Project: IEEE P802.15 Working Group for Wireless Personal Area Networks (WPANs)

Submission Title: Link Budget Analysis for Terahertz Fixed Wireless Links
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Abstract: Based on Link Budget Analysis the basic properties of THz Waves are investigated and for Terahertz Fixed Wireless Links the achievable data rates for different atmospheric conditions are derived. Conclusions for the applicability of THz-waves for fixed wireless with distances up to 1km and technical requirements are given.

Purpose: Informing IG THz on analysis of achievable data rates for Terahertz Fixed Wireless Links.

Link Budget Considerations for THz Fixed Wireless Links

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Source: Thomas Schneider, Andrzej Wiatrek, Stefan Preußler, Michael Grigat, and Ralf-Peter Braun, Member, IEEE; Link Budget Analysis for Terahertz; Fixed Wireless Links IEEE TRANSACTIONS ON TERAHERTZ SCIENCE AND TECHNOLOGY, VOL. 2, NO. 2, MARCH 2012

Content

- THz solutions from network operator view
- Fixed wireless link scenario
- Link budget analysis
- Data rates for THz fixed wireless links
- Technical requirements
- Conclusions

Future network and access traffic development demands for THz solutions

Fast growing network traffic over the next years[1]

- Annual global IP traffic will reach the Zettabyte threshold by the end of 2015.
- In 2015, the gigabyte equivalent of all movies ever made will cross global IP networks every 5 minutes.
- Traffic from wireless devices will exceed traffic from wired devices by 2015.
- Internet video is now 40% of consumer internet traffic, and will reach 62% by the end of 2015.
- IP traffic in western Europe will reach 19 Exabyte per month by 2015.

=> New technologies are needed to offer capacity and energy requirements in the networks of tomorrow

[1]Source: http://www.ciscosecure.net/en/US/solutions/collateral/ns341/ns525/ns537/ns705/ns827/white_paper_c11-481360_ns827_Networking_Solutions_White_Paper.html

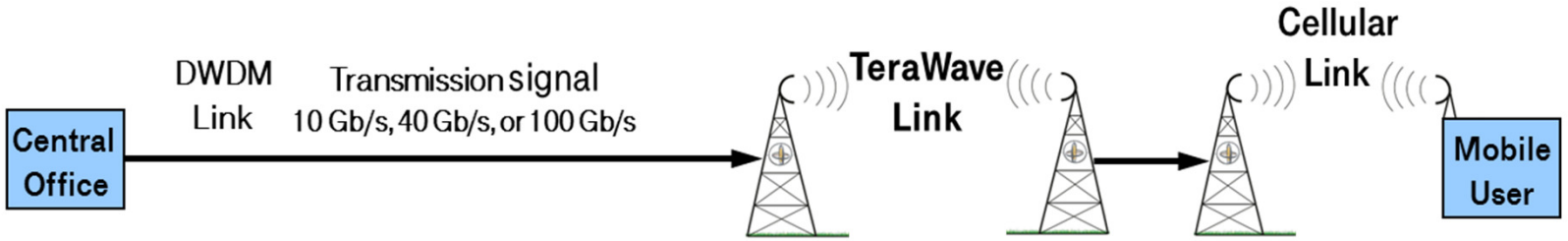
THz use cases

- Quasi mobile and wireless communications
  - hot window (< 1 m)
  - hot spot (< 10 m)
  - access (< 1 km) **=> fixed wireless link scenario**
  - secure Electromagnetic Compatibility (EMC) , Electromagnetic resistance (airplanes, trains, server farms, etc.)
- Ultra-High rate bidirectional-connectivity
  - Wireless LAN scenario
    - download of HDTV display / upload of user input to server
  - Wireless component/server connections
- Automotive communications
  - beacon – car / In-car / car-to-car

