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, $(L_I)_{\mathrm{dB}}$.
  - The appropriate value of $(L_I)_{\mathrm{dB}}$ depends on the particular cellular system being deployed and the maximum expected load level.

Shadowing

- **With shadowing the received signal power is**

$$\Omega_{p\ (\text{dBm})} = 10\log_{10}(k) + \Omega_{t\ (\text{dBm})} - 10\beta\log_{10}(d) + \epsilon_{(\text{dB})}$$

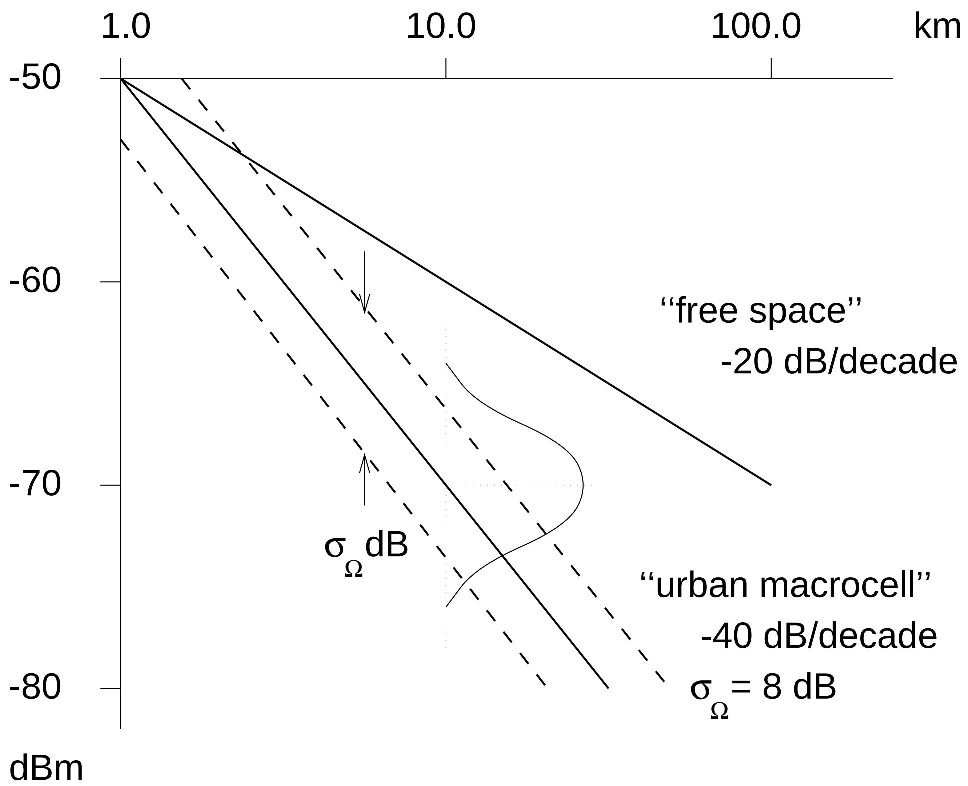
where the parameter $\epsilon_{(\text{dB})}$ is the error between the predicted and actual path loss.

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

- **That is, the probability density function of $\epsilon_{(\text{dB})}$ is**

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

- **Typically, σ_Ω ranges from 4 to 12 dB depending on the local topography; $\sigma_\Omega = 8$ dB is a very commonly used value.**



Path loss and shadowing in a typical cellular environment.

Outage

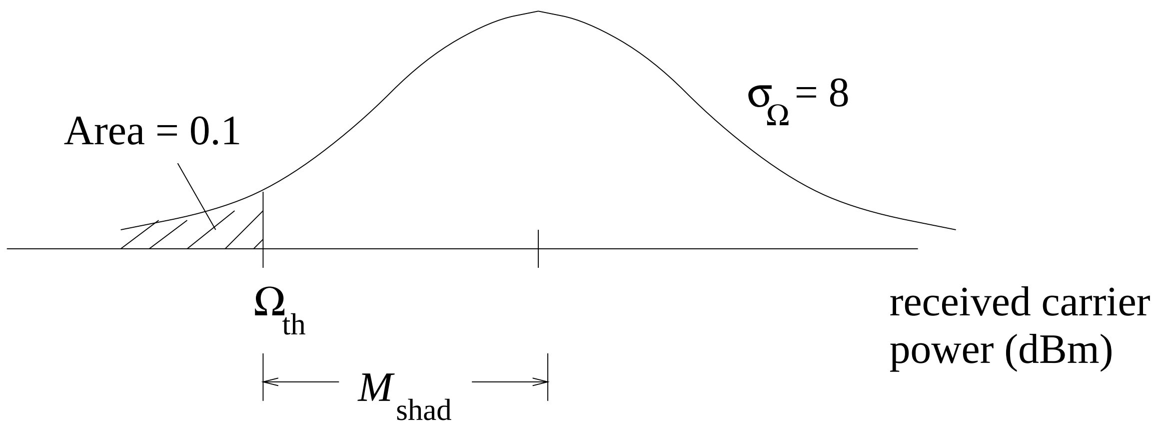
- **The quality of a radio link is acceptable only when the received signal power $\Omega_{p \text{ (dBm)}}$ is greater than a threshold value $\Omega_{\text{th (dBm)}}$.**

