Ray Tracing Meets Terahertz: Challenges and Opportunities

Haofan Yi, Danping He, P. Takis Mathiopoulos, Bo Ai, Juan Moreno García-Loygorri, Jianwu Dou, and Zhangdui Zhong

The authors present a study for the application of ray tracing for THz channel modeling. Because of the extremely short wavelengths of THz signals, they argue that signal propagation in the THz spectrum can be precisely modeled by employing RT techniques, and thus accurate channel models can be obtained in an efficient manner.

Abstract

It is very likely that the terahertz (THz) spectrum will be used for the operation of the upcoming 6th generation wireless communication systems. This article presents a study for the application of ray tracing (RT) for THz channel modeling. Because of the extremely short wavelengths of THz signals, we argue that signal propagation in the THz spectrum can be precisely modeled by employing RT techniques, and thus accurate channel models can be obtained in an efficient manner. We first review recent research and standardization activities related to RT-assisted channel modeling that mainly deal with millimeter-wave applications and, to a much lesser extent, have been applied the THz spectrum. Then we present the basic THz wave propagation characteristics, including reflection, scattering, penetration, and shadowing as well as signal absorption by atmospheric molecules and tiny particles under different weather conditions. The methodologies for the appropriate construction of target scenarios are presented as well as efficient computational methods for the effective RT operation. Finally, various research and development challenges related to RT-based channels for future THz communication systems are identified, and possible solutions are highlighted.

Introduction

According to Edholm's law (i.e., the data rate equivalent of the well-known Moore's law), it is expected that by 2030, commercial demands will exceed data rates of more than terabit per second. It is thus quite certain that the 6th generation (6G) wireless communications will use the terahertz (THz) frequency band. This part of the spectrum, 100 GHz–10 THz, can provide necessary ultra-wide bandwidths for the successful operation of services that require ultra high-rate communication capabilities, such as robotic controls, information shower, high-definition holographic gaming, and high-rate wireless data distribution in data centers [1].

For effective communication using such ultrahigh data rate signals, accurate channel modeling is of paramount importance. In the past, there have been two main methodologies for channel modeling, namely, the stochastic [2] and the deterministic [3] approaches. The first one is based on extensive channel measurement data obtained through well-planned and time-consuming measurement campaigns. However, such measurement campaigns are extremely difficult to carry out for millimeter-wave (mmWave) frequencies (up to 100 GHz) let alone for the quasi-optical THz frequency band. Highly directional antennas are required to compensate for the significant path loss. Furthermore, in order to capture the multipath components (MPCs) from all directions, the measuring equipment should always be located on top of a platform that is typically rotated mechanically. It is underlined that this procedure is very time-consuming, and the accuracy of the obtained channel measurement data is not always very accurate due to misalignment and errors of the measurement system [4]. On the other hand, the deterministic approaches, such as ray tracing (RT) and the finite-difference time-domain (FDTD) method, are based on electromagnetic (EM) wave propagation principles. In the past, they have provided an excellent match between measurement- and simulation-based data under the condition that an accurate propagation scenario is available.

Ever since the initial design of 5G systems, RT has emerged as a viable approach for enriching the rather sparse channel measurement data, and in fact has significantly contributed to a more accurate characterization of the mmWave channel. An important advantage of RT, as compared to actual measurements, is that even for mmWave mobile communications the channel characterization can be much more easily obtained through RT, even though the transmitter (Tx) and receiver (Rx) are located on mobile units (e.g., vehicle and drone). For commercial use, communication operators have deployed RT for network planning and radio coverage prediction for the public network.

Despite the accumulated knowledge and experience from the use of RT for mmWave channel modeling, a more specialized parameterization of the THz channels is still necessary so that it can be effectively described by their propagation mechanisms. Even though THz waves propagate as other lower-frequency signals do, that is, through direct paths, reflections, scattering, diffraction, penetration, and shadowing, their key characteristic difference is that their propagation mechanisms should be approximated by geometric optical principles. RT naturally becomes more

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Haofan Yi, Danping He (corresponding author), Bo Ai, and Zhangdui Zhong are with Beijing Jiaotong University, China; P. Takis Mathiopoulos is with National and Kapodistrian University of Athens, Greece; Juan Moreno García-Loygorri is with Universidad Politecnica de Madrid, Spain; Jianwu Dou is with ZTE Corporation and State Key Laboratory of Mobile Network and Mobile Multimedia Technology, China.

