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Principal Multipath Component Analysis for Outdoor Microcell Scenario at 39 GHz

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Abstract

Tremendous research funding and efforts have been invested in millimeter-wave (mmWave) communication systems for fifth-generation (5G) and beyond wireless communications. Understanding the influence of the surrounding environment on the propagation channel is vital to mmWave system design and deployment. In this paper, principal multipath components (MPCs) are studied in in an outdoor microcell scenario at 39 GHz. The direction-scan channel sounding measurement is conducted in a typical urban living district. By adapting the 3D environment model and material parameters, the ray-tracing simulator is tuned to match the simulated MPCs with the measurement. Based on this, the main propagation mechanisms and influential objects are identified. The method, observations, and analysis in this work are useful for understanding mmWave channel and developing communication systems.

1 Introduction

In the past five years, tremendous research funding and efforts have been invested in millimeter-wave (mmWave) communication systems for fifth-generation (5G) and beyond wireless communications. The World Radio Conference in 2019 (WRC-19) approved a number of mmWave bands for 5G, including 24.25-27.5 GHz, 37-43.5 GHz, and 66-71 GHz. Due to the importance of mmWave channel modeling and the novelty of using frequencies above 6 GHz for mobile communications, many researchers around the world are active in sharing knowledge on mmWave channel characteristics and producing accurate channel models for different environments. Among which, extracting the multipath components (MPCs) and their power-time-spatial features from channel measurement is a primary step.

In order to meet this demand, channel measurement technologies have been evolving from single element narrowband to (virtual) array wideband [1]. High-resolution parametric methods like Space-Alternating Generalized Expectation-maximization (SAGE) and MUSIC [2] are widely used to extract parameters. The authors of [2, 3, 4] employ a direction-scan method, in which the transmitter (Tx) and receiver (Rx) can be rotated to scan and collect the angular information of the channel. Directional horn antenna is usually used. Narrower the half-power beamwidth (HPBW) results in better scanning resolution, while the number of rotating steps and the scanning time increase. Although the information on angles of departure and arrival can be estimated via advanced measurement technology, it is still challenging to reveal the exact propagation mechanisms and the interactions among objects. Therefore, the observation can mislead the decision on clustering and parameter characterization for channel modeling. To tackle this problem, the works in [5, 6, 7] employ ray-tracing (RT) technology. With classical but evolving propagation models of reflection, diffuse scattering and diffraction, RT can accurately describe multi-path effects for a given environment model and deployment configuration [8]. Each simulated MPC contains detailed information on intersection points and objects, delay time, angle of arrival, and angle of departure. The results of the aforementioned works indicate that the combination of RT with limited channel measurement is very useful in revealing propagation mechanisms and exploring hidden features of the channel.

In this work, principal MPCs are studied with 39 GHz outdoor microcell deployment. The direction-scan channel sounding measurement is conducted in a typical urban living district. The ray-tracing simulator is tuned in terms of the 3D environment model and the material-related parameters to match the principal MPCs with the measurement in power, delay time and angular domains. Based on this, the main propagation mechanisms and important objects are identified. The method, observations, and analysis in this work are useful for understanding the propagation channel and developing mmWave communication systems.

The rest of this paper is organized as follows. Section 2 describes the channel measurement campaign and system. Principal MPCs and the influence of the surrounding objects are analyzed in Section 3. Conclusion are drawn and future work is described in Section 4.

2 Measurement Campaign and System

The channel measurement is conducted at the campus of China Research Institute of Radio Propagation in Qingdao.

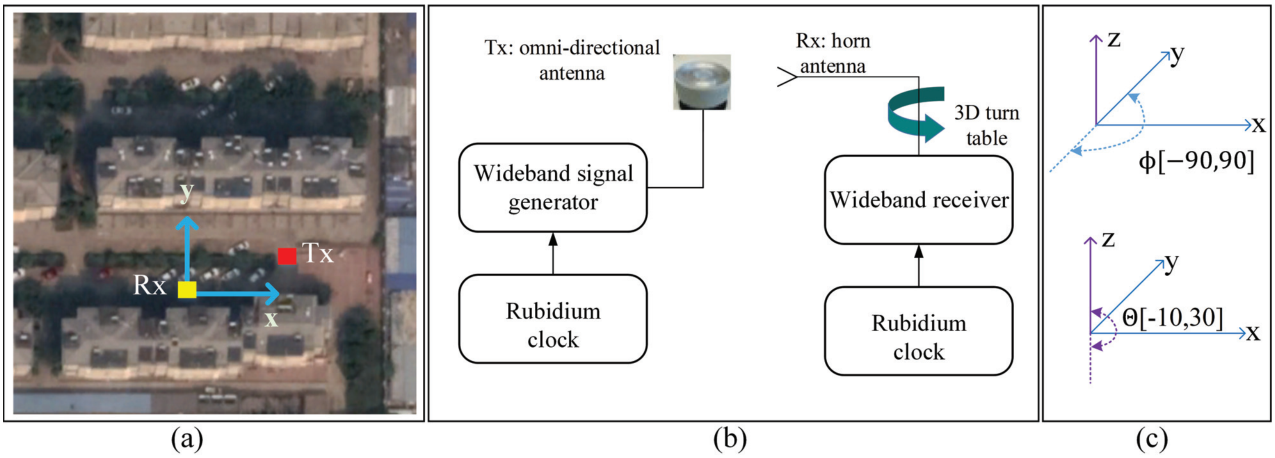

Figure 1. Measurement information: (a) the bird's view of the measurement campaign, (b) the measurement system, (c) the coordinate system

