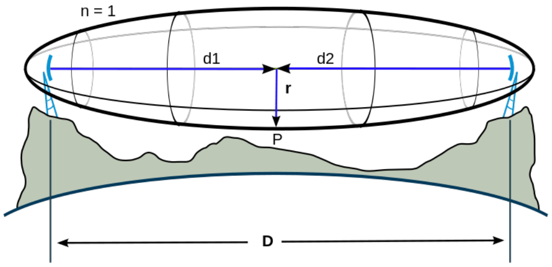
ELEX 7860 : Wireless System Design
2013 Winter Session

Fresnel Zones and Diffraction

Fresnel Zones

A Fresnel zone is the group of locations where the difference between the length of the direct path and the length of a reflected path is a multiple of a half wavelength ($\lambda/2$). Rays from odd-numbered Fresnel zones cause destructive interference (reduction in received signal level) while even-numbered ones cause constructive interference (and an increase in received signal level).

Fresnel zones are ellipsoids consisting of all points where the path length difference is $n\lambda/2$ as shown in the following diagram from Wikipedia:



For $d_1 \gg r$ and $d_2 \gg r$ the radius of the nth Fresnel zone radius at distances d_1 and d_2 can be approximated by:

$$r_n \approx \sqrt{\frac{n\lambda d_1 d_2}{d_1 + d_2}}$$

A practical implication of Fresnel zones is that for point-to-point links a simple line of sight is not sufficient. Objects should also be kept out of (at least) the first Fresnel zone to avoid causing destructive interference and signal loss. A rule of thumb for point-to-point microwave links is that a minimum of 60% of the first Fresnel zone should be kept clear of obstructions.

Exercise 1: An cellular base station antenna is mounted on a tower above a building. The line-of-sight path from the antenna to the nearest user passes near the edge of the building. The distance from the antenna to the edge is 3 metres and from the edge to the user is 100m. The system operates at a frequency of 900 MHz. By how much must the line-of-sight (LOS) path clear the edge of the building to ensure that diffraction effects are negligible?

Diffraction

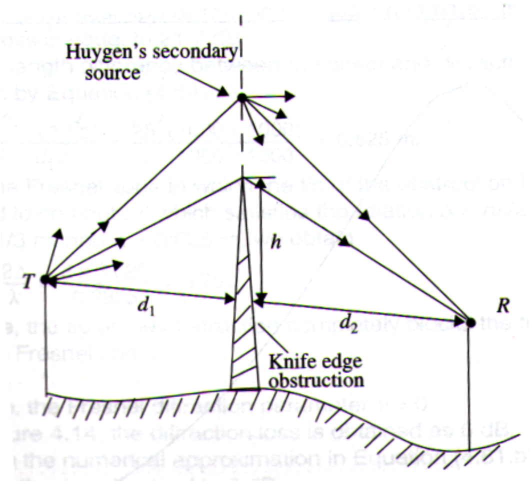
Diffraction is probably the most important non-line of sight (NLOS) propagation mechanism. Cellular systems rely on diffraction over rooftops and indoor systems rely on diffraction around wall edges and door openings for coverage.

Diffraction can be explained by the Huygens-Fresnel principle which states that each point on a wavefront acts as a point source. This means that even if the direct path between the transmitter and receiver is blocked, some energy can reach the receiver from the portions of space that are visible to both the transmitter and receiver.

Knife-Edge Diffraction Model

Analytical solutions for the diffracted signal level are difficult even for relatively simple geometries and they are impractical for real-world situations. However, the simple model of diffraction over a "knife edge" can give an idea of the magnitude of the signal level provided by diffraction.

The model is that a plane shields a portion of the wavefront that would normally propagate from the transmitter to the receiver. Diffraction takes place due to the contribution of points on the portion of the plane that is not hidden by the "knife edge". The following diagram (from Rappaport) shows the geometry:



For this geometry we can compute a parameter called the Fresnel-Kirchoff diffraction parameter, ν:

$$\nu = h\sqrt{\frac{2(d_1+d_2)}{\lambda d_1 d_2}}$$

which is related to the phase difference between the direct and reflected paths, ϕ:

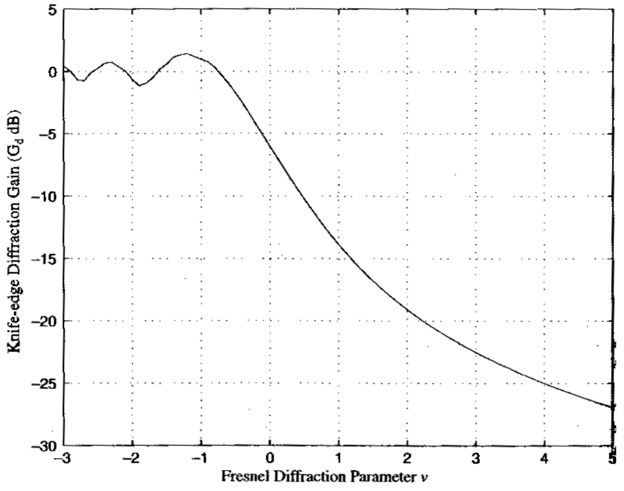
$$\phi = \frac{\pi}{2}\nu^2$$

The signal level due to knife-edge diffraction is given by integrating the contributions from the unobstructed portions of the wavefront. The solution is given in terms of the Complex Fresnel Integral, $F(\nu)$.

The actual path gain (typically, a loss) in dB is given by:

$$G_d(\mathrm{dB}) = 20\log|F(\nu)|$$

The following graph (from Rappaport) shows the value of the complex Fresnel Integral in dB:



When h is negative (knife edge below the line of sight) the loss due to diffraction is relatively low. At $h = 0$ half the signal power is lost (-6dB) as might be expected. As h increases the diffraction loss increases.

The total path loss for such a path will be given by the sum (in dB) of the loss due to diffraction and the loss given by the Friis equation for the total path length.

In practice the situation will be much more complex. Various propagation mechanisms (transmission, reflection, diffraction, scattering) will be active and the geometries of the propagation paths will be complicated. The received signal will be the (vector) sum of all of these components.

It is often difficult to predict the dominant propagation mechanism or path so for planning NLOS wireless communication systems we must rely on statistical descriptions of propagation (next lecture).