Fixed Wireless Link Scenarios

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

Example:
Wireless backhaul extension for cellular Network



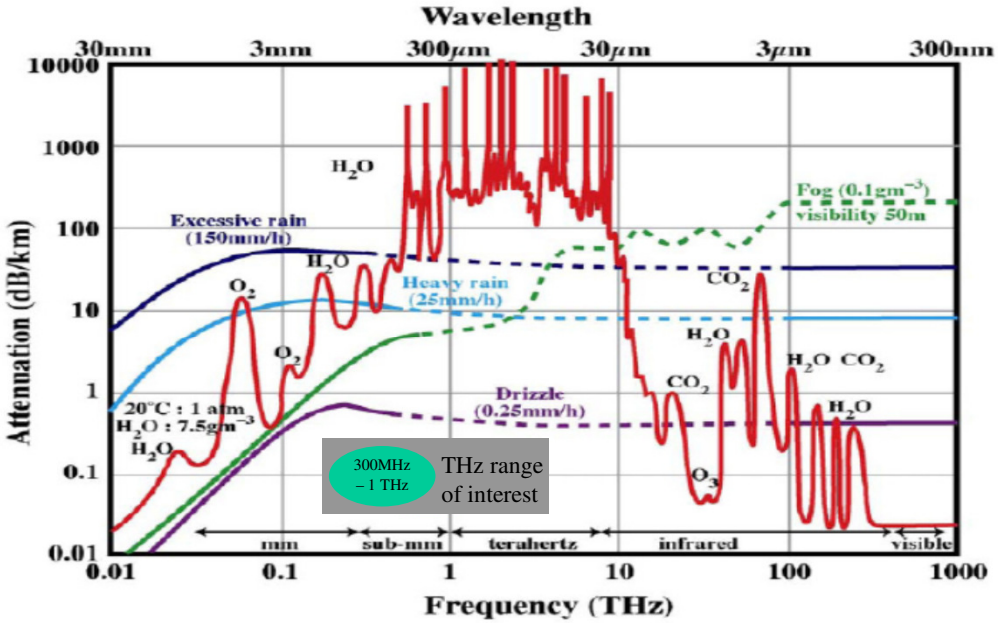
DWDM Dense Wavelength-Division Multiplex

Link Budget Analysis
Environmental Influences

- THz range above 1 THz with significant higher attenuation than range up to 1 THz

ITU Rec. ITU-R P.676-8, ITU, Oct. 2009

"The am atmospheric model, submillimeter array," Tech. Memo #152 [Online]. Available: https://www.cfa.harvard.edu/~spaine/am/

