

Link and Coverage Analysis of Millimetre (mm) Wave Propagation for 5G Networks Using Ray Tracing



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Abstract Globally the Millimetre-wave (mm-wave) technology is leading over the fifth-generation (5G) networks because of higher frequency bands and therefore wider spectrum. The mm-wave communications are now seen as a viable 5G technology. It can improve the speed and remove congestion as the present cellular networks fall short. Link and coverage analysis play very vital role before deploying any network. We should have known everything about the spectrum and its behaviour for every scenario. Deployment of 5G networks has started in many countries, in India it could be started soon, so before deployment link and coverage, analysis is necessary for better network coverage in every area. Though there are several challenges in implementation which include the success of a multi-phase characterization of the mm-wave that characterizes the trustworthy and high-speed channel interfaces and system designs. In this paper, we analyse links in non-line-of-sight conditions and coverage using ray tracing method with different numbers of reflections and launched rays in science faculty, University of Allahabad (A Central University) campus.

Keywords Millimetre-wave (MMW) · Ray tracing (RT) · Shooting and bouncing rays (SBR)

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1 Introduction

As per universal by 2021 projections on cellular data demand, the estimated capacity of wireless data will be 143 Exabyte per quarter. It is seven times higher than the demand in 2016. Studies on millimetre-wave (mm-wave) antennas and propagation are critical for 5G wireless communications to attain the requisite coverage of the mobile system [1]. Nowadays requirement of data is in high demand which is used by numerous mobile applications oscillating as data that is constantly available for cloud services, high-definition video conferencing, and mobile movies available on demand. To fulfil this need, the 5G may support drastically different technologies as compared to current generations [2]. Recent advancements in radio frequency (RF) technology have made it possible to produce low-cost radios that operate in carrier frequencies in the typical sub-6 GHz bands. Also available in a variety of configurations, most of which are aimed at very short-range applications [2]. Moreover, the use of mm-wave frequencies which enable mobile data access is getting attention. It can also consider for next-generation wireless technologies. Some of the ways for increasing network performance have been well-known, including (i) improving spectral efficiency in the given connection, (ii) using greater bandwidth, and (iii) the effectiveness of spatial reuse is being updated. The use of mm-wave bands yields considerable gains in all dimensions. When antennas can attain stronger directivity at higher frequencies, signal strength and spectral efficiency improve, and the antennas also enable the intrinsic beam-forming. The frequency bands in the 28, 32, 39, and 60 GHz are used casually and also permit possibly a lot of channel bandwidth. For example, the 28 GHz band has bandwidth of up to 1.5 GHz which is the chief contiguous channel of 850 MHz bandwidth [1, 3]. In the current spectrum, 60 GHz band (unlicensed) has up to 7 GHz. The massive transmission in mm-wave bands certainly minimizes interference. In this manuscript, we have studied the behaviour of the 32 GHz bands. To determine the possibility of mm-wave wave band usages, (mm-wave access) characterization of the mm-wave channel is needed [4]. The propagation of electromagnetic waves in mm-wave frequencies differs significantly from that in sub-6 GHz bands. Various corresponding methods are available to understand the millimetre-wave channel; conducting well-organized and complete measurement operations is an enormously valued but costly and time-taking method [5]. NYU has recently performed widespread campaigns, but MATLAB currently only maps roughly 20 reception points and three send locations in one section of New York City. Ray tracing methods for determining channel gross statistics have become a viable alternative in recent years, especially at lower frequencies [6].

In this manuscript, we elaborate on our findings of channel and capability which has been found by ray tracing for the 32 GHz mm-wave band. As per the best of our knowledge, a few of the findings are novel results that describe several properties of the channel [7, 8]. We have discussed our findings with the availability 32 GHz scenario and different findings are also highlighted. The remaining manuscript is organized as below: Sect. 2 gives the survey of many relevant related works to this area. In Sect. 3 the used model is presented. The Simulation environment, Results,

and discussions are presented in Sect. 4. Finally, the paper ends up with a conclusion and future scope in Sect. 5.

