RF propagation (Lecture 19)

Outage time in patch antenna links

* Outage time is primarily caused by fading.
* For microwave links, the fading depends on
  - frequency
  - path length
  - humidity, temperature & fry
  - terrain
  - wind
  - rain regime in the area

* Each of the above factors influences variability of the ERL at the RX.
* The task of the engineer is to provide sufficient margin so that
  for a large percentage of time, received ERL exceeds required ERL.

A practical approximation of the outage time is given by

\[ T_{op} = 0.4 \cdot f \cdot T \cdot D^2 \cdot 10^{-FM/10} \]

where
- \( T_{op} \) - outage time in seconds per year
- \( f \) - frequency in GHz
D - distance in miles
T - temperature in Fahrenheit (average annual)
c - climate factor

The FM is defined as:

\[ FM = ESL - RxSens \]

where

- RxSens - the sensitivity of the receiver
- ESL - received signal level

* Average annual temperature and climate factors are tabulated for different parts of the country.

* Hand out two figures - one for climate factors / one for average temperature.

Example: Consider predicting the one-way reliability of a 6 GHz U-Wire link located in Orlando, FL. Sites A & B are separated by 10 miles. Transmission power is 1W (30 dBm) and RxSens = -77 dBm.

Other link parameters:

<table>
<thead>
<tr>
<th>Site A</th>
<th>Site B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cable loss [dB/100']</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

\[ \text{L}_{fs} = 9.66 + 20 \log f + [G_{tx} + G_{rx}] \log 10 = \]

\[ = 9.66 + 20 \log 6 + 20 \log 10 = 132.16 \text{ dB} \]

Received Signal level

\[ \text{RSL} = 50 \text{ dBu} + 82 + 36 - (2.3 + 1.2 \frac{150}{100} + 12 \frac{90}{100}) = 132.16 \]

\[ = -45.04 \text{ dBu} \]

Therefore

\[ FH = \text{RSL} - \text{Rx Sens} = (-45.04) - (-77) = 31.96 \text{ dB} \]

For Orlando, FL \( c = 6 \) and \( T = 70 \text{ F} \). The outage second can be calculated as

\[ T_{yp} = 0.4 \cdot 6.6 \cdot 70 \cdot 10^{3} \cdot 10^{-2146/10} \]

\[ = 642 \text{ seconds} \]

The reliability of the pole is given by

\[ R = 100 \left( 1 - \frac{642}{365 \cdot 24 \cdot 60 \cdot 60} \right) = 99.9979 \% \]

The outage calculated thus far did not include the outage due to the rain.
Atmospheric Attenuation and Rain Effects

*M-u-wave signals experience additional absorption when propagating through the atmosphere.

At low frequencies ($f<8.5\,\text{GHz}$), these effects can be neglected.

At higher frequency ($f>10\,\text{GHz}$), these losses must be taken into account.

There are two components of the atmosphere that affect the loss of the $\mu$-wave. They are $H_2O$ and $O_2$. The absorption losses of water and oxygen are given in the following figure:

![Absorption Peaks](image)

- The oxygen content of the atmosphere is fairly constant.
- Attenuation due to oxygen in the frequency range up to 40 GHz is fairly small ($<0.1\,\text{dB/km}$).
- Humidity of the air changes and therefore water absorption changes as well.

*(Hand out atmospheric absorption curves for different humidity)*
\textbf{(Hand out rain attenuation graph) - 54}

Empirical relation between rain attenuation and rain rate can be expressed by

\[ A_{\text{dB}} = a \cdot R^b \cdot D \cdot \frac{90}{90 + 40} \]

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

\( a, b \) are coefficients that depend on frequency range. As seen, the coefficients depend on the polarization. \( (\text{Hand out the values for } a \text{ & } b) \)

\textbf{Example.} Calculate the attenuation due to the rain falling at the rate of 100mm/hr if the opening frequency is 12 GHz. Assume circular polarization. The length of the microwave link is 10 km.

For 12 GHz:

\[ a = 1.68 \times 10^{-2} \]

\[ b = 1.2 \]

\[ A_{\text{dB}} = 1.68 \times 10^{-2} \cdot (100)^{1.2} \cdot 10 \cdot \frac{90}{90 + 40} = \]

\[ = 29.21 \text{ dB} \]

Rain attenuation causes significant path loss for frequencies above 10 GHz.
Example: Consider the y-intercept of the graph of accuracy of 20GHz.

\[ L = 0.8 \text{dB/km} \times 10 \times 1.669 = 12.87 \text{ dB} \]

For \( h = 6 \text{dB} \), the loss is given as \( L = 1.61 \text{dB} \).

For \( h = 61 \text{dB} \), the loss is given as \( L = 1.61 \text{dB} \).

For \( h = 0.8 \text{dB} + 20 \log(120 + 20 \log(10)) = 142.62 \text{dB} \)

\[ P_{SI} = 966 + 20 \log(120 + 20 \log(10)) = 142.62 \text{dB} \]
When designing link we need to have an idea of the rain that can be expected in a given region. USA is divided into several rain regions. A – E. Locations within the same rain region has approximately the same rain statistics. Handout Rain Region map and corresponding table were derived by Crete (Crete rain model)

*Example: Consider Florida region – E*

- 99% of the time (630720 sec) the intensity of the rain exceeds 2 w/m².

