RF propagation (Lecture 17)

Outage time in practical wireless links.

* Outage time is primarily caused by fading.
* For wireless links, the fading depends on:
  - Frequency
  - Path length
  - Humidity, temperature, and fog
  - Terrain
  - Wind
  - Rain regime in the area

Each of the factors introduces variability of the RSL at the RX.

Task: provide sufficient margin so that for the required percentage of time the RSL exceeds minimum allowed RSL.

A practical approximation of the outage time may be given as:

$$T_{out} = 0.4 C f T D^2 / 10$$

where:
- $T_{out}$ - outage time in seconds per year
- $f$ - frequency in GHz
- $D$ - distance in miles
- $T$ - temperature in $^\circ F$ (average annual)
- $C$ - climate terrain factor

The FH is defined as:

$$FH = RSL - Rx Sens$$

where:
- $RSL$ - required signal level
- $Rx Sens$ - The sensitivity of the RX
The average annual temperature and climate factors are tabulated for different parts of the country.

Example. Consider prediction of one-way reliability of a 6 GHz
microwave link located in Orlando, FL. Sites A & B are separated by
10 miles. Transmitted power is 1 W (30 dBm) and Rx Sens = -77 dBm.

Other link parameters are given as follows:

<table>
<thead>
<tr>
<th>Site</th>
<th>Site B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cable loss [dB/100 ft]</td>
<td>1.2</td>
</tr>
<tr>
<td>Cable length [ft]</td>
<td>150</td>
</tr>
<tr>
<td>Jumper / connector losses [dB]</td>
<td>3.0</td>
</tr>
<tr>
<td>Antenna gain</td>
<td>33</td>
</tr>
</tbody>
</table>

Free space path loss:

\[ L_{fs} = 9.66 + 20 \log f [GHz] + 20 \log 10 \]

\[ = 9.66 + 20 \log 6 + 20 \log 10 \]

\[ = 13.216 \text{ dB} \]

RSL calculation:

\[ P_{SL} = 30 \text{ dBm} + 33 \text{ dB} + 33 \text{ dB} - \left( 2.3 + 1.2 \frac{150}{10} + 1.2 \frac{90}{10} \right) - 132.16 \]
RSL = -45.04 dBm

Therefore, the FH may be calculated as:

\[ FH = RSL - R \times Sens = (45.04) - (-77) = 81.96 \text{ dB} \]

For Orlando, FL C = 6 & T = 70 F The outage seconds may be calculated as:

\[ T_{ip} = 0.4 \cdot 6 \cdot 6 \cdot 70 \cdot 10 = 642 \text{ seconds} \]

The reliability of the path is given as:

\[ R = 100 \left( 1 - \frac{642}{865.24.60.60} \right) = 99.99976 \% \]

The outage calculated outage does not include the effects of the rain. They are considered separately.

Atmospheric attenuation and Rain Effects

\( x \) \text{-wave signal experiences additional absorption (beyond free space) when propagating through the atmosphere}

\( x \) At lower frequencies (\( f < 8 \text{GHz} \)) these effects may be neglected

\( x \) At higher frequencies (\( f > 8 \text{GHz} \)) these losses need to be taken into account

There are two components of the atmosphere content that have high impact on wireless propagation losses. These components are \( O_2 \) and \( H_2O \). These absorption losses associated with the two are presented in the following figure.
The oxygen content of the atmosphere is fairly constant.

Attenuation due to oxygen in the frequency range up to 40 GHz is fairly small (≤ 0.1 dB/km).

Humidity of the air varies significantly and hence the absorption due to water changes as well.

- Hand out absorption curves for different humidity.
- Hand out Rain attenuation graphs.

Empirical formula between attenuation and rain rate may be given as

\[ A[dB] = a R^b \cdot \frac{D}{90+D} \]

where \( D \) is distance expressed in km.

\( a, b \) are coefficients but depend on frequency range.

\( R \) is rain rate in mm/hour.

[Hand out the values for \( a, b \).]
Example. Calculate the attenuation due to the rain falling at
the rate of 100 mm/hour if the operating frequency is
12 GHz. Assume vertical polarization and the length of the ground
loop at 10 km.

for 12 GHz: $a = 1.68 \times 10^{-2}$
$b = 1.2$

$\Delta [\text{dB}] = 1.68 \times 10^{-2} \times (100)^{1.2} \times \frac{90}{90^2 + 4 \times 10}$

$= 29.21 \text{ dB} \Rightarrow \text{relatively large}$

Rain attenuation causes significant attenuation for frequencies
above 10 GHz.

Example. Consider a microwave link operating at the frequency of
20 GHz. Estimate the attenuation of the path loss when the
humidity of the air varies from 5 g/m$^2$ to 30 g/m$^2$. The
distance between sites is 10 miles.

