Radio link hop design above 17 GHz

by J Henriksson
NOKIA Research Center
Helsinki, FINLAND

Contents

- Introduction
- Frequency bands
- Transmission quality
- Propagation phenomena
- Antenna heights
- Calculation of transmission quality
- Interference

Introduction

- Most of the design techniques similar to links in lower bands (below 10 GHz)
- New aspects above 17 GHz
  - Rain
  - Attenuation due to atmospheric gases
  - Importance of ***availability***
- Literature available
  - RECOMMENDATION ITU-R P.530-8: PROPAGATION DATA AND PREDICTION METHODS REQUIRED FOR THE DESIGN OF TERRESTRIAL LINE-OF-SIGHT SYSTEMS
  - RECOMMENDATION ITU-R P.838-1: SPECIFIC ATTENUATION MODEL FOR RAIN FOR USE IN PREDICTION METHODS
  - RECOMMENDATION ITU-R P.837-2: CHARACTERISTICS OF PRECIPITATION FOR PROPAGATION MODELLING
  - e.g. J.Henriksson: *Route Design for Radio Links above 17 GHz*

Frequency bands

Atmospheric attenuation and rain attenuation depend on frequency

- **18 GHz** (17.7-19.7 GHz)
  - rain and multipath
  - d >~ 20 km (in Scandinavia)
  - γ_{tot} about 0.1 dB/km
  - γ_{rain} about 1 dB/km @ 20 mm/h
  - antennas about 60-180 cm
  - vertical and horizontal polarizations used

Frequency bands (cont)

- **23 GHz** (21.2-23.6GHz)
  - rain (and multipath)
  - d <~ 20 km (in Scandinavia)
  - γ_{tot} about 0.2 dB/km
  - γ_{rain} about 2 dB/km @ 20 mm/h
  - antennas about 30-120 cm
  - vertical and horizontal polarizations used

Frequency bands (cont)

- **27 GHz** (25.25-27.5 GHz),(27.5-29.5 GHz)
  - rain
  - d <~ 15 km (in Scandinavia)
  - γ_{tot} about 0.1 dB/km
  - γ_{rain} about 3 dB/km @ 20 mm/h
  - antennas about 30-60 cm
  - vertical and horizontal polarizations used

Frequency bands (cont)

- **38 GHz** (37.0-39.5 GHz)
  - rain
  - d <~ 10 km (in Scandinavia) but sometimes 15 km
  - γ_{tot} about 0.12 dB/km
  - γ_{rain} about 5 dB/km @ 20 mm/h
  - antennas about 30 cm
  - only vertical polarization used

Frequency bands (cont)

- **55 GHz** (54.25-57.2 GHz)
  - rain
  - d a couple of kilometers
  - γ_{tot} about 5 dB/km
  - γ_{rain} about 7 dB/km @ 20 mm/h
  - antennas about 15 cm
  - only vertical polarization used

Frequency bands (cont)

- **58 GHz** (57.2-58.2 GHz)
  (Unregulated use, lots of channels, interference is not problem)
  - rain
  - d less than a couple of kilometers (even <1 km)
  - γ_{tot} about 12 dB/km
  - γ_{rain} about 7 dB/km @ 20 mm/h
  - antennas about 15 cm
  - only vertical polarization used

Frequency bands(cont)

- There are new bands under consideration
- Both below 60 GHz and above 60 GHz

Transmission quality
Public networks

- National administrations decide
- *Availability* often the most important
- in most cases local grade (subscriber line) or medium grade (junction lines)

Error performance

- outages shorter than 10 s
- multipath decisive below about 23 GHz (depends on climate)
- worst month calculations

Transmission quality
Public networks (cont)

Availability

- outages longer than 10 s
- rain,(multipath, k-fading), faults, human errors
- about 1/3-2/3 can be allocated to propagation
- calculations over the whole year (or more)
- NOTE: both transmission directions