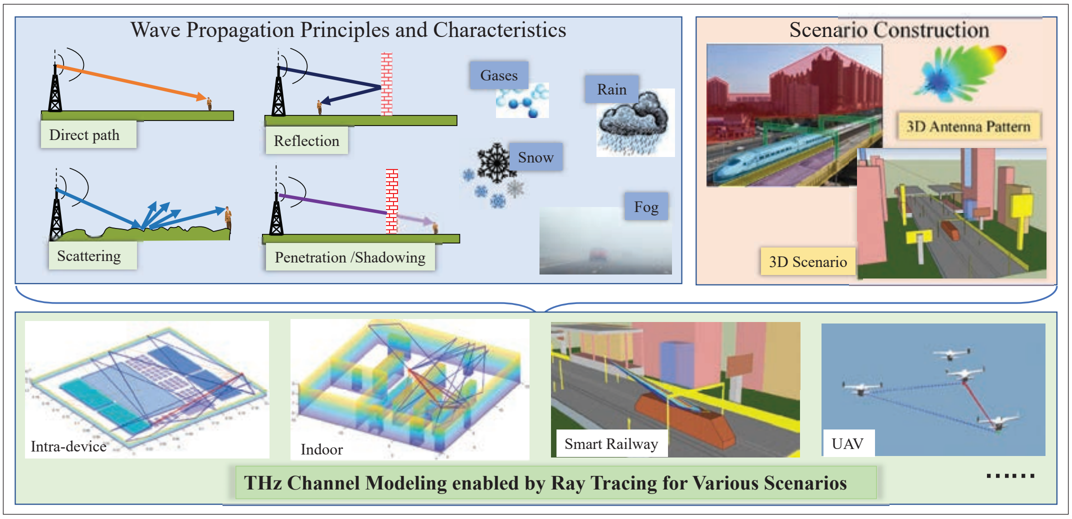

FIGURE 1. THz channel modeling enabled by RT.

accurate for communication systems using very short wavelengths and stronger corpuscular properties, as is the case with the THz band [5]. Thus, an increasing number of new applications and scenarios for the 6G system are envisioned [1], making the need for efficient RT-assisted channel modeling of paramount importance.

Thanks to the ultra-wide bandwidth offered by the THz spectrum, the time-delay resolution increases, and hence it is much easier to distinguish MPCs. Fortunately, as opposed to real-world channel measurements, RT is not limited by bandwidth, and as such it can accurately distinguish MPCs by estimating their propagation characteristics, including amplitude, phase, and angle of arrival/departure of each ray. Ongoing research activities from our group on THz have shown that various channels can be effectively described by visible rays through RT thanks to the proper propagation characteristics and scenario construction. More visual details on this are illustrated in Fig. 1.

Motivated by the above, this article presents a study toward the successful application of RT to THz channel modeling. In particular, we first review the recent research on RT-assisted channel modeling, which mainly focuses on mmWave and, to a lesser extent, in the THz band. Next, the major propagation characteristics of the THz band are discussed. Furthermore, the general methodology of how to construct the target scenario with an efficient accelerated engine is presented. Finally, various research opportunities and open research challenges are identified and discussed.

An Overview of RT-Based Channel Modeling and R&D Activities

Frequency Bands Below 100 GHz

RT-based simulations can bypass the limitations of measurement and obtain full-dimension channel characteristics. For example, in the past, various academic organizations, including Technische Universität Braunschweig (TUBS), Katholieke Universiteit Leuven, New York University, and Beijing Jiaotong University (BJTU), are leading research activities for the design and development of RT-based methodologies for channel modeling in various scenarios and applications for 5G. In particular, RT-based methods have been used to estimate the delay and angular characteristics of MPCs supporting link- and system-level performance evaluation. Among these research and development (R&D) activities, CloudRT developed by BJTU is employed on a high-performance platform with 96 computing nodes (1600 CPUs and 10 GPUs) to improve its processing and computational capabilities [3]. Other commercially available RT-based simulators (e.g., WinProp and Wireless Insite) have been utilized by communication operators for radio coverage prediction and network planning since the beginning of 4G development.