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

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

- **The area outage probability, P_O, is defined as the probability that $\Omega_{p \text{ (dBm)}} < \Omega_{\text{th (dBm)}}$ 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_{shad} so that the shaded area under the Gaussian density function is equal to 0.1. Hence, we solve**

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

- **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

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

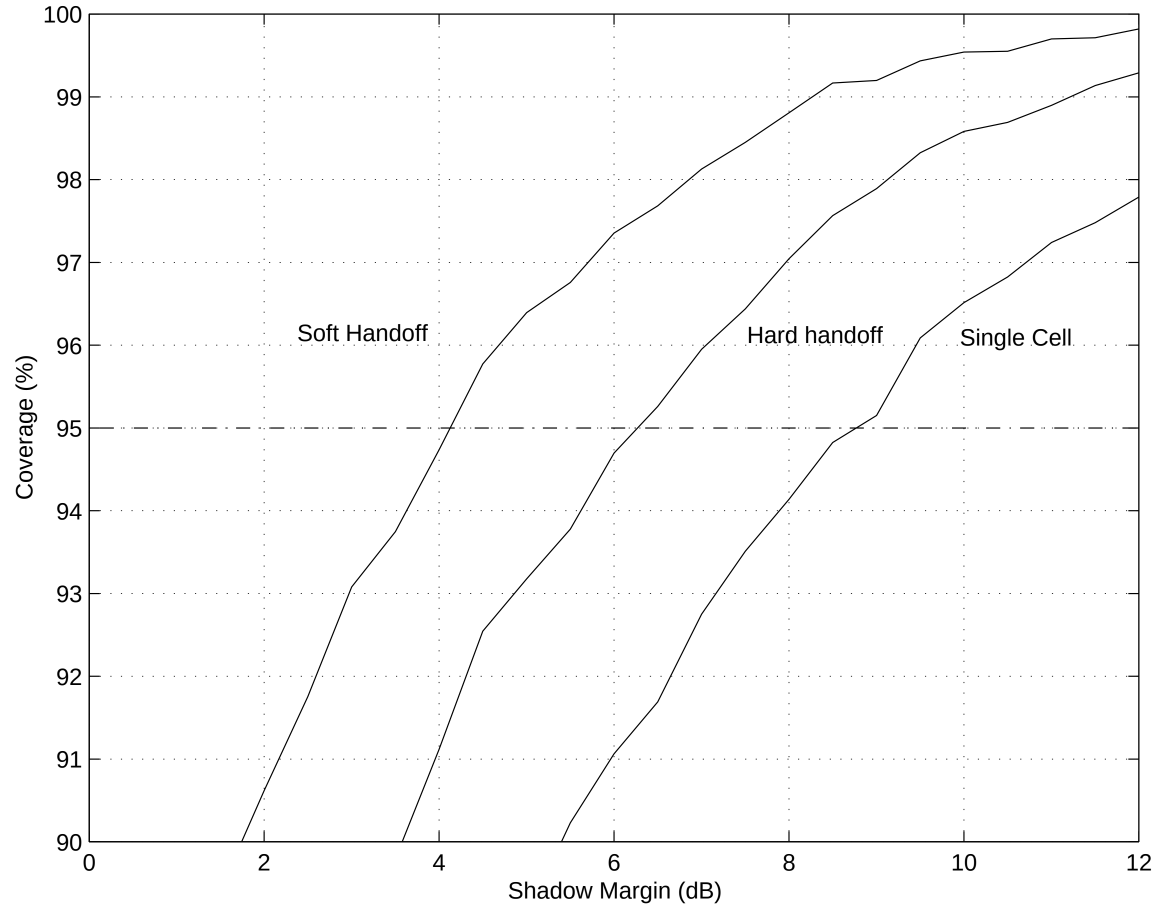
  From this we can solve for the required shadow margin, M_{shad}.

- **Note that $P_O < P_E$ for the same value of M_{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

$$L_{\max\ (\text{dB})} = \Omega_{t\ (\text{dBm})} + G_{\text{T}\ (\text{dB})} + G_{\text{R}\ (\text{dB})} - S_{\text{RX}\ (\text{dBm})} - M_{\text{shad}\ (\text{dB})} - L_{I\ (\text{dB})} + G_{\text{HO}\ (\text{dB})} .$$



Typical handoff gain for hard and soft handoffs. In this plot shadow margin is defined as $M_{\text{shad}} - G_{\text{HO}}$*, where* M_{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, $L_{\mathrm{max\ (dB)}}$, for the different systems by using a common quality criterion.

- Then

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

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

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

- To provide good coverage it is desirable that d_{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**

$$\begin{aligned} L_1 - L_2 &= 10\beta\,(\log_{10} d_1 - \log_{10} d_2) \\ &= 10\beta\left(\log_{10}\frac{d_1}{d_2}\right) \end{aligned}$$

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,

$$\frac{A_1}{A_2} = 10^{2(L_1 - L_2)/(10\beta)} \quad .$$

- **Suppose that A_{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.**