DF Propagation (Lecture 5)

Diffraction over multiple obstructions

* So far, we have considered effects of a single obstruction.
* In a special case, when the obstruction is in a form of NE,
  we have analytical solutions.
* Extension of the analysis to the multi-obstruction case is very difficult.
  Requires large amount of data for description of the obstructions.
* In practice, several empirical methods are suggested.
* Different methods have different accuracy.
  One usually finds a tradeoff between accuracy and complexity.

The most common approach - replace multiple obstructions with multiple knife edges.

Two fundamental problems that need to be addressed.

1) Problem of identifying position and length for multiple knife edges.
2) Problem of dividing an efficient and accurate algorithm for combining losses from multiple edges.

1) Identification of multiple edges.

\[ \text{Diagram showing propagation between } \text{TX and RX.} \]

Method #1

Method #2
There may be several ways of approximating beam profile with multiple KE.

There is no standard way that is universally accepted in engineering practice.

2) Algorithms for combining multiple KED losses.

Several algorithms in use today:

1) Ballington
2) Epstein-Paterson (provided in the textbook)
3) Japanese (method)
4) Deygret (method)

Ballington method

Equivalent obstruction

* Multiple obstructions are replaced by a single equivalent obstruction.
* The losses are calculated by applying KE formula to the equivalent obstruction.
* This method is simple but has a relatively low accuracy.
* The method under-predicts in two important cases:

1) The obstructions below 20° are ignored → optimistic
2) The obstructions are close to either TX or RX → equivalent obstruction is large → pessimistic prediction.
4) Epstein-Peterson method

- Considers each individual obstacle
- Total loss is sum of individual losses
- Relatively easy to implement in software
- Generally conservative

**Total loss:**

\[ L_{\text{Total}} = L_1 + L_2 + L_3 \]

- \( L_1 \) - Loss from \( O_1 \) when TX is at \( T_1 \) & RX is at \( R_1 \)
- \( L_2 \) - Loss from \( O_2 \) when TX is at \( T_2 \) & RX is at \( R_2 \)
- \( L_3 \) - Loss from \( O_3 \) when TX is at \( T_3 \) & RX is at \( R_3 \)

**Example:** Calculate aggregate KED loss for the problem shown in the figure. The heights of the obstacles are as given in the figure. The operating frequency is \( f = 800 \text{ MHz} \).

\[ x = \frac{c}{4} = \frac{2.17 \times 10^8 \text{ m/s}}{800 \times 10^6 \text{ /s}} = 0.2675 \text{ m} \]

Total loss \( \Rightarrow \) \( L_T = L_1 + L_2 + L_3 \).
2) Spherical Wavefront

- Approach: Similar to spherical waves, intensity is proportional to 2nd order inverse distance.

- Example:
  - $L = \frac{L_0 + L_1}{2}$
  - $L_0 = \frac{1500}{2} = 750 \text{ dB}$
  - $L_1 = 5 \text{ dB}$

- $L = 750 - 5 = 745 \text{ dB}$

- $d = 2 \times (r_{1} + r_{2})$

- $r_{1} = \frac{H_2 - H_1}{d_1}$

- $r_{2} = \frac{H_1 - H_2}{d_2}$

- $d_1 + d_2 = 2r_{1} + 2r_{2}$

- Solving for $r_1$ and $r_2$:
  - $r_1 = 1500 \text{ m}$
  - $r_2 = 1000 \text{ m}$

- $L = 745 \text{ dB}$

- Diagram:
  - A diagram showing antenna positions and distances is present.
Total loss: \( L_7 = \sum_i L_i \)

4) Deegard method

* Seems to perform slightly better than all other available methods
* Recursive in the way that losses are calculated
* At each recursive step
  - Find the main edge
  - Calculate losses due to main edge
  - Divide problem into two smaller ones

\[ L^{(2)} = \sum \left[ \frac{1}{2} \left( H^{(1)} \right)^2 \right] \]

1) Calculate \( L \) for each obstruction assuming that no other obstructions exist
2) The obstruction with largest \( L \) is declared as the main edge
3) The losses from the main edge are calculated as if it were alone
4) The main edge “splits” the original problem into two smaller subproblems. The process 1-3 is repeated for each of the two subproblems. The TX and RX for each subproblem are placed on the main edge.

5) Total loss is obtained by adding all the losses from main edges.

Theoretically, there may be many recursion levels. In practice, the computations are done only up to the third level.

**Effective Antenna Height**

* The pull loss depends on the height of the TX antenna relative to the terrain profile.

* Consider the two-ray model.

\[ \text{PL(dB)} = 40 \log(d) - 20 \log(h_b) - 20 \log(h_T) \]

\[ \text{antenna height dependence} \]

Most of the time, more significant are variations of the transmitter antenna. In practice, propagation models usually apply some form of the TX height correction factor.

