**IEEE P802.15**

**Wireless Personal Area Networks**

|  |  |  |
| --- | --- | --- |
| Project | IEEE P802.15 Working Group for Wireless Personal Area Networks (WPANs) | |
| Title | Additional Text for the Section on Backhaul/Fronthaul of the TG3d CMD | |
| Date Submitted | July 2015 | |
| Source | Thomas Kürner | E-mail: kuerner@ifn.ing.tu-bs.de |
| Re: |  | |
| Abstract |  | |
| Purpose | Supporting document for the development of the amendment 3d of IEEE 802.15.3 | |
| Notice | This document has been prepared to assist the IEEE P802.15. It is offered as a basis for discussion and is not binding on the contributing individual(s) or organization(s). The material in this document is subject to change in form and content after further study. The contributor(s) reserve(s) the right to add, amend or withdraw material contained herein. | |
| Release | The contributor acknowledges and accepts that this contribution becomes the property of IEEE and may be made publicly available by P802.15. | |

# Backhaul/Fronthaul

## Introductory Remarks

The mitigation of the high path loss at 300 GHz requires high gain antennas in the order of 40 dB at both sides of the link for a transmission distance of several hundred meters. This requires a LOS connection. In addition such high gain antennas are spatial filters, that supress multi path propagation at large. A path loss model to evaluate the link budget is sufficient as a first approximation.

## Path loss model

The relevant propagation mechanism in such an environment, which are contributing to increase the free space loss are described in [6.1]:

* Atmospheric gas attenuation
* Cloud and fog attenuation
* Rain attenuation

For terrestrial links it can be assumed that the link is operated below the height of clouds. The situation that a link penerates clouds may happen for example in some alpine regions with one transceiver at a high mountain, but it is unlikely, that ultra-high capacity links are required there. Therefore the attenuation by clouds may be less relevant. However, the influence of fog may be interest also for dense urban area.

### Calculation of the Overall Path Loss

The overall path loss at a distance d and a carrier frequency f can be modelled as:

(1)



where



### Specific Attenuation by Atmospheric Gases according to ITU-R P.676-10

Two methods are decribed in ITU-R P.676-10 [6.2]:

* A more detailed line –by-line calculation of gaseous attenuation
* A simplified method, based on curve-fitting of the line-by-line calculation agrees with the more accurate calculations to within an average of about ±10% at frequencies removed from the centres of major absorption lines. The absolute difference between the results from these algorithms and the line-by-line calculation is generally less than 0.1 dB/km and reaches a maximum of 0.7 dB/km near 60 GHz.

In the following the specific attenuation due to dry air and water vapour, is estimated using the simplified algorithms, valid for the frequency range 120 to 350 GHz:

The specific attenuation o due to dry air is calculated using the following equations:



(2)



(3)



(4)

Where *f*  frequency (GHz)

*rp* = *ptot*/1013, where *ptot* represents total air pressure

*rt* = 288/(273 + *t*)

*p*  pressure (hPa)

t  temperature (°C)

The specific attenuation w due to water vapour is calculated using the following equations:



(5)

(6)



(7)



(8)

where ρ is the water-vapour density (g/m3).

Exemplary result for the specific attenuation from 1 to 350 GHz at sea-level for dry air (p=1013 hPa, t=15°C) and water vapour with a density of =7.5 g/m3 (from [6.2])



Figure 7: Exemplary results for specific attenution due to dry air and water vapour

### Calculation Specific Attenuation R due to Rain according to ITU-R P. 838-3

The specific rain attenuation R is calculated according to according to ITU-R P. 838-3 [6.3]:

(9)



where:

*R* rain rate in mm/h

*k*  either *kH* or *kV* for horizontal and vertical polarization, respectively

α  either α*H* orα*V*. for horizontal and vertical polarization, respectively

Values for k and a for the frequencies 200, 300 and 400 GHz and horizontal/vertical polarization are given in Table 6.1

Table 6.1: Values for k and  in the frequency range 200-400 GHz

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Frequency (GHz) | *kh* | α*H* | *kV* | α*V* |
| 200 | 1.6378 | 0.6382 | 1.6443 | 0.6343 |
| 300 | 1.6286 | 0.6296 | 1.6286 | 0.6262 |
| 400 | 1.5860 | 0.6262 | 1.5820 | 0.6256 |

For linear and circular polarization, and for all path geometries, the coefficients in equation (9) can be calculated from the values given the previous table using the following equations



(10)

(11)



where  is the path elevation angle and  is the polarization tilt angle relative to the horizontal ( = 45° for circular polarization).