2 Related Work and Literature Review

It has been already known that 6 GHz communication systems are fronting various issues about the rising demand for high data rates and more quality services. Therefore, to meet these requirements, the fifth-generation (5G) mobile communication considers frequency space in the millimetre-wave (mm-wave) spectrum (30–300 GHz). The lack of bandwidth in the sub-6 GHz band is fulfilled with the smart use of mm-wave technology. Additionally, it can give considerably more throughput, and capability. Regardless of the view that a large bandwidth is engaged, this technique faces path loss, atmospheric-attenuation, etc. from rough substance, and the different loss which causes decline in the transmission of power signal. Thus, precise and consistent channel method is significant in the mm-wave bands, mainly for the indoor-environment. Besides these various complementary methods are required to understand the MMW channel; well-organized and comprehensive movements are an exceptionally valued technique. Several researchers have done channel sounding and classification for different millimetre-wave bands. In [5] measurement of campaign 28 GHz bands have been described and the derived channel parameters have also been elaborated [4] and summarized [9]. Limited studies have been reported in Samsung [7] whereas Ericsson has also stated certain primary measurement findings. Nonetheless, performing certain kinds of measurement movements in every single use case is complex and costly. Another methodology to understand the channel of wireless communication is RT [10]. This technique apprehends the environment in geometrical aspect and is mainly beneficial in getting the technology that is likely to be relatively specular. Whereas RT might be unable to model all the information of the environment but it can offer a tremendous characterization of gross statistics. Some of the current papers have also defined RT findings for this technology. In [7], these findings outdoor environment was provided whereas [11, 12] for indoor findings 60 GHz propagation was studied. In [9], it was done for 72 GHz channel, and findings were also reported. In this article, we have considered the features of channels like received power, angles of departure and arrival, path range for a one base station and spread these notions to complex multi-cellular dispositions [13].

3 Model Used

We used the Ray Tracing model in the simulation. Ray tracing models use 3-D environment geometry to determine propagation pathways. It is valid from 100 MHz to 100 GHz. There are two methods in the Ray Tracing model, the first one is Shooting

and Bouncing Rays (SBR) and the second one is the image method. The determination of rays from a starting to the field point is an important aspect of ray tracing algorithms [14]. We use d SBR method because it is generally faster than the image method. Ray Tracing computes multiple paths and other models compute the only a single path. It supports 3-D indoor and outdoor scenarios. Using electromagnetic analysis, regulate the attenuation and phase shift of every ray, which includes tracking the different polarizations of a signal across the propagation path. Free-space and reflection losses are included in the path loss. The Fresnel equation is used to compute losses on the horizontal and vertical polarizations for each reflection. For up to ten route reflections, the SBR approach allows for the determination of estimated propagation pathways. Many rays are launched from a hyperbolic sphere centred at Tx in the SBR approach. The model can shoot rays that are somewhat regularly spaced due to the geodesic sphere. The approach then tracks each ray from Tx and can represent many forms of interactions between the rays and their surroundings, including reflections, diffractions, refractions, and scattering. It is worth noting that the implementation solely takes into account reflections. When a ray strikes a flat surface, R, it reflects according to the law of reflection. Based on the rule of diffraction, when a ray contacts an edge, D, it spawns multiple diffracted rays [15, 16]. A Keller cone is formed when a continuous stream of diffracted ray's forms around the diffracting edge [16]. The approach environs Rx with a sphere, called a receiving sphere, having a radius proportionate to the angular spacing the number of rays released and the distance the beam travels for each launched ray. The model deliberates the ray a legitimate path from Transmitter to Receiver if it crosses the sphere (Fig. 1).

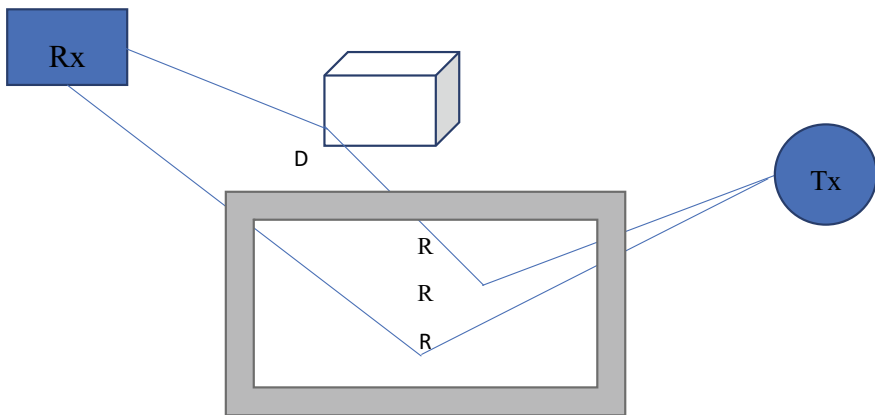


Fig. 1 The SBR technique for estimating propagation pathways from a Tx, to a Rx, is shown in this diagram

