 m | −135 dB |
| 1000 m | −150 dB |

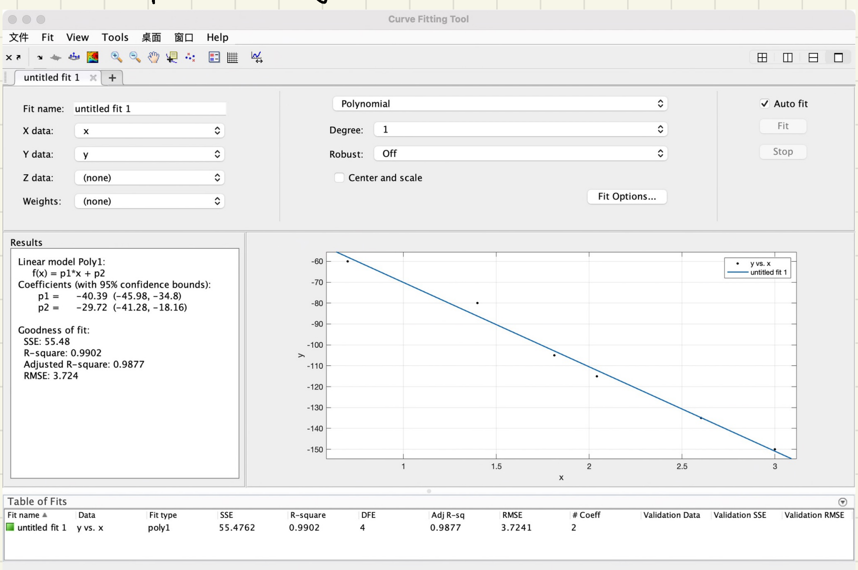
(a) $\frac{P_r}{P_t} = K\left(\frac{d_0}{d}\right)^{\gamma}$

$$\frac{P_r}{P_t}\,dB = 10\lg K\left(\frac{d_0}{d}\right)^{\gamma} = K\,dB - 10\gamma\lg d$$

code I use:

```
clc
clear
x=[log10(5) log10(25) log10(65) log10(110) log10(400) log10(1000)];
y=[-60 -80 -105 -115 -135 -150];
```

use cftool, I get:




It is clear that

$-10\gamma = -40.39$

$K\,dB = -29.72\,dB$

So, $\frac{P_r}{P_t}\,dB = -29.72\,dB - 40.39\lg d$

(b) when $d = 2000$ m, according to (a), we have:

$$\frac{P_r}{P_t}\,dB = -29.72 - 40.39 \times \lg(2000) \approx -163\,dB$$

(c) $P_{out}(P_{min}, d) = Pr[P_r(d) \leq 10\,dB]$

$$= Pr\left[\frac{\psi_{dB}}{\sigma_{\psi dB}} \geq \frac{-[10-(P_t-29.72-40.39\lg d)]}{\sigma_{\psi dB}}\right]$$

$$= 1 - Q\left(\frac{10-(P_t-29.72-40.39\lg d)}{\sigma_{\psi dB}}\right)$$

**2-19.** Consider a cellular system operating at 900 MHz where propagation follows free-space path loss with variations about this path loss due to log-normal shadowing with $\sigma = 6$ dB. Suppose that for acceptable voice quality a signal-to-noise power ratio of 15 dB is required at the mobile. Assume the base station transmits at 1 W and that its antenna has a 3-dB gain. There is no antenna gain at the mobile, and the receiver noise in the bandwidth of interest is $-40$ dBm. Find the maximum cell size such that a mobile on the cell boundary will have acceptable voice quality 90% of the time.

$\sigma_{\psi dB} = 6\,dB$.

$\because f_c = 900\,MHz$. $\therefore \lambda = \frac{c}{f_c} = \frac{1}{3}\,m$.

$SNR_r = 15\,db$. $g = 3\,dB$. $P_{noise} = -40\,dBm \Rightarrow P_r = -55\,dB$

$P_t = 1\,W$.

let $\mu(d) = P_r$ due to path loss alone

$$\therefore \mu(d) = P_r\left(\frac{\sqrt{G_l}\,\lambda}{4\pi d}\right)^2 = \frac{1.4\times 10^{-3}}{d^2}$$

$$\mu_{dB} = 10\log_{10}(\mu(d))$$

$$\because P\left(\frac{P_r(d)-\mu_{dB}}{\sigma_{\psi dB}} > \frac{-55-\mu_{dB}}{6}\right) = 0.9 \Rightarrow d = 8.68\,m$$

**2-21.** In this problem we will explore the impact of different log-normal shadowing parameters on outage probability. Consider a cellular system where the received signal power is distributed according to a log-normal distribution with mean $\mu$ dBm and standard deviation $\sigma_\psi$ dBm. Assume the received signal power must be above 10 dBm for acceptable performance.

(a) What is the outage probability when the log-normal distribution has $\mu_\psi = 15$ dBm and $\sigma_\psi = 8$ dBm?

(b) For $\sigma_\psi = 4$ dBm, find the value of $\mu_\psi$ required for the outage probability to be less than 1% – a typical value for cellular systems.

(c) Repeat part (b) for $\sigma_\psi = 12$ dBm.

(d) One proposed technique for reducing outage probability is to use *macrodiversity*, where a mobile unit's signal is received by multiple base stations and then combined. This can only be done if multiple base stations are able to receive a given mobile's signal, which is typically the case for CDMA systems. Explain why this might reduce outage probability.

(a) $P_{min} = 10$ dBm

$$P_{out} = 1 - Q\left(\frac{P_{min} - \mu_\psi}{\sigma_\psi}\right) = 1 - Q\left(-\frac{5}{8}\right) = Q\left(\frac{5}{8}\right) = 26\%$$

(b) $Q(z) = Q\left(\frac{P_{min} - \mu_\psi}{\sigma_\psi}\right) > 99\%$

$$\therefore \frac{10 - \mu_\psi}{4} < -2.33 \Rightarrow \mu_\psi \geq 19.32 \text{ dB}$$

(c) $$\frac{10 - \mu_\psi}{12} < -2.33 \Rightarrow \mu_\psi \geq 37.8 \text{ dB}$$

(d) $\because$ All the base stations are unlikely to experience an outage at the same time, so the probability of power outage will be reduced.