Typical rain rates for various rain intensities, which are required in equation (9) are listed in table 6.2.

Table 6.2: Typical rain rates [6.1, 6.4]

|  |  |  |
| --- | --- | --- |
| Type of Precipitation | Range of R (mm/h) | Intensity |
| Drizzle | R < 0,1 | Light |
| Drizzle | 0,1 < R < 0,5 | Moderate |
| Drizzle | R > 0,5 | Heavy |
| Rain | R < 2,5 | Light |
| Rain | 2,5 < R < 10 | Moderate |

Exemplary results for specific rain attenuation R at the carrier frequencies 200, 300 and 400 GHz are listed in Table 6.3

Table 6.3: Exemplary results for specific rain attenuation R

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| f/GHz | Horizontal Polarisation | | | Horizontal Polarisation | | |
| R/ mm/h | | | R/mm/h | | |
| 0,1 | 5 | 50 | 0,1 | 5 | 50 |
| 200 | 0,38 | 4,57 | 19,89 | 0,38 | 4,56 | 19,66 |
| 300 | 0,38 | 4,49 | 19,12 | 0,39 | 4,46 | 18,87 |
| 400 | 0,38 | 4,35 | 18,37 | 0,37 | 4,33 | 18,28 |

### Calculation of Attenuation due to Clouds and Fog

A calculation method is described in ITU-R 840-6 [6.5]:

The specific attenuation within a cloud or fog can be written as:

                dB/km (12)

where:

γ*c* : specific attenuation (dB/km) within the cloud

*Kl* : specific attenuation coefficient ((dB/km)/(g/m3))

*M* : liquid water density in the cloud or fog (g/m3).

At frequencies of the order of 100 GHz and above, attenuation due to fog may be significant. Typical water content for different fog types are listed in table 6.5.

Table 6.4: Typical liquid water density of fog types [6.5]

|  |  |
| --- | --- |
| Fog type | Typical liquid water density in g/cm3 |
| medium fog (visibility of the order of 300 m) | 0.05 |
| thick fog (visibility of the order of 50 m) | 0.5 |

A mathematical model based on Rayleigh scattering, which uses a double-Debye model for the dielectric permittivity ε ( *f*) of water, can be used to calculate the value of *Kl* for frequencies up to 1 000 GHz:

               (dB/km)/(g/m3) (13)

where *f* is the frequency (GHz), and:

 (14)

The complex dielectric permittivity of water is given by:

 (4)

 (15)

where:

ε0 = 77.66 + 103.3 (θ – 1) (16)

ε1 = 0.0671 (17)

ε2 = 3.52 (18)

θ = 300 / *T* (19)

with *T* the temperature (K).

The principal and secondary relaxation frequencies are:

*fp* = 20.20 – 146 (θ – 1) + 316 (θ – 1)2                GHz (20)

*fs* = 39.8*fp*                GHz (21)

In [6.6] some values for the average liquid water content of clouds are given, see table 6.5

Table 6.5: Liquid water content of cloud types [6.6]

|  |  |
| --- | --- |
| Cloud type | Average water content in g/cm3 |
| large cumulus | 2.5 |
| fair weather cumulus | 0.5 |
| Stratocumulus | 0.2 |
| Stratus | 0.2-0.3 |
| Altostratus | 0.2 |

## Antenna gain/pattern

## Scenario Definitions

### Xxx1

#### Angular Dispersion

#### Temporal Dispersion

#### Other

### Xxx2

#### Angular Dispersion

#### Temporal Dispersion

#### Other

### Xxx3

#### Angular Dispersion

#### Temporal Dispersion

#### Other

# References

[6.1] G. A. Siles, J. M. Riera, P. Garcia-del-Pino, Atmospheric Attenuation in Wireless Communication Systems at Millimeter and THz Frequencies, IEEE Antennas and Propagation Magazine, Vol. 57, No. 1, February 2015, pp. 48-59

[6.2] Rec. ITU-R P.676-10, Attenuation by atmospheric gases, 2013

[6.3]Rec. ITU-R P.838-3, Specific attenuation for rain for use in prediction methods, 2005

[6.4] Guide to Meteorological Instruments and Methods of Observation, World Meteorological Organization (WMO), Geneva, Switzerland, 2008.

[6.5] Rec. ITU-R P.840-6, Attenuation due to clouds and fog, 2013

[6.6] H. J. aufm Kampe, Visibility and Liquid Water Content in the free Atmosphere, Journal of Meteorology, Vol. 7, p. 54-57, February 1950