*Example: Consider a design of the micro link in Orlando FL.*

*Estimate the maximum separation between TX and RX given the link budget data provided in the figure assuming P = 99.99%.*

Assume humidity at 30%n/m³.

\[ \text{TX} \quad \text{30dB} \quad \text{3dB} \quad \text{RX} \quad -3dB \quad F = 1.6 \text{MHz} \]

\[ T = 286 \text{Hz} \quad F = 4 \text{dB} \quad S/N_{RX} \quad \text{BER}(10^{-4}) = 1.5 \text{dB} \]

1° Rx Sensitivity = \[ 10 \log \left( \frac{4 \cdot 10^{-18} \text{W/m}^2 \cdot 1.6 \cdot 10^6 \text{Hz}}{\text{Hz}} \right) + F \text{ [dB]} + S/N \text{ [dB]} \]

\[ = -92.94 \text{ dBm} \]

2° \[ \text{RS}L_{A} = -92.94 \text{ dBm} + 3 \text{dB} - 30 \text{ dB} = -119.94 \text{ dBm} \]

3° \[ \text{ERP} = 40 \text{dBm} - 3 \text{dB} + 30 \text{dB} = 67 \text{dBm} \]
4. Estimate total outage seconds

\[ R = 100 \left(1 - \frac{r}{365.24.60.60}\right) \]

\[ T_a = (1 - \frac{0.99}{100}) \cdot 365.24.60.60 = 3153,500 \text{ sec/year} \]

5. Paid loss without rain

\[ PL = 96.6 + 20 \log P + (6.1) + 20 \log D + D \cdot 0.8 = 96.6 + 20 \log P + (6.1) + 20 \log D + 0.8 D \]

\[ = 125.5 + 20 \log D + 0.8 D \]

\[ FH = ERP - PSL - PL = 67 - (-19.9) - PL \]

\[ = 61.4 - 20 \log D - 0.845 D \]

Outage due to TX/RX separation

\[ T_{y,p} = 0.4 \cdot 0.8 \cdot 0.7 \cdot D^2 A_0 [1 - \left(\frac{1}{10} (6.4 - 20 \log D - 0.845 D)\right) = \]

\[ = 0.4 \cdot 0.8 \cdot 0.7 \cdot D^2 A_0 \left(\frac{1}{10} (6.4 - 20 \log D - 0.845 D)\right) = \]

\[ = 0.704 \cdot D^2 A_0 \left(\frac{1}{10} (6.4 - 20 \log D - 0.845 D)\right) \]
outage Due to the rain.

\[ T_{or} = f_2 (R_r) \text{, where } R_r \text{ is the rain rate and } f_2 \text{ is specified by} \]

Croni's table:

\[ R_r = \frac{\left( 90 + 40 \cdot 1.609 \right)^{1/b}}{90a \cdot D \cdot 1.609} \quad a = 0.167 \quad b = 1 \]

just inside rain rate

\[ R_r = \frac{90 + 6.43 \cdot D}{24.18 D} \quad FM = \frac{90 + 6.43D}{24.18D} \quad (6.43 - 26.15D - 0.8045D) \]

\[ T_{tot} = f_1 (D) + f_2 (D) \]

<table>
<thead>
<tr>
<th>D</th>
<th>Ty, P</th>
<th>( R_r )</th>
<th>( T_{min} )</th>
<th>( T_{tot} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>10</td>
<td>240</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>0.2</td>
<td>172</td>
<td>1968</td>
<td>1968</td>
</tr>
<tr>
<td>3</td>
<td>2.03</td>
<td>72</td>
<td>8000</td>
<td>8002</td>
</tr>
<tr>
<td>4</td>
<td>11.5</td>
<td>53</td>
<td>15749</td>
<td>1777</td>
</tr>
<tr>
<td>5</td>
<td>47.34</td>
<td>41</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>158.7</td>
<td>33</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>462.15</td>
<td>28</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>1213.9</td>
<td>24</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>2940.1</td>
<td>21</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>6722.9</td>
<td>18</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\[ \text{The distance is 2 miles.} \]

As seen the distance is

limited by the rain attenuation

As an exercise a repeat

problem for

HOMEWORK: Repeat the design for

state of texas
Link improvement measures

1) Monitored Hot Standby.

- Data in
  - TXA
  - TXB
  - RXB
  - RXA
  - Spb1

Hot standby reduces the equipment failure based downtime.

2) Space diversity

- Sub in
  - TXA
  - TXB

Diversity d = 3 km.

\[ T_{sp} = 7 \cdot 10^{-5} \text{ if } \delta^2 \leq 10^{84/10} \]
where

- $D$ = difference between main or diversity signal
- $f$ = Frequency in GHz
- $s$ = Separation in feet
- $FH$ [dB] = fade margin in dB
- $D$ = distance in miles

The outage time for system with SD:

$$T_{y,SD} = \frac{T_y}{T_{SD}}$$

Example. Nominal reliability of a non-diversity link is 99.99343%. The link is between two separated by 17 miles at 10.6 GHz. Fade margin in 84 dB and antenna spacing 30 ft. If the main and diversity signals are equal, calculate the reliability of diversity system.

$$T_{UP} = \frac{100 - 99.99343}{100} \cdot 365 \cdot 24 \cdot 58.60 = 2071.98$$

$$T_{SD} = \frac{7 \cdot 10^{-5} \cdot 10.6 \cdot 12 \cdot 10^2 \cdot 10^{84/10}}{17} = 9.867$$

$$T_{y,SD} = \frac{2071.98}{9.867} = 209.98$$

$$R = 100\left(1 - \frac{20.98}{365 \cdot 24 \cdot 60 \cdot 60}\right) = 99.999993\%$$