In parallel, various telecommunication standards development organizations have also recognized the importance of RT in channel modeling. For example, the 3rd Generation Partnership Project (3GPP) and METIS have provided for frequency bands below 100 GHz, where an alternative channel model has been developed through a map-based hybrid approach instead of taking actual channel measurements. Furthermore, the site-specific model mentioned in International Telecommunication Union — Radiocommunication Standards Sector (ITU-R) P.1238 has been obtained for indoor communications based on the uniform theory of diffraction (UTD) complemented by RT. These efforts have been supported by ITU-R P.2040, which provides data for various building materials and structures so that RT simulations can be carried out effectively. Additionally, the MiWEBE and QuaDRiGa models are "statistical" RT models, as the strong rays are generated by RT while weak rays are generated randomly. In other standardization activities, it is noted that IEEE 802.11ad uses RT for the development of various stochastic models in different scenarios at 60 GHz.

Frequency Bands for THz Spectrum

As far as the THz spectrum is concerned, the IEEE P802.15 Working Group (WG) has proposed the first worldwide channel modeling standard for THz spectrum in the 252–325 GHz frequency band. The communication system employing this standardized channel model has demonstrated

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Frequency	Scenario	Antenna	Group	Category and main contributions
130–143 GHz	Indoor office [7]	SISO	SJTU	RT-statistical hybrid model that verified the spatial consistency
275–325 GHz	Indoor office [8]	SISO	TUBS	The first RT-statistical models for THz communications
300 GHz	Wireless backhaul [9]			RT-assisted model for system design under different weather conditions
300–308 GHz	Smart railway [10] Vehicular communications [11]	SISO	BJTU	Measurement-based RT calibration method
300 GHz & 350 GHz	Indoor [12]	MIMO	Uni-DUE	RT-assisted channel to estimate MIMO channel capacities

TABLE 1. Recent works on THz channel modeling assisted by RT.

impressive 100 Gb/s throughput performance for point-to-point communications [6]. Furthermore, research within this WG has successfully used RT techniques to generate channel data, and they subsequently proposed different stochastic channel models considering various scenarios.

Table 1 summarizes some recent contributions made by academia focusing on RT-assisted channel modeling in the sequence of each operating frequency. TUBS first modeled the 300 GHz path loss with the aid of RT for an indoor scenario [8] and then, by further considering various weather conditions, proposed appropriate channels for outdoor scenarios [9]. Employing a 140 GHz vector network analyzer (VNA), measurement campaigns were conducted by Shanghai Jiaotong University (SJTU) that analyzed the temporal and angular distribution of MPCs in the meeting room scenario and then established an RT-based statistical hybrid model [7]. CloudRT, developed by BJTU, has been calibrated by a few channel measurements for smart railway [10] and autonomous vehicle applications [11]. By means of extensive RT simulations, the first-order reflected ray was proven to rebuild the wireless link for a non-line-of-sight (NLoS) condition. The University of Duisburg-Essen (Uni-DUE) used RT for a 64 multi-input multi-output (MIMO) communication system, in which RT was used to estimate how the rough surfaces will influence the channel capacity [12].

Challenges and Opportunities for the Extraction of MPCs

In order to extract the properties of each MPC in a dynamic measurement, multipath estimation algorithms, such as SAGE, RiMAX, and MUSIC, are developed to match the paths to the surrounding objects in the scenarios. Nevertheless, these algorithms are sensitive to the prior setting (e.g., the number of paths and signal amplitude thresholds). Another problem is that the identification and correlation of multipaths can only be realized in a simplex dimension, and thus uncorrelated ones are easily aliased.

Fortunately, these problems can be solved with the employment of RT methods as they can compensate the sparse measurement data and at the same time offer the full-dimensional channel characteristics, including amplitude, phase, angle, and polarization. In particular, the series of ray information can be obtained through the precise three-dimensional (3D) geometric and EM propagation calculations. On the other hand, how to construct the target scenario in an efficient way and simulate the THz waves by accurate propagation mechanisms is discussed in the following sections.

Propagation Characteristics at the THz Band

This section presents the three important propagation phenomena that characterize the THz spectrum, namely:

- Molecular absorption, which introduces significant attenuation to outdoor THz signals due to different whether conditions, including atmospheric gases, fog, rain, and snow
- Reflection and diffuse scattering, as EM waves with very short wavelengths are very sensitive to the rough surfaces, and diffuse scattering will significantly influence the reflected propagation
- Penetration losses and shadowing, where several measurements are supported to study penetration losses for typical materials as well as shadowing by static and moving objects

Molecular Absorption

For the THz band, multipaths are characterized by "spherical spreading" exactly as at lower frequencies, while they are superimposed with additional molecular absorption caused by atmospheric gases, rainfall, fog, and snowflakes under different weather conditions. Thus, the high free-space path loss present at the THz band coupled with additional absorption caused by its inherent molecular absorption is recognized as the main limitation for employing outdoor communication systems for THz spectrum.

