ECE6604
PERSONAL & MOBILE COMMUNICATIONS

Lecture 3

Interference and Shadow Margins, Handoff Gain, Coverage
Interference Margin

- As the subscriber load increases, additional interference is generated from both inside and outside of a cell. With increased interference, the coverage area shrinks and some calls are dropped. As calls are dropped, the interference decreases and the coverage area expands.
  - the expansion/contraction of the coverage area is a phenomenon known as cell breathing.

- We must introduce an interference degradation margin into the link budget to eliminate cell breathing.
  - To account for the maximum interference degradation, we reduce the maximum allowable path loss by an interference margin, \((L_I)_{dB}\).
  - The appropriate value of \((L_I)_{dB}\) depends on the particular cellular system being deployed and the maximum expected load level.
Shadowing

• With shadowing the received signal power is

\[ \Omega_p \text{ (dBm)} = 10\log_{10}(k) + \Omega_t \text{ (dBm)} - 10\beta\log_{10}(d) + \epsilon_{(dB)} \]

where the parameter \( \epsilon_{(dB)} \) is the error between the predicted and actual path loss.

• Very often \( \epsilon_{(dB)} \) is modeled as a zero-mean Gaussian or normal random variable with variance \( \sigma_\Omega^2 \), where \( \sigma_\Omega \) in decibels (dB) is called the shadow standard deviation.

• That is, the probability density function of \( \epsilon_{(dB)} \) is

\[ p_{\epsilon_{(dB)}}(x) = \frac{1}{\sqrt{2\pi\sigma_\Omega^2}} e^{x^2/2\sigma_\Omega^2} \]

• Typically, \( \sigma_\Omega \) ranges from 4 to 12 dB depending on the local topography; \( \sigma_\Omega = 8 \text{ dB} \) is a very commonly used value.
Path loss and shadowing in a typical cellular environment.
Outage

- The quality of a radio link is acceptable only when the received signal power $\Omega_p \text{ (dBm)}$ is greater than a threshold value $\Omega_{th} \text{ (dBm)}$.

- An outage occurs whenever $\Omega_p \text{ (dBm)} < \Omega_{th} \text{ (dBm)}$.

- The edge outage probability, $P_E$, is defined as the probability that $\Omega_p \text{ (dBm)} < \Omega_{th} \text{ (dBm)}$ at the cell edge.

- The area outage probability, $P_O$, is defined as the probability that $\Omega_p \text{ (dBm)} < \Omega_{th} \text{ (dBm)}$ when averaged over the entire cell area.

- To maintain an acceptable outage probability in the presence of shadowing, we must introduce a shadow margin.
Determining the required shadow margin to give $P_E = 0.1$. 
• Choose $M_{\text{shad}}$ so that the shaded area under the Gaussian density function is equal to 0.1. Hence, we solve

$$0.1 = Q\left(\frac{M_{\text{shad}}}{\sigma_\Omega}\right) \quad Q(x) = \int_x^\infty \frac{1}{\sqrt{2\pi}} e^{-y^2/2} dy$$

• We have

$$\frac{M_{\text{shad}}}{\sigma_\Omega} = Q^{-1}(0.1) = 1.28$$

• For $\sigma_\Omega = 8$ dB we have

$$M_{\text{shad}} = 1.28 \times 8 = 10.24 \text{ dB}$$

• The area outage probability is

$$P_O = Q(X) - \exp\left\{XY + Y^2/2\right\} Q(X + Y)$$

where

$$X = \frac{M_{\text{shad}}}{\sigma_\Omega}, \quad Y = \frac{2\sigma_\Omega \ln 10}{10 \beta}$$

From this we can solve for the required shadow margin, $M_{\text{shad}}$.

• Note that $P_O < P_E$ for the same value of $M_{\text{shad}}$. 
Handoff Gain

• At the boundary area between two cells, we obtain a macrodiversity effect.

• Although the link to the serving base station may be shadowed such that $\Omega_p \, (\text{dBm})$ is below the receiver threshold, the link to another base station may provide a $\Omega_p \, (\text{dBm})$ above the receiver threshold.

• Handoffs take advantage of macrodiversity and reduce the required shadow margin over the single cell case, by an amount equal to the handoff gain, $G_{HO}$.

• There are a variety of handoff algorithms used in cellular systems. CDMA system use soft handoffs, while TDMA systems usually use hard handoffs.

• The maximum allowable path loss with the inclusion of the margins for shadowing and interference loading, and handoff gain is

$$L_{max} \, (\text{dB}) = \Omega_t \, (\text{dBm}) + G_T \, (\text{dB}) + G_R \, (\text{dB}) - S_{RX} \, (\text{dBm}) - M_{\text{shad}} \, (\text{dB}) - L_I \, (\text{dB}) + G_{HO} \, (\text{dB})$$.
Typical handoff gain for hard and soft handoffs. In this plot shadow margin is defined as $M_{\text{shad}} - G_{\text{HO}}$, where $M_{\text{shad}}$ is the shadow margin required for a single cell. We also plot the area averaged outage rather than the edge outage.
Cellular Radio Coverage

- Radio coverage refers to the number of base stations or cell sites that are required to “cover” or provide service to a given area with an acceptable grade of service.

- The number of cell sites required to cover a given area is determined by the maximum allowable path loss and the path loss exponent.

- To compare the coverage of different cellular systems, we first determine the maximum allowable path loss, $L_{\text{max}}$ (dB), for the different systems by using a common quality criterion.

- Then

$$L_{\text{max}} \text{ (dB)} = C + 10\beta \log_{10}d_{\text{max}}$$

where $d_{\text{max}}$ is the radio path length that corresponds to the maximum allowable path loss and $C$ is a constant.

- The quantity $d_{\text{max}}$ is equal to the radius of the cell.

- To provide good coverage it is desirable that $d_{\text{max}}$ be as large as possible.
Comparing Coverage

- Suppose that System 1 has $L_{\text{max (dB)}} = L_1$ and System 2 has $L_{\text{max (dB)}} = L_2$, with corresponding radio path lengths of $d_1$ and $d_2$, respectively. The difference in the maximum allowable path loss is related to the cell radii by

  \[ L_1 - L_2 = 10\beta \left( \log_{10} d_1 - \log_{10} d_2 \right) \]

  \[ = 10\beta \left( \log_{10} \frac{d_1}{d_2} \right) \]

  or looking at things another way

  \[ \frac{d_1}{d_2} = 10^{(L_1 - L_2)/(10\beta)} \]

  Since the area of a cell is equal to $A = \pi d^2$ (assuming a circular cell) the ratio of the cell areas is

  \[ \frac{A_1}{A_2} = \frac{d_1^2}{d_2^2} = \left( \frac{d_1}{d_2} \right)^2 \]

  and, hence,

  \[ \frac{A_1}{A_2} = 10^{2(L_1 - L_2)/(10\beta)} . \]
Suppose that \( A_{\text{tot}} \) is the total geographical area to be covered. Then the ratio of the required number of cell sites for Systems 1 and 2 is

\[
\frac{N_1}{N_2} = \frac{A_{\text{tot}}/A_1}{A_{\text{tot}}/A_2} = \frac{A_2}{A_1} = 10^{-2(L_1 - L_2)/(10\beta)}
\]

Example: Suppose that \( \beta = 3.5 \) and \( L_1 - L_2 = 2 \) dB.

- \( N_2/N_1 = 1.30 \).
- Conclusion: System 2 requires 30% more base stations to cover the same geographical area.