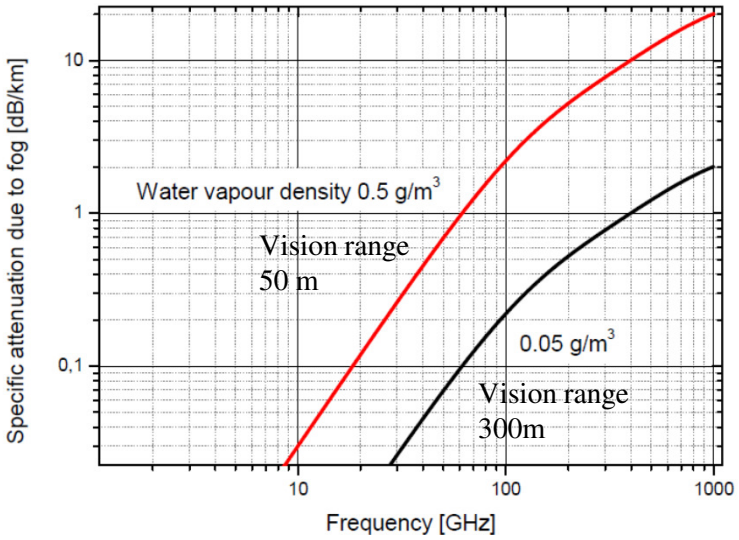


http://www.hitran.com/
http://www.watervaporcontinuum.com/refs_am.html

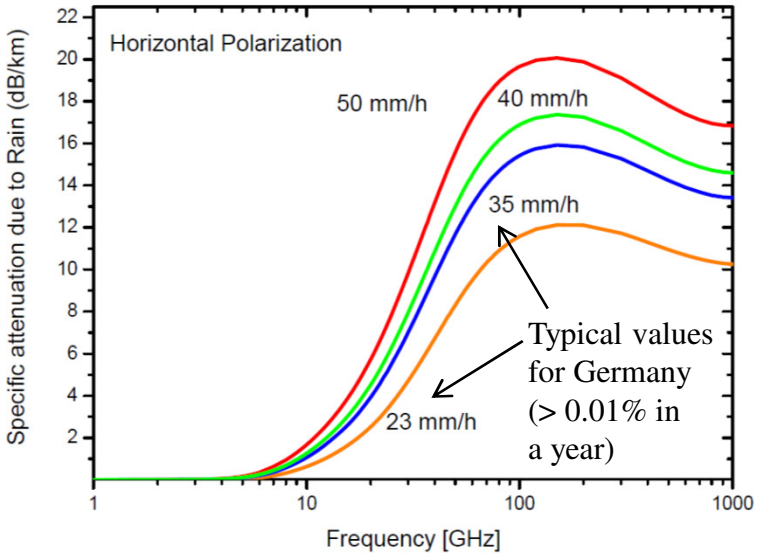
Link Budget Analysis
Environmental Influences

- Attenuation due to Fog / Rain

Attenuation due to Clouds and Fog
ITU Rec. ITU-R P.840-4, ITU, Oct. 2009.



Specific Attenuation Model for Rain for Use in Prediction Methods
ITU Rec. ITU-R P.838-3, ITU, 2005.



Link Budget Analysis

- Used physical model
  - Shannon based capacity
  - Free space path loss (Friis)

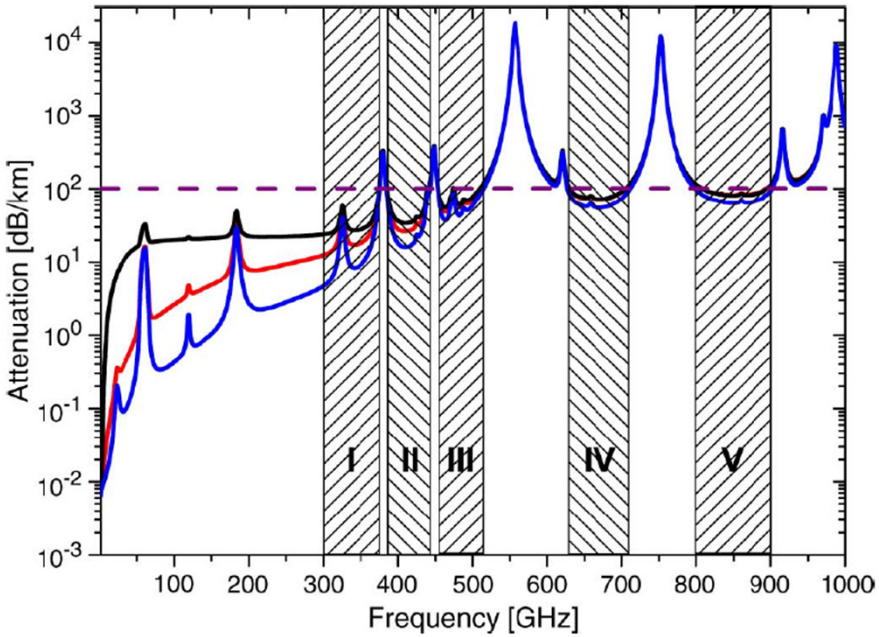
$$C = B\log_2(1+SNR)$$

$$SNR = \frac{P_{Rx}}{FkTB}$$

$$P_{Rx} = P_{Tx}G_{Tx}G_{Rx}\left(\frac{c}{4\pi df}\right)^2 e^{-\alpha d}$$

  - α: attenuation due to the motion of atmospheric molecules, fog, or rain
  - Distance „d“: 1km
  - Transmit Power P_{Rx}: 10 dBm
  - Noise figure F: 10 dB
  - Ambient temperature T: 300 K