4 Simulation Environment, Results and Discussion

In this section, we discussed the simulation environment and results. We did a simulation for a small cell scenario in a dense urban environment. First we took the map of science faculty, University of Allahabad from OpenStreetMap shown in Fig. 2. Firstly, we analyse the coverage in the science faculty campus. To analyse coverage, we placed the transmitter in front of J. K. Institute building with antenna height 10-m, carrier frequency 32 GHz, transmitting power 5 W, and coverage map for a maximum range of 250 m from the base station. The coverage map indicates the received power for a receiver at each ground position, but not for the tops or sides of buildings shown in Fig. 3. The coverage map showed that millimetre-waves were blocked by buildings and showed power -40dBm at the centre and -70dBm at the edges. After coverage analysis, we define a receiver site at some distance of transmitter which is obstructed by the building. Then we plot line-of-sight propagation which showed shadowing due to obstructions shown in Fig. 4. After this, in Fig. 5 we set non-line-of-sight propagation with single reflection and get received power (-68.8 dBm), phase change (0.48 rad), distance (144.97 m), and angles of departure (104az , -3.3el) and arrival (-150.8az , 4el) from the simulation. After this we simulate with double reflection with weather loss and effect of material shown in Fig. 6. We take concrete as building and terrain material. Received power with weather loss and terrain effect is -80.2 dBm , phase change is 3.69 rad. , distance is 150.46 m , angle of arrival is -150 az , -3.8 el , and angle of departure is 102.7 az , -4.3 el . Received power using perfect reflection is -69.1019 dBm , received power using concrete materials is -77.56 dBm , received power including weather loss is -78.9512 dBm , and received power with two-reflection paths is -76.5014 . We can enhance the received power by Beam Steering. We simulate this code using MATLAB. The simulation runs on a desktop computer having Intel Xeon Core(TM) i7-10700 CPU @ 2.90GHz processor, 16 GB RAM, and Windows 10 operating system.

Finally, it is obvious that extending a descriptive environment to smaller entities does not appear to ensure improved RT accuracy, especially if the geometrical portrayal of these objects is inaccurate and the scattering/electromagnetic characteristics of such tiny objects are unknown. However, in future research, this problem should be considered more extensively.

5 Conclusion and Future Scope

Of total, we have noted that Ray Tracing methods are beneficial to stimulate the gross characteristics of this channel. Our findings for dense urban scenario at 32 GHz match the received power measurements and other parameters from the state of art. Measurements at 32 GHz from as well as ray tracing are being used for developing, an initial channel model. The received power, phase shift, angle of arrival and departure indicate that millimetre-wave does not travel long distances and cannot penetrate