Transmission quality
Dedicated networks

- In principle, transmission quality can be freely chosen
- The objectives for public networks (ITU-R) are a good starting point

Examples of quality
(unavailability)

Medium grade (class 3)

- ITU: HRDS(50 km) unavailability 0.05 %
- assume 8 hops @ 5 km between switching centers

  ⇒ 40 km route
- whole objective divided linearly

  ⇒ 0.00625 % per hop for this route
- One may allocate, e.g., half to propagation

  ⇒ 0.0031 % per hop

Examples of quality ...(cont)

Local grade

- ITU-R: 0.01 % ...1 %
- In Finland: for subscriber line - 0.06 % due to propagation

Propagation phenomena

- k-fading
  - short hops ⇒ not important
  - enough clearance is cheap to achieve
- Multipath fading
  - below 23 GHz, depending on climate
  - calculations as below 10 GHz
  - nonselective at least up to about 35 Mb/s
  - hops are short ⇒ nonselective fading may apply for much higher bit rates
  - new calculation methods under study

Attenuation due to atmospheric gases

- For oxygen attenuation below 57 GHz:

$$\gamma_o = \left[\frac{7.27\ r_t}{f^2 + 0.351\ r_p^2\ r_t^2} + \frac{7.5}{(f - 57)^2 + 2.44\ r_p^2\ r_t^5} \right] f^2\ r_p^2\ r_t^2 \times 10^{-3}$$

- For oxygen attenuation between 57 GHz and 63 GHz:

$$\gamma_o = \frac{(f - 60)(f - 63)}{18}\ \gamma_o(57) - 1.66\ r_p^2\ r_t^{8.5} (f - 57)(f - 63) + \frac{(f - 57)(f - 60)}{18}\ \gamma_o(63)$$

- For oxygen attenuation between 63 GHz and 350 GHz:

$$\gamma_o = \left[2 \times 10^{-4}\ r_t^{1.5} \left(1 - 1.2 \times 10^{-5}\ f^{1.5}\right) + \frac{4}{(f - 63)^2 + 1.5\ r_p^2\ r_t^5} + \frac{0.28\ r_t^2}{(f - 118.75)^2 + 2.84\ r_p^2\ r_t^2} \right] f^2\ r_p^2\ r_t^2 \times 10^{-3}$$

f :	frequency (GHz)	p :	pressure (hPa)
$r_p =$	$p / 1013$	t :	temperature (°C)
$r_t =$	$288/(273 + t)$		

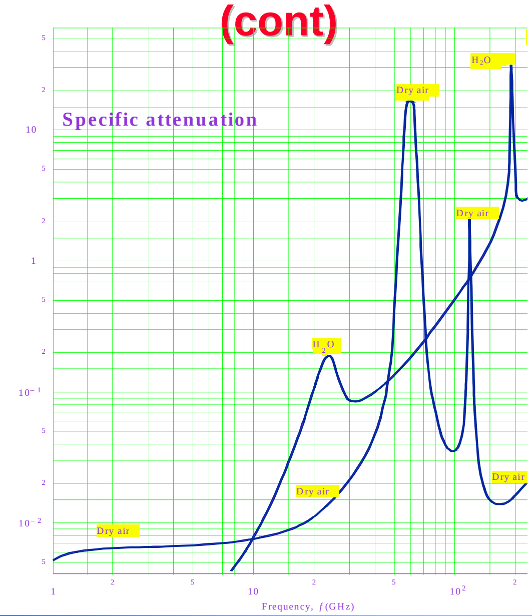
Attenuation due to water vapour

- For water vapour attenuation below 350 GHz:

$$\gamma_w = \left[3.27 \times 10^{-2}\ r_t + 1.67 \times 10^{-3}\ \frac{\rho\ r_t^7}{r_p} + 7.7 \times 10^{-4}\ f^{0.5} + \frac{3.79}{(f - 22.235)^2 + 9.81\ r_p^2\ r_t} + \frac{11.73\ r_t}{(f - 183.31)^2 + 11.85\ r_p^2\ r_t} + \frac{4.01\ r_t}{(f - 325.153)^2 + 10.44\ r_p^2\ r_t} \right] f^2\ \rho\ r_p\ r_t \times 10^{-4}$$

f :	frequency (GHz)
$r_p =$	$p / 1013$
$r_t =$	$288/(273 + t)$
p :	pressure (hPa)
t :	temperature (°C)
ρ:	the water-vapour density (g/m3)

