Towards Propagation and Channel Models for the Simulation and Planning of 300 GHz Backhaul/Fronthaul Links

Thomas Kürner[(1)], Akihiko Hirata[(2)], Bo Kum Jung [(1)], Eisaku Sasaki[(3)], Petr Jurcik[(4)] and Tetsuya Kawanishi[(4)]

(1) Technische Universität Braunschweig, Germany
(2) Chiba Institute of Technology, Japan
(3) NEC Corporation, Japan
(4) Deutsche Telekom AG, Germany
(5) Waseda University, Japan

Abstract

The need for high data rates of several Gbit/s in 5G and beyond wireless networks will require capacities of 100 Gbit/s in the backhaul and fronthaul links. 300 GHz wireless links are promising candidates to provide these links. The paper describes the ongoing activities in the EU-Japan project ThoR towards suitable propagation and channel models applicable for the simulation and planning of such links. The corresponding modelling activities are based on ray tracing models, which are enhanced by taking into account atmospheric propagation effects, measured characteristic of building materials and the effect of wind to the poles, where the antennas are mounted. First results applied to realistic simulation scenarios are presented.

1 Introduction

Already in 2015 the Next Generation Mobile Networks Alliance (NGMN) has predicted in its White Paper [1] traffic densities of several Tbps/km² for the 5G networks in ultra-dense networks. This puts extreme requirements for the data rates on the corresponding backhaul and fronthaul links, which may be in the order of 100 Gbit/s and beyond [2]. Since not all base stations in an ultra-dense network have access to fiber, wireless 300 GHz links are a viable option. Recently IEEE 802 has completed a first 300 GHz wireless standard [3] and ITU [4] has identified 154 GHz of spectrum in the range of 275 to 450 GHz usable for fixed and mobile services at the World Radio Conference (WRC) 2019. The Horizon 2020 EU-Japan ThoR (Terahertz end-to-end wireless systems supporting ultra-high data Rate applications) project [5] is working on the hardware demonstration of this application. ThoR is also dealing with the fundamental algorithms and methods for the simulation and planning of such links [6]. The basis for these methods and algorithms are propagation and channel models. The ThoR models [7] are based on ray tracing, which is enhanced by taking into account atmospheric effects, reflection properties derived from measurements and the effect of wind to the poles, where the antennas are mounted. This paper shortly describes the ongoing activities on propagation and channel models and presents first preliminary results. The remaining paper is organized as follows. Chapter 2 presents the ThoR simulation scenarios. The subsequent chapter 3 describes the

propagation modelling activities. Examples of some first preliminary results are presented in chapter 4. Conclusions and an outlook on future directions is presented in chapter 5.

2 ThoR Simulation Scenarios

Six simulation scenarios have been defined in the German and Japanese cities of Berlin, Hanover and Shinjuku [8], for which detailed 3D building data is available. The five scenarios vary between 1 and 25 km² and include a span from dense urban areas with high rise buildings to a suburban are with dominantly single family house. Different densities of base stations are assumed in the five scenarios. Figure 1 shows one of the scenarios in Berlin, where the Olympic stadium is connected to a big congress center with 300 GHz links.
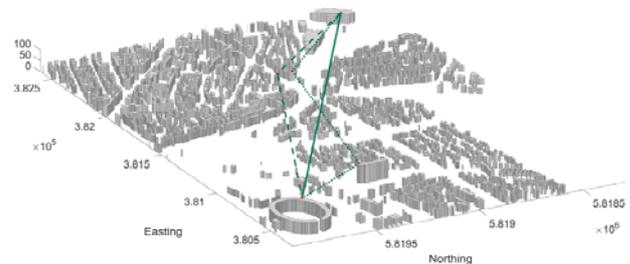

Figure 1. Exemplary simulation scenario at Berlin with links connecting the Olympic Stadium with the International Congress Center

3 Modelling the Relevant Propagation Mechanism

For channel and propagation prediction, ray tracing is used as the basic tool [7] in two implementations: An in-house developed ray tracer available in TUBS' Simulator for Mobile Networks (SiMoNe) [9] and a commercial ray tracer available at CIT [10]. These tools have been enhanced by the models and features described in the following three sections.