Attenuation in THz transmission windows



THz Transmission Windows

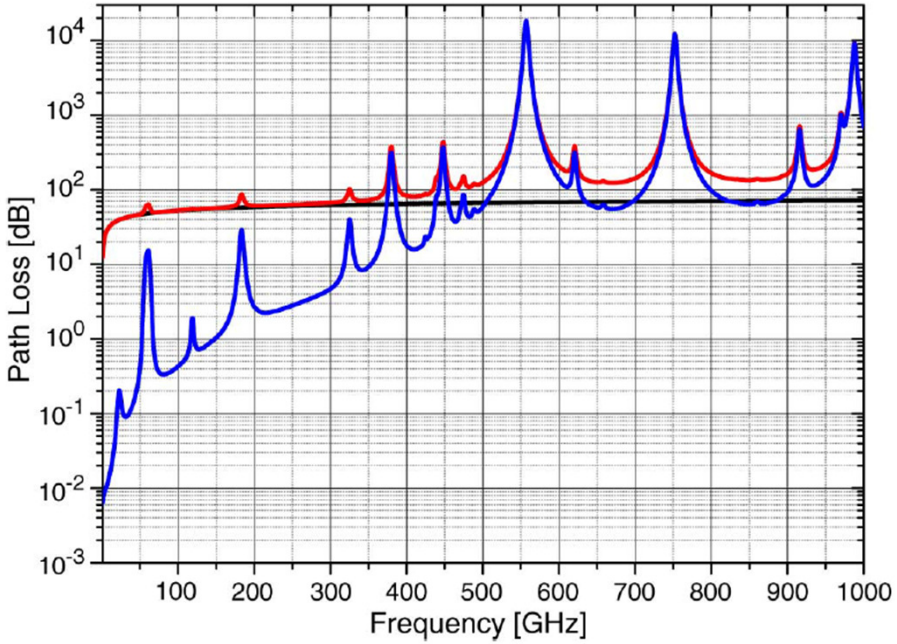
Window	Bandwidth [GHz]	Center Frequency [GHz]
I	76	338
II	58	414
III	62	484
IV	85	669
V	94	855

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.

ITU Rec. ITU-R P.676-8, ITU, Oct.2009

"The am atmospheric model, submillimeter array," Tech. Memo #152 [Online]. Available: https://www.cfa.harvard.edu/~spaine/am/

Attenuation in THz transmission windows – Example for link distance of 1 km



Tx & Rx antenna gain:
40 dBi

Link distance:
1km

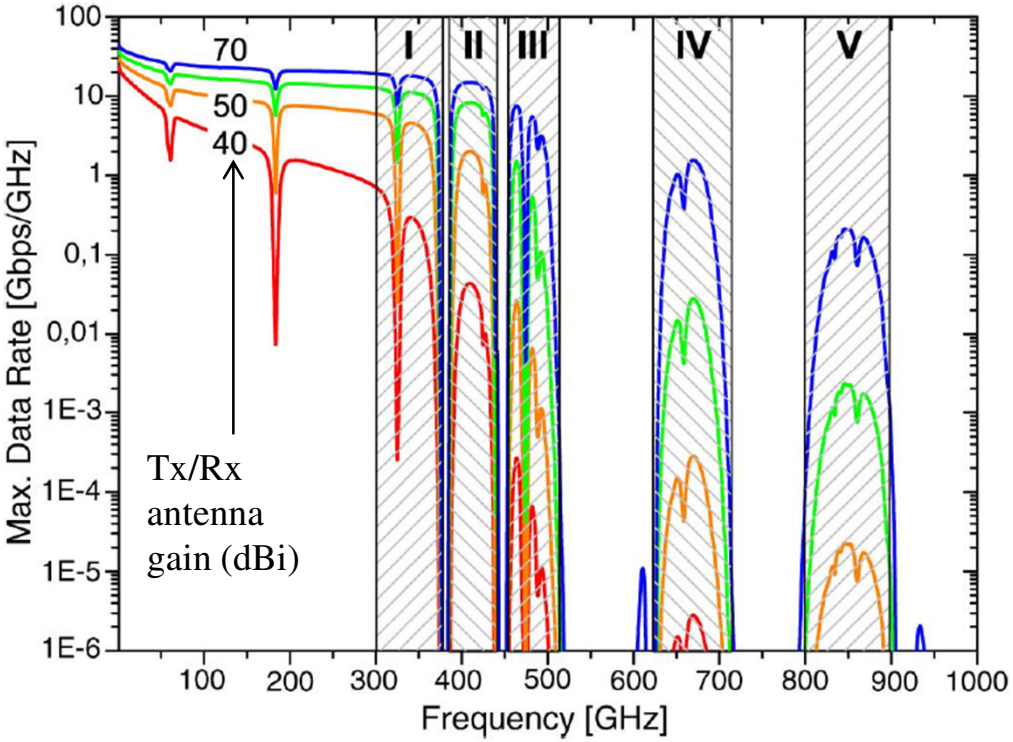
Calculation based on Free Space Path loss (Friis formula)

Attenuation in **clear atmosphere (blue),** **free space path loss (black)** [antenna gain of 40 dBi for the transmitting and receiving antenna] and **the superposition of both losses (red)** for a distance between the antennas of 1 km.