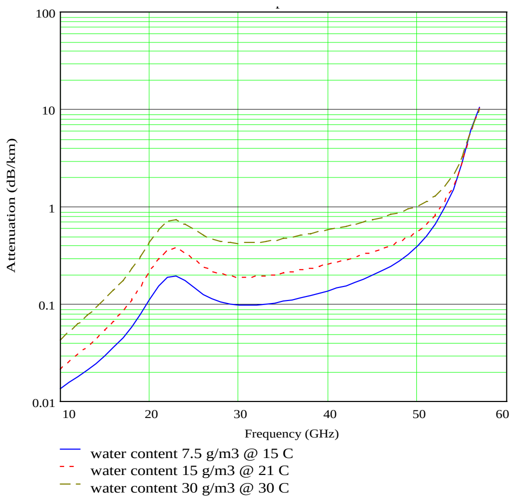
Attenuation due to atmospheric gases (cont)



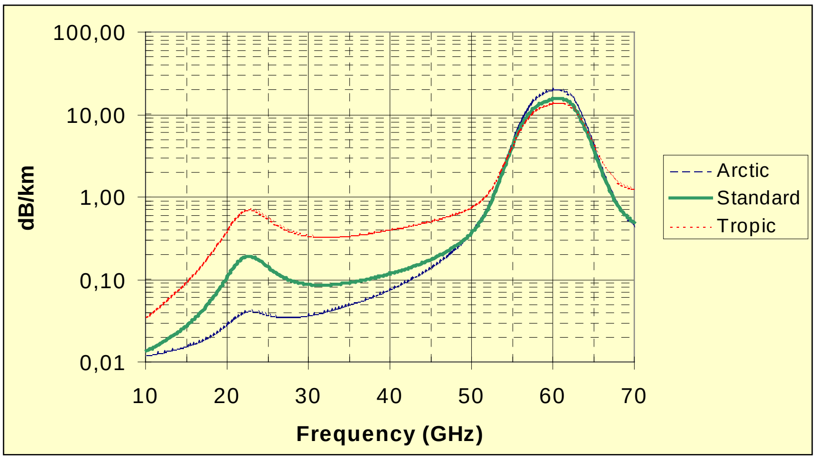
Attenuation due to atmospheric gases (cont)

- ITU-R normal climate: Water vapor content 7.5 g/m^3, 15 ^{o}C (about 58 % humidity), normal pressure (1013 hPa)
- The following figure includes also:
  - 15g/m^3, 21 ^{o}C ("pessimistic" Scandinavian) about 82 % humidity
  - 30 g/m^3, 30 ^{o}C ("pessimistic" tropic) about 99 % humidity

Total attenuation (per km)