3.1 Atmospheric Attenuation

Atmospheric attenuation becomes relevant at the distances and carrier frequencies considered in the application described in this contribution. This is depicted in Figure 2, where the frequency-dependent attenuation of electromagnetic radiation in standard atmosphere (atmospheric pressure of 101.3 kPa and temperature of 15°C) due to atmospheric gases (atmospheric attenuation) is shown [2]. In the same figure, the attenuation is compared with free space loss and propagation loss at a link distance of 100 m. The calculations are based on ITU-R atmospheric gas [11]
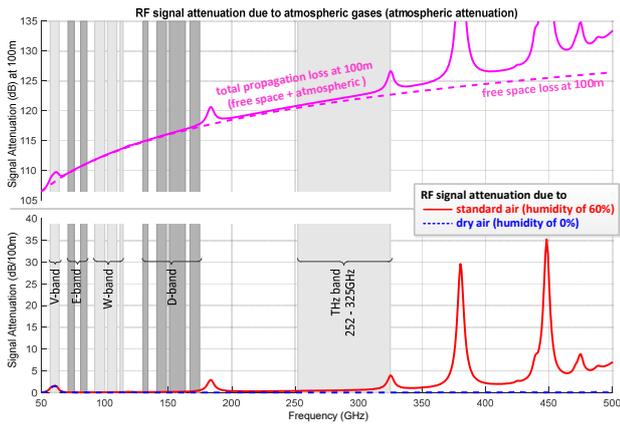
Figure 2. Frequency-dependent RF signal attenuation due to atmospheric gases (atmospheric attenuation), and as a reference, total propagation loss (free space loss + atmospheric attenuation) at a distance of 100 m.

A total of four additional attenuation effects have to be considered on top of the free-space path loss. All four effects can be described by a specific attenuation:

- The specific attenuation of dry air γ_0 and water vapour γ_w is caused by the individual resonance of the oxygen and water vapour in the atmosphere [11].
- The specific attenuation of rain γ_r is caused by the scatterings from the rain which has a power-law relationship to the rain rate [12].
- The specific attenuation model for clouds & fog γ_c is based on the Rayleigh scattering from the liquids within clouds & fog [13].

Taking these specific attenuations into account, the path loss of a wireless link with length d at frequency f can be modelled as

$$\frac{PL}{dB} = 92.4 + \frac{20\log d}{km} + \frac{20\log f}{GHz} + (\gamma_0 + \gamma_w + \gamma_r + \gamma_c)d/km \quad (1)$$

## 3.2 Building Materials for Reflections and Scattering

In none-line-of-sight situations as depicted in Figure 3, a connection might be established via one reflection. In order to increase the accuracy of ray tracing algorithms, accurate material property models are required to be considered in the transmission and reflection processes. The corresponding material parameters described in Recommendations of ITU-R are usually used for the propagation simulations [14] and [15] at lower frequency bands. However, there is no recommendation that can be used for the 300-GHz-band THz wave propagations.
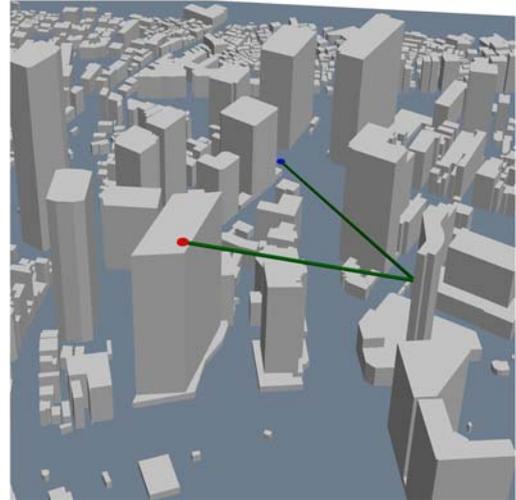

Figure 3. Example for connecting two antennas without LOS in the Shinjuku area via one reflection