Signal absorption by atmospheric gases, which mainly contain water vapor and oxygen molecules, is caused by the resonance between molecules and the propagating EM waves. FThe ITU-R P.676 model provides an accurate methodology to calculate atmospheric attenuation for frequencies up to 1 THz. It is interesting to note that the high path loss, due to the natural Friis path loss on top of the atmospheric absorption, makes certain frequencies (e.g., 183, 325, 380, 450 GHz) exhibit very high signal attenuation, which can be used for very short distance secure communications, such as the "whisper radio" [1]. For communication purposes, the usable frequency bands are the absorption-free spectra that are typically below 1 THz. Beyond 1 THz, even if efficient transceivers are realized, communication systems with a very high transmission power to overcome the THz frequency band losses would most probably be harmful to health.

On the other hand, signal attenuation due to fog is caused by the density of liquid water present in the air and has been modeled in ITU-R P.840 by a Rayleigh approximation that accurately predicts the fog-caused attenuation. Other studies [13] have pointed out that Mie scattering occurs when the scatterers have a similar size to the propagating signal wavelengths. Hence, when rain particles and snowflakes have similar sizes to the wavelength of incident rays, studying the influence of rainfall and snowfall on THz propagation is important. The ITU-R P.837 model provides the average annual rainfall rate worldwide through a digital map with the corresponding latitude and longitude information. From these data and by using the ITU-R P.838 model, rain attenuation, which is frequency-dependent and relevant to the polarization angle, can then be predicted for a given rainfall rate. However, as the literature is lacking data on snow attenuation, ITU groups have not yet identified methods to accurately predict snow attenuation for the THz spectrum. To date, there have been some preliminary attenuation measurements reported in [13], which have concluded that THz waves suffer higher attenuation from snow than rain, and that wet snow causes higher attenuation loss as compared to dry snow.

Reflection and Diffuse Scattering

As the characteristics of the THz wave are corpurscular and related more to optical signals, their reflections can be more accurately estimated by using geometric optics. The specular reflection of an ideal smooth and homogeneous reflective surface, such as glass, can be accurately characterized by the Fresnel reflection coefficient, which is given by the incident angle of the arriving signal and the frequency-dependent complex dielectric constant of the reflecting materials. As opposed to classical wireless communications, the complex refractive index, $\tilde{n}$, which is used for visible spectrum is usually considered separately from the complex dielectric constant, $\tilde{\varepsilon}_r$. However, this difference is not incorporated in all the available RT platforms as some of them do not distinguish between them, although they can be converted to each other. It is underlined that, in general, the actual values of these materials' properties still remain unknown in the frequency range of 1–10 THz because of the difficulty in conducting such measurements. However, it is possible to calculate the dielectric constant by theoretical methods based on microstructures. For instance, the Drude model, originally proposed to describe the optical properties of solids, can be applied to metals as well as to heavily doped semiconductors. This model is based on the kinetic theory of electrons in a metal, where the dielectric constant is determined by the operating frequency and the two physical characteristics of a certain material itself, namely electron collision frequency and plasma frequency. Lorentz extended the model to a dielectric medium by proposing that the electron is bound by a force to the nucleus of the atom, which possesses a much larger mass and behaves according to Hooke's law (i.e. with a spring-like force). An applied electric field would then interact with the charge of the electron, causing stretching or compression of the spring, which would set the electron into an oscillating motion. Through the microscopic movement inside the medium, the dielectric constant function can be obtained.

It is underlined that the Fresnel reflection coefficient is used only for wave reflecting on smooth surfaces. On the other hand, the Rayleigh criterion is used to classify the surface as rough or smooth, that is, whether or not the reflection coefficient can be directly calculated by the Fresnel equation. In particular, as the Rayleigh criterion depends on the operating frequency, the same surface can be classified as smooth at a lower frequency or rough at a higher frequency. The level of the roughness can be described by the root mean square (RMS) height, σ, which characterizes the surface's height distribution; and the correlation length, *l*, which indicates the dependency of two points on the surface according to the correlation function having, in general, a threshold of 1/*e*. For an ideal smooth surface, σ is defined as 0, while *l* approaches infinity. To account for the resulting scattering loss in the specular direction, the Fresnel reflection coefficient should be modified by the Rayleigh roughness factor. For example, Fig. 2 shows the reflection coefficient of plaster at 300 GHz with the change of incident angle and roughness for transverse electric (TE) and transverse magnetic (TM) modes, respectively [12].