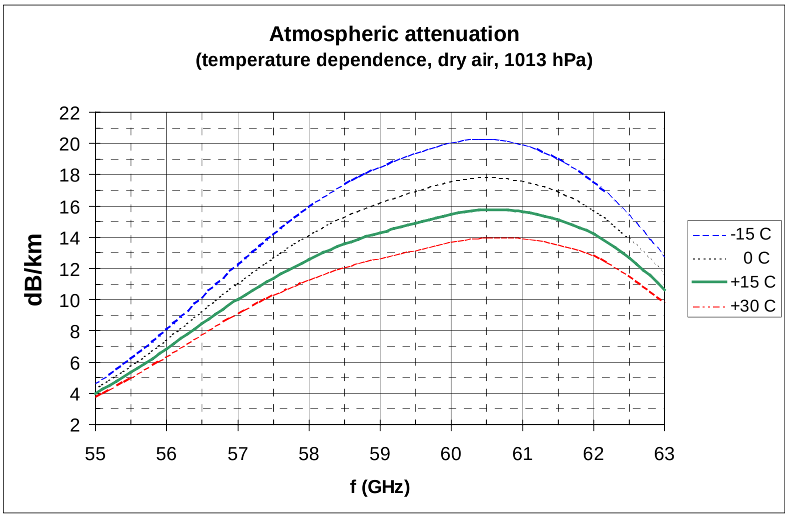


Specific atmospheric attenuation



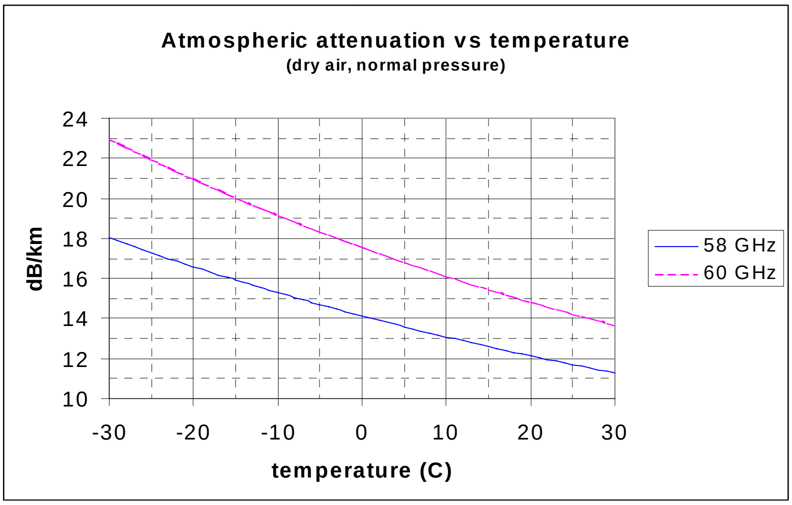
Arctic: -15 C, 1 g/m^3, relative humidity about 62 %
Standard: +15 C, 7.5 g/m^3, relative humidity about 58 %
Tropic: +30 C, 30 g/m^3, relative humidity about 99 %

Temperature dependence during normal pressure



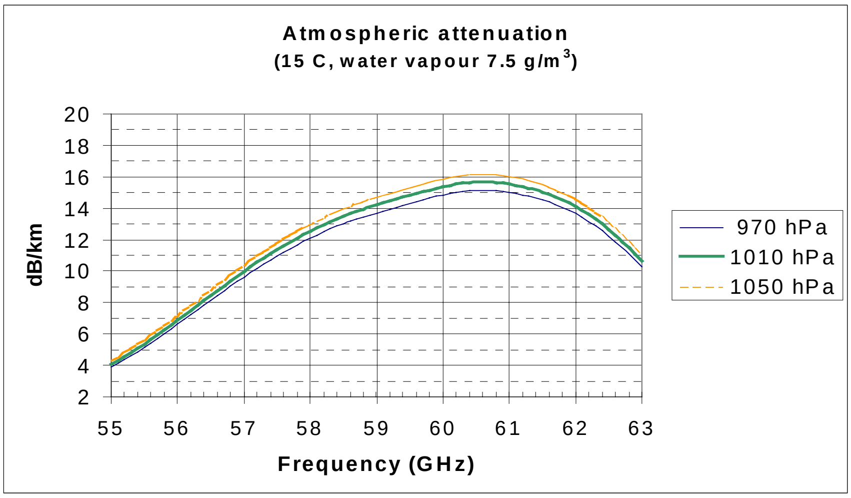
1013 hPa is the normal pressure

Temperature dependence at two frequencies



- Attenuation is less at higher temperatures

Dependence on barometric pressure



- Attenuation is less for low pressure; the difference is not very significant

Attenuation due to rain

- Specific attenuation γ_R due to rain
- k and α can be found in tables or nomograms (ITU-R)
- **vertical** polarization has **smaller** attenuation
- also approximate calculation formulas available
  e.g., J H:
  Route Design for Radio Links above 17 GHz

