Submission Title: Propagation Aspects of Terahertz Outdoor Fixed Wireless Links

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Abstract: Based on previous presented Link Budget Analysis for Terahertz Fixed Wireless Links (15-12-0582) some additional link aspects for Terahertz Fixed Wireless Links are further discussed, addressing the influence of fog and rain and impairments of pole twist and sway effects for high gain antenna links.

Purpose: Informing IG THz on propagation aspects of Terahertz Outdoor Fixed Wireless Links.

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THz Outdoor fixed wireless link aspects

• Considerations on fog and rain conditions
  – Combined fog/rain scenario assessment
  – Scintillation impairments

• High gain antenna link robustness
  – Influence of sway/twist of antenna poles
Outdoor Fixed Wireless Link Scenarios

THz Link can provide a High Capacity Bridge for Backbone and Access Networks

Example:
Wireless backhaul extension for cellular Network
Attenuation in THz transmission windows

Influence of Fog or Rain

THz Transmission Windows

<table>
<thead>
<tr>
<th>Window</th>
<th>Bandwidth [GHz]</th>
<th>Center Frequency [GHz]</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>76</td>
<td>338</td>
</tr>
<tr>
<td>II</td>
<td>58</td>
<td>414</td>
</tr>
<tr>
<td>III</td>
<td>62</td>
<td>484</td>
</tr>
<tr>
<td>IV</td>
<td>85</td>
<td>669</td>
</tr>
<tr>
<td>V</td>
<td>94</td>
<td>855</td>
</tr>
</tbody>
</table>

Attenuation as a function of frequency for a clear atmosphere at sea level (blue), fog with a range of vision of 50 m (red) and Rain with 50 mm/h (black).

The shaded regions describe the ranges above 300GHz in which, even for the worst case, the attenuation is below 100 dB/km.


Attenuation in THz transmission windows

Influence of Fog/Rain: Additive Scenario

- Both (fog, rain, and gas)
- 50 mm/h (rain and gas)
- 50 m vision (fog and gas)
- Clear atmosphere at sea level

Shaded regions: Attenuation < 100dB/km
For worst case conditions


“Am atmospheric model, submillimeter array,” Tech. Memo #152
Assessment of rain/fog scenarios

• Assumption: Wireless link may only be partly impaired by rain or fog, respectively.
• Depicted results for rain (50mm/h) + fog (vision range 50m) only a „worst-worst“ case, which will not occur in real-world deployments.
• Heavy rain (50 mm/h) assumed to be worst case condition. Therefore, already presented values in document 15-12-0582 are still valid.
• Contrary to IR links the scintillation impairments are not relevant for THz links, as published by recent research work¹.

Fixed Wireless Links
High Gain Antenna Aspects

- Depending on the frequency, for a gain of 70 dBi, the diameter of the parabolic antenna is between 0.3 (1 THZ) and 1 m (300 GHz), assuming an ideal antenna.
- Tolerable angle for fluctuations of pole is reduced to a range of 1° and below.
Fixed Wireless Links
High Gain Antenna Aspects

Antenna dimension and radiated area as function of antenna gain for the first THz-window (center frequency 337 GHz)

Antenna Gain [dBi] vs. Antenna Diameter [m] and Diameter of Radiated Area [m]

Link distance of 1 km
Fixed Wireless Links
High Gain Antenna Aspects

1) Link impairments by pole sway (f = 337 GHz):

- Pole sway impairment: 
- Loss of connectivity: $\phi_{\text{max}} = 0.13^\circ$
  - 70 dBi antenna
  - 1km link distance

Loss of connectivity $\phi_{\text{max}} = 2 \times b / d$

<table>
<thead>
<tr>
<th>Antenna Gain [dBi]</th>
<th>Tolerable Angle [°]</th>
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<tbody>
<tr>
<td>20</td>
<td>40.62</td>
</tr>
<tr>
<td>40</td>
<td>12.84</td>
</tr>
<tr>
<td>60</td>
<td>4.06</td>
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<td>80</td>
<td>1.28</td>
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<tr>
<td>10</td>
<td>0.13</td>
</tr>
<tr>
<td>1</td>
<td>0.04</td>
</tr>
</tbody>
</table>
Fixed Wireless Links
High Gain Antenna Aspects

2) Link impairments by pole twist (f = 337 GHz):

- Pole twist impairment:
- Loss of connectivity: $\phi_{\text{max}} = 0.13^\circ$
  - 70 dBi antenna
  - 1km link distance

$d = 1 \text{ km}$

\[ \phi_{\text{max}} = 2 \times \frac{b}{d} \]

70 dBi

$b = 1.12 \text{ m}$

Tolerable Angle [°]

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$\phi_{\text{max}} = 0.13^\circ$
Conclusion

• Although both rain and fog attenuation can occur within a fixed wireless link, worst case is assumed to be under heavy rain conditions.

• Even for the worst case scenario (rain rate of 50 mm/h) THz-wireless links offer extremely high data rates over a link of 1km.

• Recent research results conclude that for fog there is no additional impairment by scintillation effects in comparison to IR links.

• Required high gain antenna solutions up to 80 dBi for outdoor fixed wireless links result in loss of connectivity for angles below 0.04° for antenna pole sway and twist.

• Requirement for active control mechanism to compensate for pole sway/twist depends on the grade of sway/twist impairments, given by antenna installation (type of pole, building).

• Outdoor fixed wireless link technology has to support different features in comparison to indoor based technology to cope with link critical aspects: Atmospheric attenuation and active steering mechanisms for high directive links.