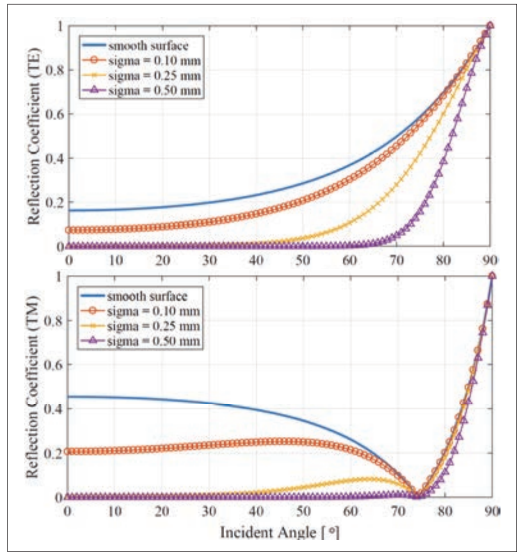

FIGURE 2. Reflection coefficient for TE and TM polarized wave.

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To obtain the scattering properties (i.e., amplitude, phase, polarization, and width of scattering lobe), extensive measurements can be carried out by employing VNA or THz time-domain spectroscopy (THz-TDS). For accurate experimental estimation, it is necessary to conduct such measurements with different incident angles and scattering angles in the 3D upper half of the surfaces under test. However, since these measurements are complex, time-consuming, and very costly, EM simulation software, such as FEKO and CST, can be used instead to simulate the propagation of THz waves interacting with a rough surface. For example, in our recent work [14], after deploying FEKO on a high-performance computing platform, we have conducted EM simulations with the solution algorithm of the multilevel fast multipole method (MLFMM) at 300 GHz. Various performance evaluation results have shown that as σ increases and *l* reduces, the rough level of a surface increases. Furthermore, as illustrated in Fig. 3, the rougher the surface, the wider will be the lobe width, while the power in the specular reflection direction is dispersed due to the roughness. Additionally, by comparing the simulated scattering lobes of dielectric materials to those of

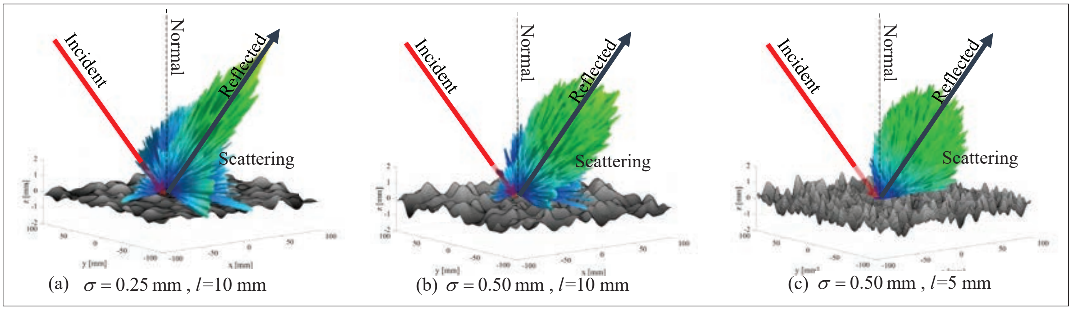

FIGURE 3. Typical examples of scattering on different rough surfaces.

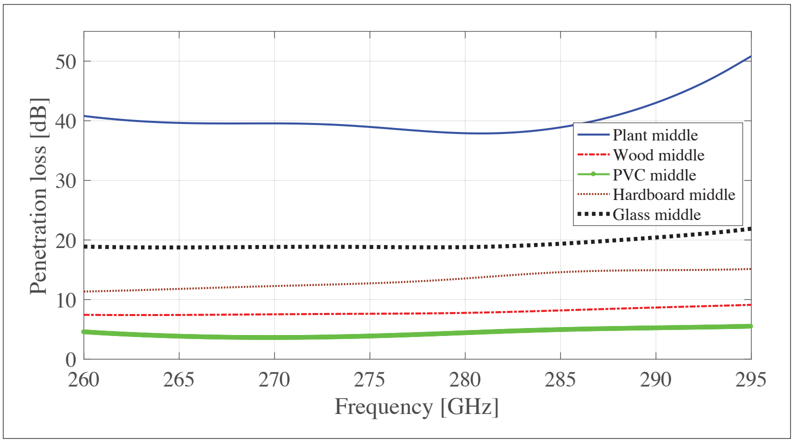

FIGURE 4. Penetration loss at 260–295 GHz.