$$\gamma_R = k \cdot R^{\alpha}$$

Regression coefficients for α and k

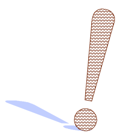
Frequency (GHz)	k_H	k_V	α_H	α_V
1	0.0000387	0.0000352	0.912	0.880
2	0.000154	0.000138	0.963	0.923
4	0.000650	0.000591	1.121	1.075
6	0.00175	0.00155	1.308	1.265
7	0.00301	0.00265	1.332	1.312
8	0.00454	0.00395	1.327	1.310
10	0.0101	0.00887	1.276	1.264
12	0.0188	0.0168	1.217	1.200
15	0.0367	0.0335	1.154	1.128
20	0.0751	0.0691	1.099	1.065
25	0.124	0.113	1.061	1.030
30	0.187	0.167	1.021	1.000
35	0.263	0.233	0.979	0.963
40	0.350	0.310	0.939	0.929
45	0.442	0.393	0.903	0.897
50	0.536	0.479	0.873	0.868
60	0.707	0.642	0.826	0.824
70	0.851	0.784	0.793	0.793
80	0.975	0.906	0.769	0.769
90	1.06	0.999	0.753	0.754
100	1.12	1.06	0.743	0.744
120	1.18	1.13	0.731	0.732
150	1.31	1.27	0.710	0.711
200	1.45	1.42	0.689	0.690
300	1.36	1.35	0.688	0.689
400	1.32	1.31	0.683	0.684

Attenuation due to snow, fog, dust etc

Snow

- Attenuation due to dry snow is small
- rain statistics take into account the effect of snow
- Ice and snow on antenna may become a problem

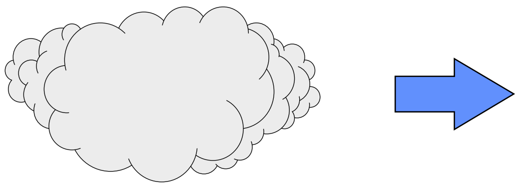
Radome helps



Attenuation due to snow, fog, dust etc (cont)

Fog

- Only noticable at frequencies above 100 GHz
- Thick fog with visibility 50 m



attenuation only about 1 dB/km @ 60 GHz

Attenuation due to snow, fog, dust etc (cont)

Dust

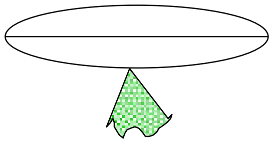
- Sandstorms and dust are not important

not even in countries where they exist

(hop lengths are relatively short)

Antenna heights

- like in lower bands (over 3 GHz)
- For temperate climate:
  - First Fresnell zone free when k=1.33

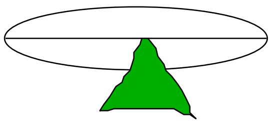


Antenna heights (cont)

- Additional checks (in difficult situations)
  - Below 15 km hops

    Obstructions at most up to line-of-sight at k=0.7
  - Above 15 km hops

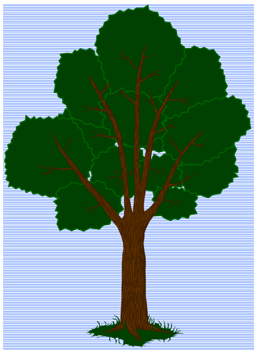
    Obstructions at most up to line-of-sight at k=0.5



(normally these are unnecessary checks)

Notice!