Therefore first measurement campaigns have been performed in ThoR in order to retrieve reflection/transmission characteristics of glasses with different thickness typically used in buildings using a Vector Network Analyzer [7]. The reflection/transmission characteristics of glasses are measured by a VNA [7, 16] and two diagonal horn antennas with a gain of 25 dBi each attached to the frequency extenders. The experimental setups and the photographs are shown in Figure 4.
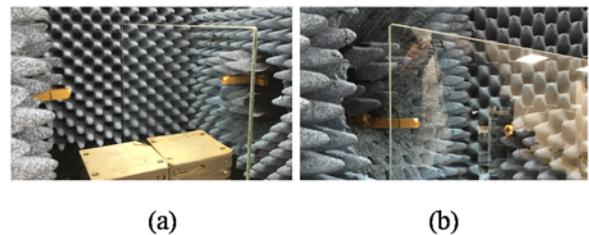
Figure 4. Experimental setups of the measurments of the reflection characteristics

The experimental setup shown in Figure 4 (a) is used for the evaluation of reflection/transmission characteristics of the glasses, and that in Figure 4 (b) is used to measure the dependence of reflection characteristics on the incident angle (α). Figure 5 shows the reflection characteristics of glasses. The range of S_{11} is between -5 dB to -10 dB for all types of glasses. In addition, periodic fluctuations are observed. These periodic fluctuations come from the superposition of reflection wave at the glass surface and that at the glass bottom.
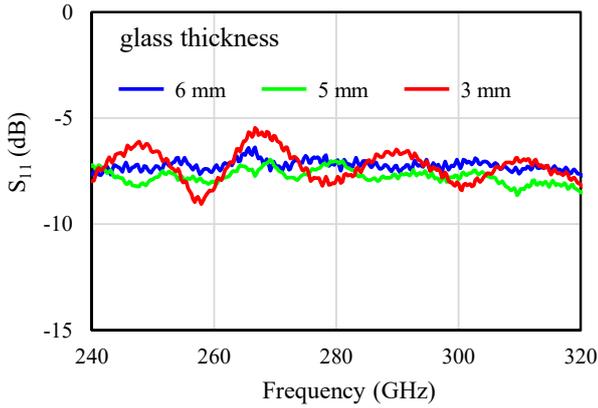
Figure 5. Measurement results of reflection characteristics of different types of glasses

3.3   Modelling the effect of Wind

For the THz link, higher antenna gain is expected to achieve practical link distance against large free space loss and large rain attenuation. As a result, the beam width becomes narrower and a more accurate antenna alignment is necessary comparing with millimeter-wave links. On the other hand, one has to be considered: the effect of the installation of the high-gain antenna on a lamp post, e. g., which may yield large fluctuations in case of by strong wind when compared with a solid tower dedicated to UHF propagation. Following the approach and the results in [17], the effect of wind on the THz link budget has been taken into account by applying a mathematical model derived from measurements described in [7] and the radiation pattern of the antenna. The antenna characteristics are similar to those of the antennas, which will be used in demonstrations of ThoR project. In particular, by assuming some mechanical conditions of structures, a mathematical model [7,17] has been derived from which for example of the availability or outage probability due to wind speed can be derived.

The assumptions on the environment are as follows:

- Application of point-to-point systems operated under line-of-sight conditions.
- The Tx site is fixed on a solid structure, such as a tower for radio communication or wall of building.
- The Rx site is installed at the top of a general pole, such as a lamp post or a traffic signal post.
- The radio equipment is connected with an antenna directly and its dimension is larger than the antenna.
- The probability distribution of wind speed is based on measurements in the Tokyo area, Japan.

Three cases were considered.

- Case 1 : Low and standard thickness pole
- Case 2 : High and standard thickness pole
- Case 3 : High and thick pole.