Maximum transmittable data rates in THz bands @1 km link distance.

- Transmittable data rate in each GHz of bandwidth as a function of frequency for rain with a rate of 50mm/h and transmitter and receiver antennas with different gains.

Spectral Efficiency per 1 GHz Bandwidth



Link distance:
1km

Rain rate:
50 mm/h

Link availability:
99,99%

Fixed Wireless Links: Available Capacity @ 1km distance.

- Available capacity for very high gain antenna (up to 70 dBi gain)

Note one source is used per channel and the 10 dBm transmitter power are split over the whole bandwidth

Window #	*B* [GHz]	Capacity for 50 dBi [GBps]	Capacity for 60 dBi [GBps]	Capacity for 70 dBi [GBps]
I	76	24.6	357.8	858.5
II	58	1.8	98.0	452.6
III	62	0.0	0.4	32.9
IV	85	0.0	0.0	0.9
V	94	0.0	0.0	0.1

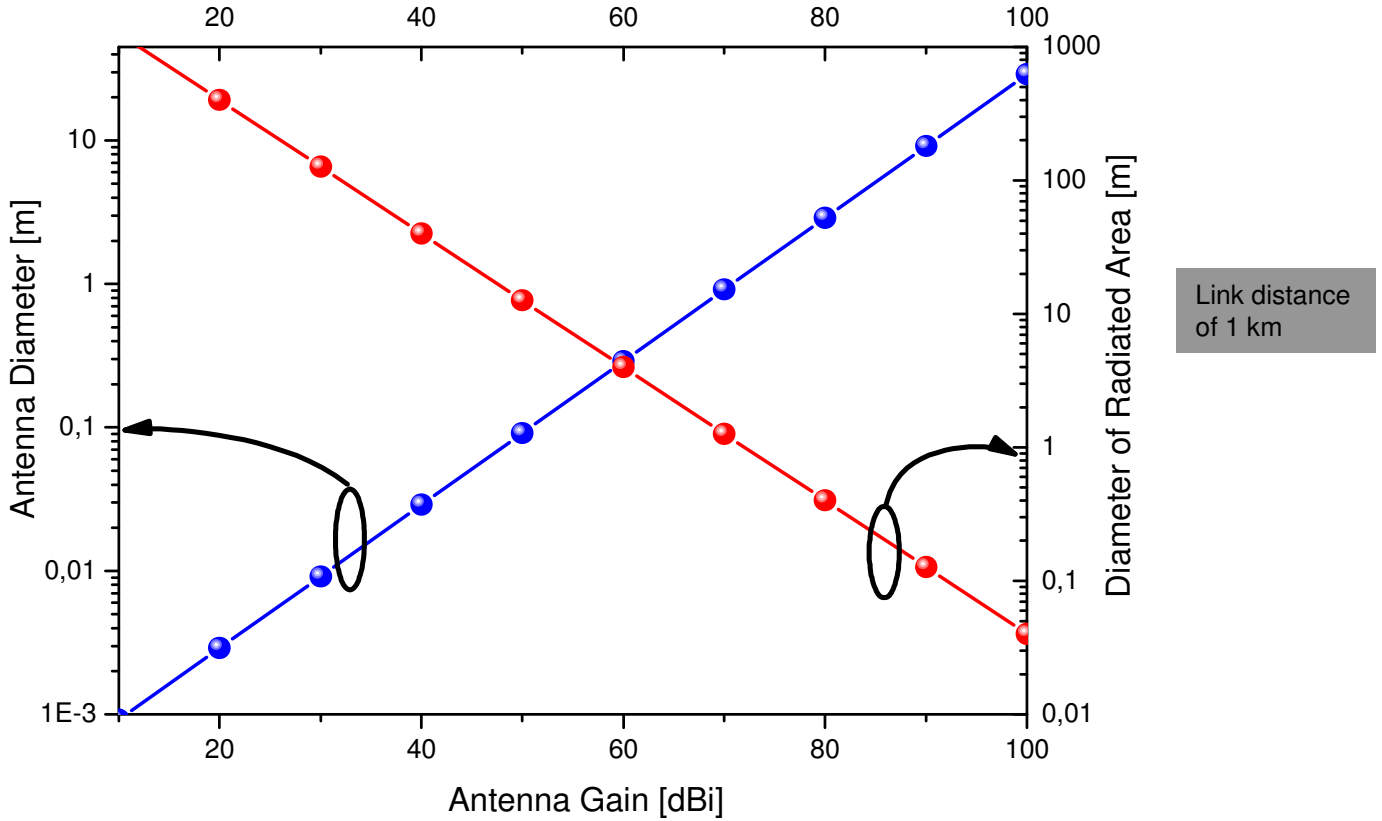
Technical Requirements for THz Fixed Wireless Link