$\text{FSPL} = 96.6 + 20 \log(20) + 20 \log(10) = 142.62 \text{ dB}$

For humidity of 5 g/m$^2$ the loss is given as $L = 0.1 \text{ dB/km}$

$L = 0.1 \text{ dB/km} \times 10 \times 1.609 = 16.1 \text{ dB}$

For humidity of 30 g/m$^2$ the loss is given as $L = 0.8 \text{ dB/km}$

$L = 0.8 \text{ dB/km} \times 10 \times 1.609 = 12.87 \text{ dB}$

$\text{Loss (5 g/m}^2) = 144.23 \text{ dB} \Rightarrow \text{Difference} = 126 \text{ dB}$

$\text{Loss (30 g/m}^2) = 155.49 \text{ dB}$
Rain attenuation rates

- Rain attenuation for frequencies below 85 GHz is negligible.
- Above 10 GHz, rain attenuation becomes significant.
- The attenuation is proportional to the rain intensity over rate.

When designing the link, one needs to have an idea on the rain that can be expected in a given region. USA is divided into several rain regions B-E. Locations within the same region have approximately the same rain rates.

[Handout: rain regions map and corresponding table derived by Crane]

Example. Consider FL - region E
2%/of the time (620.720 sec/year) the intensity of the rain exceeds 2in./hour

Example. Consider a design of the microwave link in Orlando, FL. Estimate the maximum separation between TX & RX given the link budget data provided in the figure. Assume R = 99.99% and humidity 20% /h. Operating frequency is 28.6 GHz.

\[
\begin{align*}
\text{TX} & & \text{A} & & \text{RX} \\
-30\text{dB} & & -3\text{dB} & & \\
-3\text{dB} & & \\
\text{RF} & & \\
\text{BW} = 1.6\text{ MHz} & & \\
F = 4\text{ dB} & & \\
(S/N)_{eq} = 15\text{ dB} & & (BER = 10^{-12})
\end{align*}
\]
1. \[ R_x S_{e n s} = 10 \log \left( 4 \cdot 10^{-18} \text{mW/Hz} \cdot 1.6 \cdot 10^6 \text{Hz} \right) + 4 \text{dB} + 15 \text{dB} \]
   \[ = 9.244 \text{dBm} \]

2. \[ R_{SLA} = 92.94 \text{dBm} + 3 \text{dB} - 20 \text{dB} = 73.94 \text{dBm} \]

3. \[ E_{LP} = 40 \text{dBm} - 3 \text{dB} + 80 \text{dB} = 67 \text{dBm} \]

4. Estimate the total allowed outage seconds,
   \[ R = 100 \left( 1 - \frac{T_a}{365 \cdot 24 \cdot 60 \cdot 60} \right) \Rightarrow \]
   \[ T_a = \left( 1 - \frac{49.99}{100} \right) \cdot 365 \cdot 24 \cdot 60 \cdot 60 = 2152 \text{ sec/yr} \]

5. Path loss without rain
   \[ PL = 96.6 + 20\log f (614) + 20\log D + D \alpha \]
   \[ \alpha (28614) = 0.5 \text{dB/km} = 0.8045 \text{dB/mile} \text{ (atmospheric absorption)} \]
   \[ PL = 96.6 + 20\log (28614) + 20\log (D) + 0.8045D \]
   \[ = 125.54 + 20\log D + 0.8045D \]

6. \[ FH = ERP - R_{SLA} - PL = 67 - (119.49) - 125.54 - 20\log D - 0.8045D \]
   \[ = 1.4 - 20\log D - 0.8045D \]

Outage due to TX/RX separation

\[ T_{up} = 0.4 \cdot c \cdot F \cdot T \cdot D^2 \cdot \text{Alcy} \left[ \frac{1}{10} (61.4 - 20\log D - 0.8045D) \right] \]
   \[ = 0.4 \cdot 6.28 \cdot 70 \cdot D^3 \cdot \text{Alcy} \left[ \frac{1}{10} (61.4 - 20\log D - 0.8045D) \right] \]
   \[ = 4704 D^3 \cdot \text{Alcy} \left[ \frac{1}{10} (61.4 - 20\log D - 0.8045D) \right] = 0.001(D) \]
The outage due to rain

\[ T_{or} = F_2(R_r) \] where \( R_r \) is rain rate and \( F_2 \) is specified by Crane's table

\[ R_r = \left( \frac{90 + 4D}{90 + 4D \cdot 1.609} \right)^{1/6} \quad a = 0.167 \]

\[ b = 1 \]

Sustainable rain rate

\[ R_r = \left( \frac{90 + 6.43D}{24.18D} \right) = \frac{90 + 6.43D}{24.18D} (61.4 - 20 \log D - 0.8047D) \]

\[ T_{tot} = T_1(D) + T_2(D) \]

<table>
<thead>
<tr>
<th>D</th>
<th>Tyip</th>
<th>( R_r )</th>
<th>Train</th>
<th>Trar</th>
<th>Ttot</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>240</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>112</td>
<td>2.03</td>
<td>1968</td>
<td>1968</td>
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<tr>
<td>3</td>
<td>53</td>
<td>41</td>
<td>8000</td>
<td>8002</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>15999</td>
<td>28</td>
<td>21</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>158.7</td>
<td>924</td>
<td></td>
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</tr>
<tr>
<td>6</td>
<td>2947.1</td>
<td>18</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>6723.9</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\[ \text{The distance is two miles} \]

Exercise: Repeat the design for the Texas area.