- Too wide clearances may be harmful
  (reflections)
- Areas with diameters of some ten meters may cause reflections
- Too small clearances are "catastrophic"
- Obstructions with dimensions of a few meter may cause noticeable attenuation -
  even a single tree



Notice! (cont)

- Importance of an obstruction depends on the relation to the radius of the first Fresnel zone i.e. on
  - carrier frequency
    (with higher frequency smaller obstructions must be considered)
  - location on the path
    (obstructions near antennas have a pronounced effect)

Calculation of transmission quality

- Error performance
- Availability

- Calculation of fade margin

  as in links below 10 GHz

  - Free space attenuation

    additional term due to atmospheric attenuation

$$L_{at} = (\gamma_o + \gamma_w) \cdot d$$

  - Attenuation due to antenna branching & feeders

    normally included to the specs

Calculation of transm...(cont)

- Antenna gains
  - From manufacturer or approximation formula
  - Radome attenuation

    usually included in manufacturer specs

    only a few dB (wet radome)
- Calculation of error performance
  - needed in links below about 23 GHz
  - may have importance in hops above 15 km
  - multipath formulas
  - diversity is not normally used

Calculation of unavailability due to rain

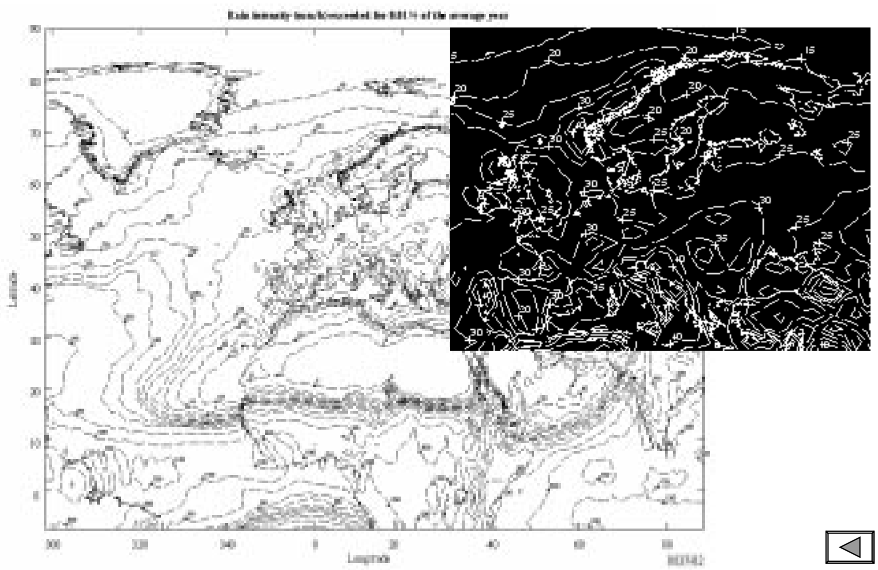
- Determine local rain climate $R_{0.01}$
  (e.g. about 22 mm/h for Finland, 35 mm/h in Central Europe)
- Compute the specific attenuation γ_R taking into account
  - polarization
  - frequency
  - rain rate

$$\gamma_R = k \cdot R^{\alpha}$$

- Compute the effective path length (reduction factor r)

$$r = \frac{1}{1 + d / d_r}$$

Rain intensity maps



Calculation of unavailability (cont)

- Reference path length d_r is

$$d_r = 35 \cdot \exp(-0.015 \cdot R_{0.01})$$

for $R_{00.1}$ > 100 mm/h, use 100 mm/h

- Path attenuation $A_{0.01}$ exceeded for 0.01%

$$A_{0.01} = \gamma_R \, d_{eff} = \gamma_R \, r \cdot d$$

Calculation of unavailability (cont)

- Other time percentages are solved from

$$\frac{A_p}{A_{0.01}} = 0.12 \, P^{-(0.546 + 0.043 \log P)}$$

P is the annual time *percentage* for attenuation greater than A_p (in dB)

