University of Tehran, ECE
Wireless Communication, spring 2020

**Due Date: ------------** HW 1

## Path loss, Shadowing, Link budget, and Coverage

1. In a wireless communication system working at $f_c = 1GHz$, the transmitted power is $0\,dBm$. The path-loss follows the simplified model of $P_L(dB) = 10 + 40\,log_{10}(d)$, where $d$ is the distance in meter. We also have a Log-Normal shadowing with a standard deviation of $6\,dB$. The acceptable RX power is $P_{r_{\min}} = -90\,dBm$ (outage = $P_r < P_{r_{\min}}$).
   a. Determine the outage probability ($P_{out}$) for users with a distance of $d$ from the transmitter. Find the distance where $P_{out}$ becomes $50\%$ ?
   b. Determine the total expected coverage area? Find the expected coverage radius.
   c. Find the needed transmitted power such that the outage probability for a user located at a distance of $100m$ becomes $P_{out}$. Sketch $P_{out}$ (from $0\%$ up to $100\%$) vs. needed TX power (in $dBm$).

2. In Fig.1, the node RX receives signal form transmitter $TX_1$ and also receives interference from $TX_2$. The path loss and shadowing between $i^{th}$ transmitter and receiver are modeled as:

$$PL_i = K + 10n\,log_{10}\left(\frac{d_i}{d_0}\right) + X_i\ (dB)\ ,\ \ i = 1,2$$

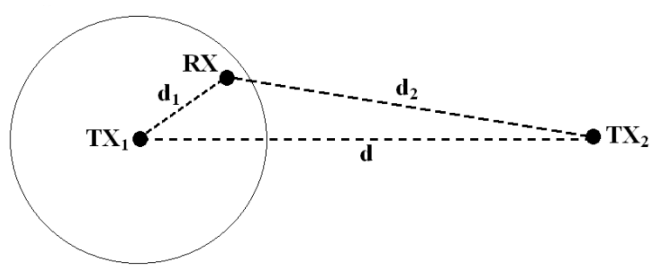


Fig.1

Where $d_i$ is the distance between the receiver and transmitter $i$ in meters, and $n$ is the path loss exponent, the terms $X_i$ are zero-mean Gaussian random variables with standard deviation $\sigma$, in dB, that model the variation of the received signals due to shadowing. Assume that the random variables $X_i$ are independent of each other and also suppose that $P_0$ is the received power at distance $d_0$ from each of transmitters. $\mathrm{SINR}_{\min}$ is the minimum required SINR at receiver for non-outage.

a. Using the parameters in Table.2, find the maximum radius R from $TX_1$, that if the receiver is in that circle, then the outage probability at each point be less than 0.05.
b. Suppose that n is parameter, find the maximum radius R as a function of n, and plot R versus n and explain the behavior of R.

c. Suppose that there is an additive white Gaussian noise at RX with $N_0 = 10^{-12}$, find the maximum radius R, for n=4 and also plot R versus n and compare the results with part b.

Table 1

| Parameter | Value |
|---|---|
| n | 4 |
| **σ** | 5 dB |
| $\mathbf{P_0}$ | 0 dBW |
| $\mathbf{d_0}$ | 1 m |
| d | 1000 m |
| $\mathbf{SINR_{min}}$ | 10 dB |

3. Consider a cellular system operating at 900 MHz where propagation follows free space path loss with variations from 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 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 -10 dBm. Find the maximum cell size so that a mobile on the cell boundary will have acceptable voice quality 90% of the time.

4. Consider a random propagation environment. The received signal power $P_r$ at a distance $d(> d_0)$ is:

$$P_r^{(dBm)} = P_0^{(dBm)} - 10\,\gamma \log_{10}\left(\frac{d}{d_0}\right) + X^{(dB)}$$

where $P_0 = 0\,dBm$ is the received power, a reference distance $d_0 = 1\,m$, $\gamma = 3$ is the path loss exponent, $X(dB)$ is a discrete random variable distributed with

$$P_{X^{(dB)}}\left(x^{(dB)}\right) = \begin{cases} 0.2 & x^{(dB)} = 0\,dB \\ 0.2 & x^{(dB)} = -2\,dB \\ 0.2 & x^{(dB)} = -1\,dB \\ 0.2 & x^{(dB)} = 1\,dB \\ 0.2 & x^{(dB)} = 2\,dB \\ 0 & otherwise \end{cases}$$

Find the maximum radius of this basestation such that the power signal received (from basestation) is larger than −90dBm with a probability of 0.8.

5. Use MATLAB to plot each part of the following question:

Consider a base-station (BS) and a lot of mobile devices randomly are located around the BS with uniform distribution in a circular ring whose distance from BS starts from $d_0 = 10\, meter$ and is limited to $D = 1000\, meter$.

The path-loss follows a simplified model with a path-loss exponent of $n = 4$. The transmitted power is such that the average received signal power at $d = d_0$ is $P_0 = 1\mu W$ . The PSD of the AWGN at the receiver is $N_0 = -174 \frac{dBm}{Hz}$ and the signal bandwidth is $1\, MHz$.

a. The average received signal power at distance $d$ ($d > d_0$) is obtained by the following equation:

$$P_r^{dBm} = P_0^{dBm} - 10nlog_{10}\left(\frac{d}{d_0}\right)$$

Simulate the $P_r^{dBm}$ of the users and plot its CDF (cumulative distribution function). (you can use cdfplot in Matlab).

b. Plot expected $SNR\ (dB) = P_r^{dBm} - P_n^{dBm}$ as a function of distance ($\log_{10} d$) for $10 \le d \le 1000$.

c. Now assume that we have Log-normal shadowing as well. The average received signal power at distance $d$ ($d > d_0$) is obtained by the following equation:

$$P_r^{dBm} = P_0^{dBm} - 10nlog_{10}\left(\frac{d}{d_0}\right) + X^{dB}$$

where $X$ is a zero-mean Gaussian random variables with standard deviation $\sigma = 5\, dB$ (independent of $d$). Plot the CDF of $P_r^{dBm}$ and $SNR\ (dB) = P_r^{dBm} - P_n^{dBm}$ for all users in the ring.

d. Plot $P_{out} = \Pr(\, SNR < SNR_{min})$ as a function of distance ($\log_{10} d$) for $10 \le d \le 1000$. $\mathrm{SNR}_{\mathrm{min}} = 20\, dB$ is the minimum required SNR at receiver for non-outage.

e. How much area of the ring is covered if we need $\mathrm{SNR}_{\mathrm{min}} = 20\, dB$ for coverage. Compare it with formula in Goldsmith.

Note: For uniformly distributed users in a ring, simulate some $10^5$ users randomly located at (dx,dy), where dx and dy are independent random coordinates with uniform distribution in [ -1000 , 1000 ]. Then select the users that are located in the intended circular ring and remove the remaining users from your user set.