- Very High gain antenna solutions to be applied
  => Increases in general antenna size
- However, due to small wavelengths in THz rather small antenna solutions with very narrow beam
- Sensitive to fluctuations of beam (e.g. antenna poles)
- Adaptive steering mechanism required

Fixed Wireless Links: High Gain Antenna Aspects.

Antenna dimension and radiated area as function of antenna gain

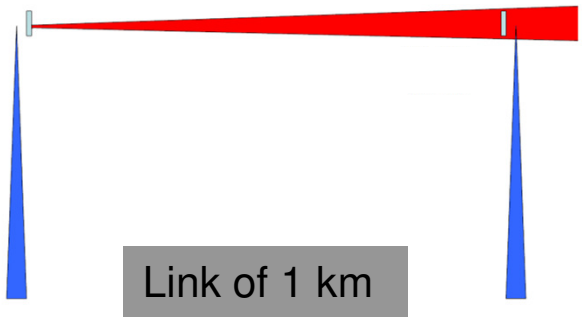
f = 330 GHz

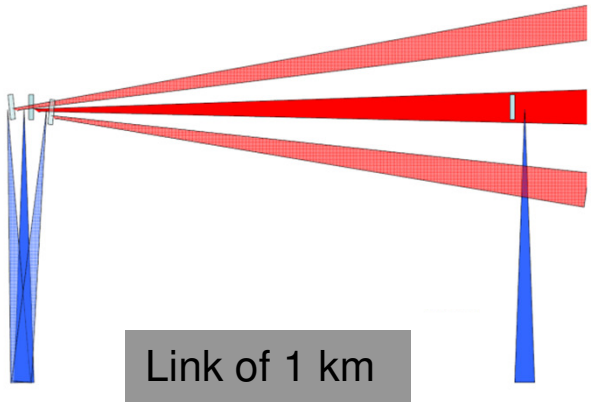


Fixed Wireless Links: High Gain Antenna Aspects.

- 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





Pros and Cons of THz Solutions

Advantages:

- High unregulated bandwidths => Very high data rates
  => Potential for fewer energy requirements by using just one source for high data rates
- Small wavelength => Small antenna size
- Small attenuation by rain & fog (compared to optical link => Low outage probability
- Integrated technology => Cost efficient small devices for portable / mobile applications
- No penetration of human body => No electro smog (EMC)

Disadvantages:

- High wireless path loss => High antenna gain, adjustment control
- No off-the-shelf devices available => Challenging technology but currently no systems available

Conclusion

- Even for the worst case scenario (rain rate of 50 mm/h) THz-wireless links offer extremely high data rates.
- Links of 1 km length and 99.99% availability are possible.
- In the first and second transmission window between 300 GHz and 450 GHz a capacity of around 1 and 0.452 Tb/s is available.
  - Just one source with a power 10 dBm can be sufficient.
  - If additional sources, higher power, polarization multiplexing or MIMO is incorporated in the link, higher data rates will be possible.
- Due to the channel capacity, seamless integration into existing 10, 40, and 100 Gbit/s Ethernet environments is possible.
- THz-Fixed Wireless Links require high antenna gains.
- Adaptive steering of the transmission direction of antenna is a prerequisite for a stable link.