the perfect electrical conductors, the EM properties of the dielectric constant affect the amplitude but not the shape of the scattering lobe. For the mmWave band, the directional scattering (DS) model has been used, in conjunction with RT techniques, to characterize the scattering lobe with a scattering coefficient, S, and an equivalent roughness, α_R. However, such modeling is not applicable to the THz spectrum because the scattering is much more sensitive for reflections on rough surfaces at these extremely high frequencies. One possible solution is to consider the RT-FEKO hybrid modeling approach, which uses FEKO simulation results to analyze the regions of a rough surface, while RT is utilized to trace the rays by the optical principles. Thus, the RT-FEKO hybrid approach should achieve very high accuracy in THz channel modeling despite the difficulty in obtaining seamless interoperation between RT and FEKO. It is thus convenient to pre-store the scattering lobe obtained by FOKO into the RT simulator and then invoke them when the ray interacts with the rough surface.

Penetration Losses and Shadowing

It is well known that, in general, signal penetration losses increase linearly with frequency because of the skin effect of the lossy media when signal penetration takes place. However, for the THz band, the effects of signal penetration have not yet been studied thoroughly, and related research activities are in their initial stages. Thus, further studies are necessary to provide important information data for NLoS communications. In fact, we have recently conducted experimental signal penetration measurements for THz indoor communications by considering typical indoor office materials, namely glass (6 mm), hardboard (6 mm), wood (10 mm), and PVC (2 mm). Furthermore, relatively small plants with their pots placed on top of work desks have been also considered, since due to their signal blockage, they will also cause signal attenuation. For this scenario, measurements over the 260–295 GHz frequency band have been taken by a VNA using a Tx and Rx, having 1 m distance between them, which is larger than the minimal distance according to the far-field region of the employed horn antennas. The penetration losses have been measured by comparing sample measurements between a reference LoS signal measurement. Figure 4 illustrates typical measurements for the penetration loss of the tested materials, indicating that the best performance (i.e., minimum penetration loss) is achieved by the PVC, followed by wood, hardboard, and glass. Clearly, for reducing penetration losses in the THz band, it is better to replace glass windows with PVC windows for possible outdoor-to-indoor communications. It is also noticed that plants have the highest penetration losses, and thus it is important to carefully consider their position and, if possible, to avoid them.

Another important effect magnified in the THz band is so-called shadowing. Due to the sharp decrease of diffraction power as the signal frequency increases, the various obstacles present in the propagation scenario will introduce sharp shadows. It is noted that although the previously mentioned plants can also create shadowing effects, this is static shadow and could be considered as penetration losses. On the contrary, when there is movement (e.g., mobile users), the shadowing is varying and must be carefully modeled. For this, we have run several experiments to measure such shadowing effects as follows. First, we have used two horn antennas pointing to each other, where the direct path is dominated in the channel. Then a person walked through the space between the transceivers, and the signal levels have been measured. Figure 5 illustrates some typical experimental results at 300–308 GHz obtained in a train wagon. These results have clearly shown the existence of deep and long shadows (e.g., signal attenuation of more than 30 dB with shadowing duration longer than 1 s) when people are walking down the aisle accompanied by the action of placing luggage on the overhead bins. However, since such measurements can be modeled by geometry-based shadowing models such as double knife-edge diffraction (DKED) and cylinder models, they can easily be applied in conjunction with RT for virtually any propagation scenario involving human movement [15].

3D Scenario Construction and Related Acceleration Techniques

In this section, first some techniques for the appropriate construction of target scenarios are presented. Then algorithmic- and hardware-based techniques that accelerate the RT engine are discussed.