Several methods are used:

* Absolute method
* Antenna height method (TAm)
* Relative method
* Slant method

**Antenna height correction**

\[ \Delta L = L_0 \log \left( \frac{h_{\text{max}}}{h_{\text{TX}}} \right) \]

where
(\(-\) constant dependent on model)

\(h_{tx}\) - effective height of the TX

\(h_{ref}\) - reference height

1) Absolute method

\[ h_{tx} \approx h_{tx} \]

* Always use actual transmitter height regardless of the shape of the terrain profile

2) Average height method

\[ h_{AHA} = \frac{h_{tx} + h_{ref}}{2} \]

\(h_{AHA}\) - Height Above Average Terrain

\(h_{tx}\) - inner boundary

\(h_{ref}\) - outer boundary

\(h_{AHA}\) - average height

\[ h_{AHA} = h_{AHA} = h_{tx} = h_{ref} \]

HAAT method is used frequently, especially in propagation models that are derived from Heise/Olivera model

+ an accurate / less weighted position well
+ fails to respond to rapid changes in terrain
Due to averaging, the model will fail to recognize that the mobile is strictly obstructed.

3) Relative method:

\[ \text{L}_{\text{TX}} = \begin{cases} \text{L}_{\text{TX0}} - \text{L}_{\text{RX0}}, & \text{L}_{\text{TX0}} \geq \text{L}_{\text{RX0}} \\ \text{L}_{\text{TX}}, & \text{L}_{\text{TX0}} < \text{L}_{\text{RX0}} \end{cases} \]

\[ \text{L}_{\text{RX}} = \begin{cases} \text{L}_{\text{RX0}} - \text{L}_{\text{TX0}}, & \text{L}_{\text{RX0}} \geq \text{L}_{\text{TX0}} \\ \text{L}_{\text{RX}}, & \text{L}_{\text{RX0}} < \text{L}_{\text{TX0}} \end{cases} \]

\[ \text{L}_{\text{TX0}} \] - Height of the antenna above local ground
\[ \text{L}_{\text{RX0}} \] - Height of the transmitting base above sea level
\[ \text{L}_{\text{RX0}} \] - Height of the receiver above sea level

4) Slope method:

* Specular wave is less powerful
* Approaches free space
* Extend the slope of the local terrain to the intersection with the transmitter axis
* Calculate $b_l$ as the height of the transmitter above intersection point
* If the terrain is sloping up $\Rightarrow$ considerable gain
* well suited for vertical polarization
* responds quickly to changes in local terrain
* its implementation requires accurate resolution

Example. Calculate effective height correction for scenario in the figure. Use slope method and assume $L_2 = 15$ dB/dec, $h_{ref} = 50$ m

$$b_l = 20 m$$

$$\alpha = 10^\circ$$

$$d_2 = 2a_m$$

$$300 m$$

$$\tan \theta = \frac{d_2}{d_1} = \frac{b_{lxe} - b_{lx}}{(a_1)$$

$$d_1 + d_2 = d$$

1) $d_2 = \frac{a_m}{\tan \theta} = \frac{20 m}{\tan 10^\circ} = 113.42 m$

2) $d_1 = d - d_2 = 300 - 113.42 = 186.58 m$

3) $b_{lxe} = b_{lx} + d \tan \theta = 30 m + 186.58 m \cdot \tan \left(\frac{10^\circ}{180^\circ}\right) = 62.84 m$
\[ \Delta \sigma = 15 \log \left( \frac{\text{time}}{\text{time}^+} \right) = 15 \log \left( \frac{62.84}{50} \right) = 1.49 \text{ dB}. \]

Prediction of path loss over terrain database

Terrain is represented as an array of length

![Terrain representation diagram]

Radio profile between TX & RX

* Path loss prediction is 3D problem
* In most practical applications it is modeled as 2D
  (Note: There are some methods that implement 3D path loss models)
* Transition from 3D to 2D is accomplished through radio path models
* Most propagation models predict path loss on the basis of radio path loss, some inhomogeneities limit the model accuracy
Bin Size (tens of resolution)

* There is a trade-off between model accuracy and bin size.
* Generally, using smaller bins improves model accuracy up to a certain bin size value.
* When the bin size is decreased below a certain value, the error between measurements and predictions increases.
* For small bin sizes, the cause of the error is in small scale propagation effects.

\[ \sigma^2_{\text{mm}} = \sigma^2 (\text{prediction} - \text{measurement})^2 \]

- Insufficient model accuracy
- Decrease of computational requirement \( \sim a^2 \)

![Graph showing relationship between bin size and accuracy](image)

- Optimum resolution is a function of terrain ruggedness.
- More rugged terrain requires smaller bins.

**SUMMARY**

1. Propagation in free space
2. Propagation on flat earth
3. Log Distance Path Loss model
4. Effects of terrain
   - Diffusion
   - Effective antennae height
   - Treating noise