Fig. 2 Map of science faculty, University of Allahabad

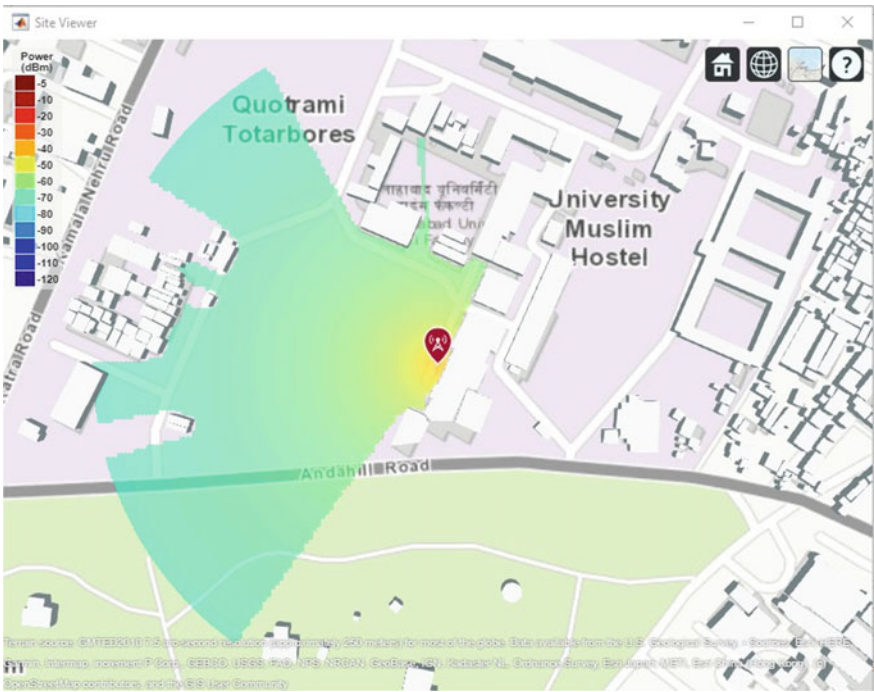


Fig. 3 Coverage analysis at carrier frequency 32 GHz in science faculty campus

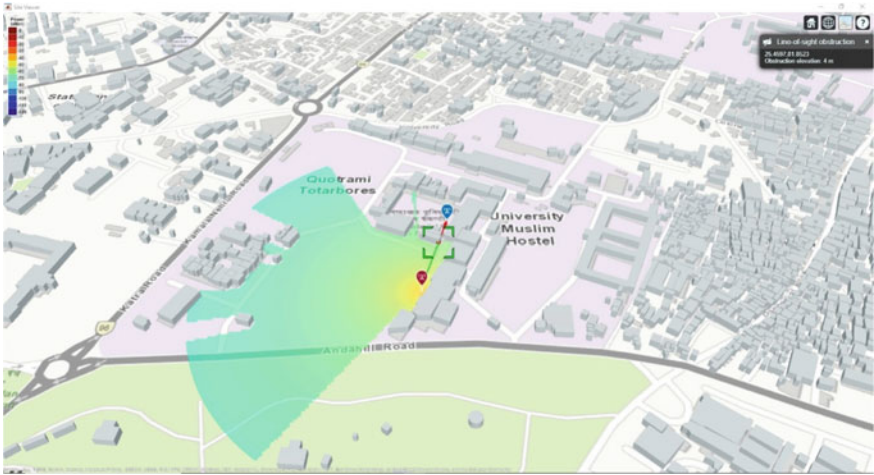


Fig. 4 Line-of-sight propagation with obstructed path

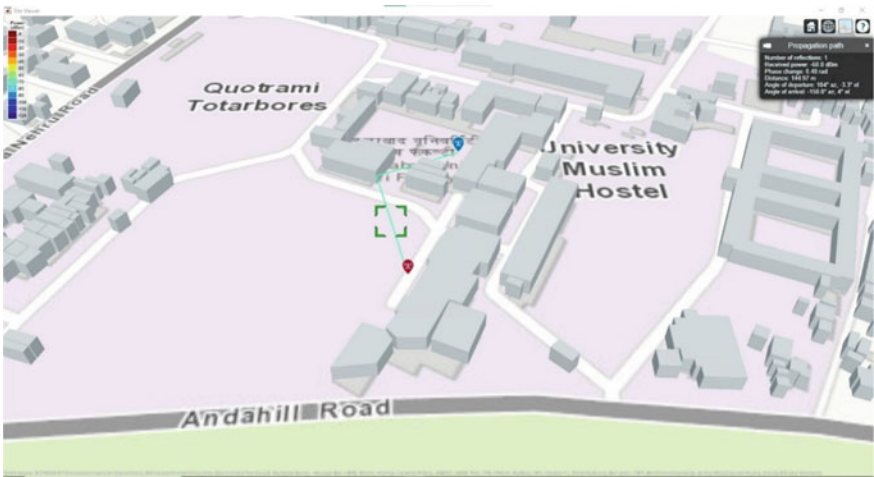


Fig. 5 Non-line-of-sight propagation with single reflection

into concrete walls. The small cell receiver shows that 250 m strong coverage in the millimetre-wave spectrum. The incapability of ray tracers to model smaller objects has also been found along with the contribution to additional rays. It has been known that now the 5G wireless communication networks are being set up globally since 2020 with extra competencies like high data rate, larger bandwidth, and guaranteed low latency. Though it is likely that 5G will not meet all expectations in the future until 2030 and beyond, 6G wireless communication networks will likely deliver worldwide coverage, the better quality of service, and security, amongst other things.

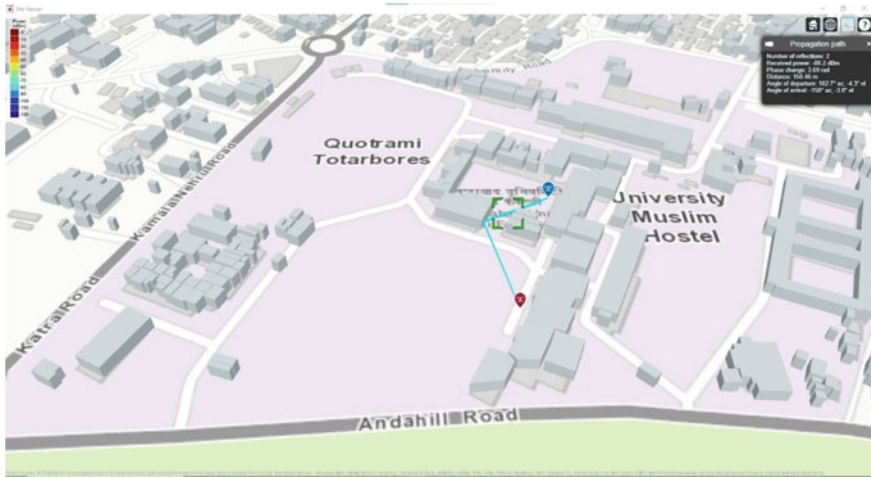


Fig. 6 NLOS propagation with weather loss and effect of material (concrete)

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