An example for the output form of this model is shown in Figure 6, where the antenna gain degradation as a function of the wind speed is depicted. Degradation increases with antenna height and decreases with pole thickness.
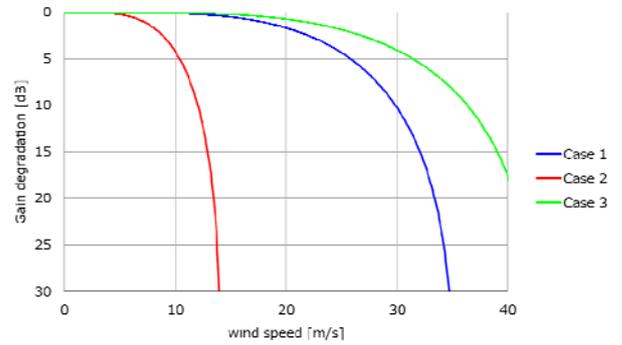
Figure 6: Wind speed vs. Gain degradation for three cases of pole thickness and pole hight

4   Preliminary Simulation Results

Parts of the approaches described in chapter 3 have been applied to SiMoNe [9] and the channel calculations have been applied to both system and link level simulations [18]. Figure 7 shows the signal vector constellations diagram using SiMoNe's link level simulator for a QPSK modulation and an assumed Signal-to-noise-ratio (SNR) of 20 dB applied to the scenario depicted in Figure 2. A system level result taking into account both noise and interference between different links is shown in Figure 7. The signal-to-noise and interference ration (SINR) has been derived for an automatically planned 300-GHz backhaul network in the city of Hanover as described in [6].
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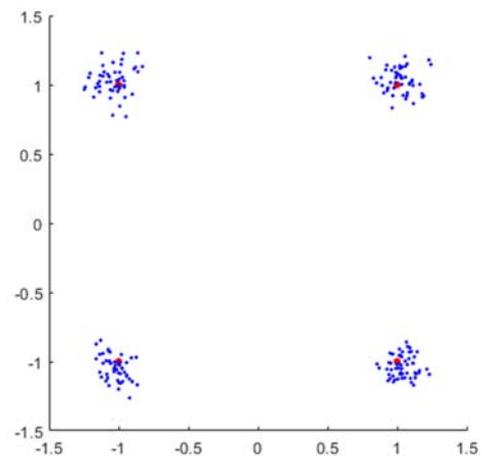
Figure 7. Signal vector configuration from link level simulation of the propagation scenario shown in Figure 2.

The SINR has been evaluated for various weather conditions. Figure 8 shows the cumulative distribution of SINR together with the required SINR value to enable the use of the highest order Modulation and Coding Scheme defined in [3]. The comparison shows only a small variation of a few dB between the best and the worst weather condition. Similar results have been achieved for antenna gains with 40 dBi at both ends of the link. In this case the CDFs are shifted by approximately 20 dB towards lower SINR, which means that the influence of interference

between different links has been well mitigate by the automatic algorithm described in [6].
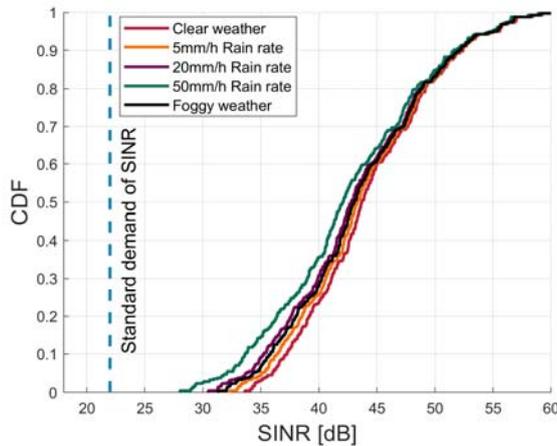
Figure 8. SINR distribution for different wheather conditions for Hanover network described in [6]

5 Conclusion and Outlook

The paper has briefly described the activities in the EU-Japan project ThoR towards the development of suitable propagation and channel models, which will be used both for simulation-based studies on 300 GHz wireless backhaul/fronthaul links as well as for the planning of backhaul at these high frequencies. In order to make the ray-optical channel models more realistic, appropriate approaches to consider weather conditions are applied and measurements for the determination of building materials have been performed. In the next step, the models will be further refined and validated by using the various hardware demonstrators built within the ThoR project in order to have a solid basis for intense simulation based studies in the four reference scenarios defined in the project.

Acknowledgement

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