- Worst month percentage (normally **not** used)

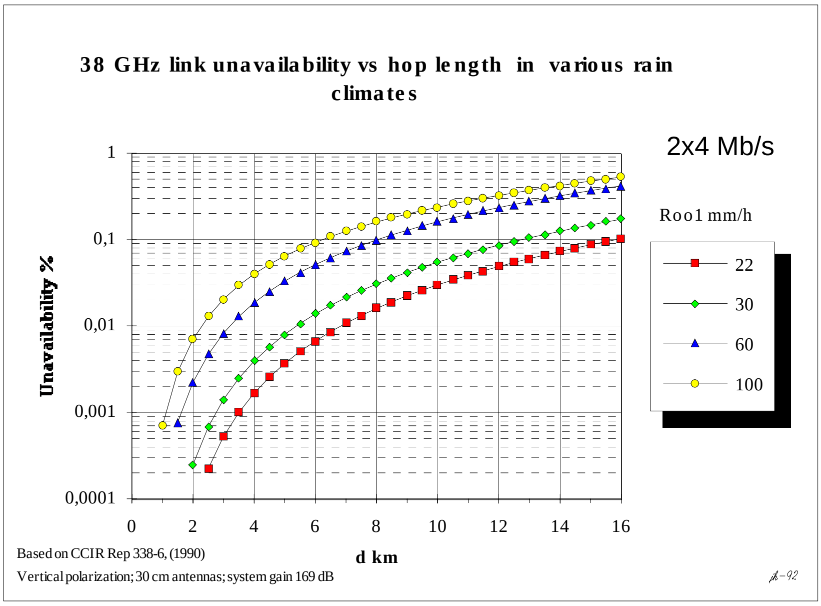
$$P_w = \left(\frac{P}{0.3}\right)^{0.87}$$

Example

```
NOKIA TELECOMMUNICATIONS                    14.11.2000

   ERROR PERFORMANCE CALCULATIONS FOR RADIO RELAY SYSTEM
   DMR38 / ITU Rec 530 Method 2

   Calculated hop from            a               to  b

   Radio frequency        38.0 GHz vertical
   Hop length              5.0 km
   Latitude                0   N
   Longitude               0   E
   Percentage pL           1.0 %
   Geoclimatic factor      7.94E-006
   Rainrate (0.01%)       35.0 mm/h

   Station heights                  0.0 m              0.0 m
   (reference levels)
   Antenna heights                 30.0 m             50.0 m
   (above station ref. levels)
   Feeder lengths                   0.0 m              0.0 m
   Feeder loss/100m                 0.0 dB             0.0 dB
   Antenna diameters                0.6 m              0.6 m

   Transmitter output power         Ptx     16.0 dBm
```

```
Free space loss                         Lo     138.7 dB
   Additional terrain loss                 Lad       0.0 dB
   Antenna branching  loss                 Lbr       0.0 dB    (ND,SINGLE)
   Feeder losses                           Lc1       0.0 dB
         (incl. connectors)                Lc2       0.0 dB
   Antenna gains                           Ga1      45.0 dBi
                                           Ga2      45.0 dBi

   Hop loss in nonfaded state              Lho      48.7 dB
   Received unfaded power                  Prx     -32.7 dBm
   Receiver threshold power                Prxth   -77.0 dBm
   at BER 10 -3

   Flat fading margin                      M        44.3 dB

   Calculated flat outage time             pfm      0.0000   %

   Total outage time (nondiversity)        p        0.0000   %
   Annual unavailability due to rain                0.0040   %
```

Drlink example



Interference

- Generally not a serious problem
  - Plenty of channels
  - Good directivity of antennas (gain over 30 dB)
- Avoid horizontal polarization (at frequencies > 27 GHz)
  - XPD loss due to rain
- Intense rain showers are only a few kilometers (2-3) wide

⇨ interference with angular separation less than about 5-10 degrees fade correlating

⇨ easier situation