3D Scenario Construction

Apart from the various signal propagation mechanisms in static and/or time-varying scenarios, for accurate channel modeling it is important to carefully model the 3D shape and position, and the types of materials the obstacles are made from and which are present in the THz communication links under consideration. Any target scenario model can be custom designed via 3D tools such as SketchUp. JavaScript Object format is often employed to transfer 3D model data into RT, including the material information and the shape as well as the position of objects. In recent years, with the increasing popularity of geospatial data in applications such as Google Earth and Google Maps, it has become common for many cities to use web services to view their 3D building structures online. Furthermore, it is possible to use the less complex 2D images of 3D buildings provided by Google Earth to accurately reconstruct 3D buildings. Additionally, with the rapid advancement of laser scanning technology, LiDAR can be used to create a 3D point cloud to more accurately present building data. It is expected that by employing such scenario modeling tools and approaches, the target scenario will be represented more accurately so that more precise radio propagation prediction and channel modeling can be obtained.

For any 3D scenario, the omnidirectional antenna with 0 dBm transmission power is always utilized in RT simulation in order to simulate the pure propagation channel without the influence of a certain antenna pattern. Then the single-beam or muti-beam pattern can easily be coupled with simulated results to evaluate the capacity for the link- and system-level design.

Acceleration Techniques

Because typically the transceivers are mobile, the visual space relationship between geometric surfaces dynamically changes for each snapshot. Furthermore, for very high frequencies and bandwidths, especially for the THz spectrum, the computational complexity for accurate channel modeling significantly increases. Thus, new techniques must be found for reducing this computational complexity. One such approach is the identification of the object faces that significantly influence the wave propagations. It is also underlined that due to the very high path loss at the THz band, the effective communication distance is typically limited to no more than 500 m, as opposed to the network planning for 5G, where geographical areas of several square kilometers must be converted.

After an appropriate digital map is selected, RT will use its data and produce computational algorithms to find the rays (direct, reflected, scattered, and penetrated) in an efficient way. Typical acceleration algorithms include reduced precision algorithms (i.e. dimensionality reduction and significance sampling) and lossless precision accelerate methods (i.e. tree-based and uniform space partitioning methods). The difference between partitioning methods of the uniform grid and k-dimensional (kD) tree space is the division of the loaded 3D scenario model using the uniform and non-uniform grids, respectively. The ray-object intersection tests will be computed in the ray-passed grids. It is noted that the computational accuracy will not be effected, since space partitioning is a preprocessing procedure that divides the entire scenario into small sub-spaces and reduces the number of candidate objects for ray-object intersection tests.

On the other hand, acceleration can also occur through the proper design of hardware structures. GPUs are massively multithreaded, multicore chips in computer video cards and embedded systems. The GPU can also be applied to speed up some numerical methods by EM simulation software, previously presented. When a CPU calls the program interface, GPUs will automatically schedule multiple cores to complete tasks. A parallel multi-core GPU-based engine will increase the computational speed of compute-intensive tasks significantly.

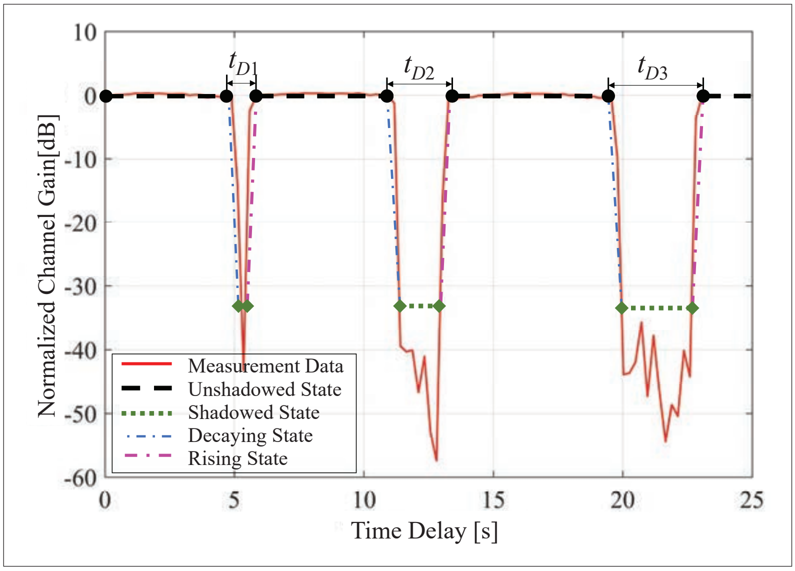

FIGURE 5. Four-state Markov model for shadowing caused by human movements.

Challenges and RT-Based Solutions

For any RT simulator, every object that exists within each scenario resembles a kind of Lego block. Once all the building blocks are realized, any communication scenario can be implemented. With the available propagation models, the full-dimensional channel information can be obtained by employing the RT methodology. It is underlined that since such channel information can be obtained in advance, MIMO channels and associated beam management techniques can be realized in a straightforward way.

Ultra-massive MIMO (UM-MIMO) systems generate very narrow beams to compensate for the very high path losses encountered in the THz band. Thanks to the very small wavelength of the THz band, UM-MIMO can be realized with several hundreds of antennas on a small scale. However, an accurate and efficient channel modeling approach for UM-MIMO at the THz band is still an open research problem. It is noted that since the RT experiments are site-specific, the correlation of all the sub-channels created by the UM-MIMO antennas can be characterized by RT. However, with possibly several hundred antennas, the computational and storage capacities for such systems will dramatically increase. One possible solution to this problem is to develop cloud-based RT with high computation and storage capabilities.

Antenna beam management is another important challenge that needs to be carefully considered. Its main function is to steer the antenna toward the strongest ray/path, thus supporting the mobility of user equipment (UE). The current assumption for 5G mmWave is that the antenna beam from the base stations (BSs) sweeps all possible directions every 5 ms, while the UEs will transmit a short message in response. However, since the THz beam will become much narrower, the time required to check all possible directions will significantly increase. With the aid of RT, first, the omnidirectional antenna can be used to directly identify the strongest path, either the direct path in LoS signal propagation conditions or the reflection path in an NLoS situation. Then the BS or/and UE can, in advance, select their own beam following the RT simulation results.

Another important issue is the relatively long duration of shadowing events, which often occur in the THz band. Once the direct path is blocked, the link is maintained by the steering antenna array by identifying an alternative path. With the aid of RT, it can very efficiently identify a first-order reflected path with relatively low path loss as the alternative link.

Complex multipath is another challenge caused by the "multi-structures" configuration (i.e., when a "penetration-reflection" path is formed), where EM waves first penetrate the glass, then are reflected by a building wall, and finally reach the Rx. One solution for identifying the characteristics of complex multipaths is to integrate the individual transfer functions of the propagation graph with the aid of RT. This is a new hybrid channel modeling approach based on the joint processing of RT and graph theory.

Conclusion

This article has presented a study that argues in favor of an RT-based THz channel modeling approach to be used in connection with 6G communication development. We have first provided a brief overview of research and standardization channel modeling activities that exist mainly for frequencies below 100 GHz and to a lesser extent for the THz spectrum. By considering the two main components of the RT simulation platform (i.e., the EM calculation and geometrical relationship), we have investigated the propagation characteristics at the THz band as well as the methodology for constructing the target scenarios using efficient acceleration approaches. Finally, open challenges and potential solutions regarding the RT-based THz propagation modeling approach are highlighted and discussed.

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Biographies

Haofan Yi [StM] (haofanyi@bjtu.edu.cn) is a Ph.D. candidate in the State Key Laboratory of Rail Traffic Control and Safety, Beijing Jiaotong University.

Danping He [M] received her Ph.D. degree from Universidad Politecnica de Madrid in 2014. She is an associate professor in the State Key Laboratory of Rail Traffic Control and Safety, Beijing Jiaotong University.

P. Takis Mathiopoulos [LSM] received his Ph.D. degree from the University of Ottawa, Canada. From 1989 to 2003, he was a faculty member (as a professor as of 2000) in the ECE Department at the University of British Columbia, Canada. Currently, he is a professor of telecommunications in the Department of Informatics and Telecommunications, University of Athens.

Bo Ai [F] received his Ph.D. degree from Xidian University, China, in 2004. He is now working at Beijing Jiaotong University as a professor. He is a deputy director of the State Key Lab of Rail Traffic Control and Safety at Beijing Jiaotong University.

Juan Moreno García-Loygorri [SM] received his Ph.D. degree from the Universidad Politécnica de Madrid in 2015. He works as a rolling stock engineer in the Engineering and Research Department of Madrid Metro and as a part-time professor at the Universidad Politecnica de Madrid.

Jianwu Dou received his Ph.D. degree in robotic mechanisms from Beijing University of Technology. He is with ZTE Corporation and the State Key Laboratory of Mobile Network and Mobile Multimedia Technology.

Zhangdui Zhong [F] received his Master's degree from Beijing Jiaotong University in 1988. He is a professor at Beijing Jiaotong University. He is a chief scientist of the State Key Laboratory of Rail Traffic Control and Safety at Beijing Jiaotong University.