Table 1. Measurement setup

Center frequency	39 GHz
Bandwidth	1 GHz
Sample length	1024
Transmitting power	40 dBm
Tx/Rx height	9 m/1.5m
Tx/Rx antenna type	Omnidirectional/ horn antenna
Tx/Rx antenna gain	3 dBi/24 dBi

The bird's view of the measurement campaign is shown in Fig. 1(a). The height of the Tx antenna is 9 m above the ground and the height of the Rx antenna is 1.5 m. A time-domain channel sounder is used together with the direction-scan method. The hardware architecture is shown in Fig. 1(b), and the system-level parameters are listed in Table 1. The signal is transmitted using a vertical-polarized omnidirectional antenna. The Rx antenna is vertically polarized with HPBW=10°. Both the Tx and the Rx are synchronized using a high precision rubidium clock. After a back-to-back calibration method between the Tx and the Rx, the measurement starts and the Rx antenna rotates. In order to obtain the complete three-dimensional(3D) angle-of-arrival information, the horn antenna is rotated from -90° to 90° with 5° angular step in the azimuth plane, and from -10° to 30° with 10° angular step in elevation domain (see Fig. 1(c)). There is no moving car or person in the area during the measurement. In the end, 37*5 directional channel impulse responses (CIRs) are obtained for further analysis.

3 Result Analysis

The 37*5 directional CIRs are merged into one omnidirectional CIR by selecting the maximum value for each delay step, and the omnidirectional power delay profile (PDP) is shown in Fig. 2. The average noise level is -75 dBm, the standard deviation is 5 dB. By selecting -70 dBm as the threshold of the noise floor, the concatenated PDPs derived

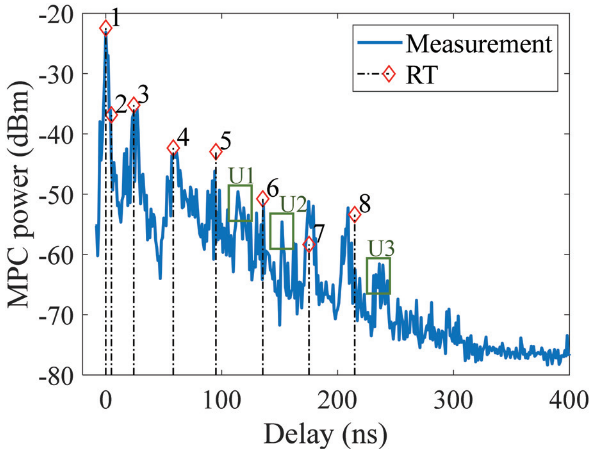

Figure 2. Omnidirectional PDP

from the azimuth plane and elevation domain are shown in Fig. 3 and Fig. 4, respectively. AOA is the azimuth angle of arrival and EOA is the elevation angle of arrival.

Based on the measurement, the 3D environment model is constructed for RT simulation (see Fig. 5). The main objects are buildings at both sides (B1 and B2), lamps (L) in the middle and the ground (G). The simulation configuration is the same as the measurement setup, except that omnidirectional antenna is used at both Tx and Rx to reproduce the omnidirectional CIR. Direct propagation and reflection propagation with a maximum of 6 bounces are considered. After manually tuning the geometric relationship among objects and the material parameters, most of the principal MPCs including the direct path and the reflection paths are traced. Fig. 5 shows the 3D view of the 8 traced rays. Table 2 details the propagation mechanisms and quantized differences between the simulation and the measurement. Due to the limit of measurement resolution, the differences of delay, AOA and EOA are calculated by using corresponding resolution steps.

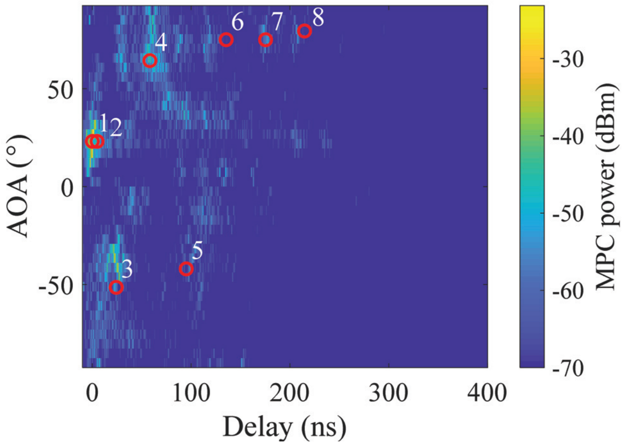

Figure 3. Concatenated PDPs in azimuth plane

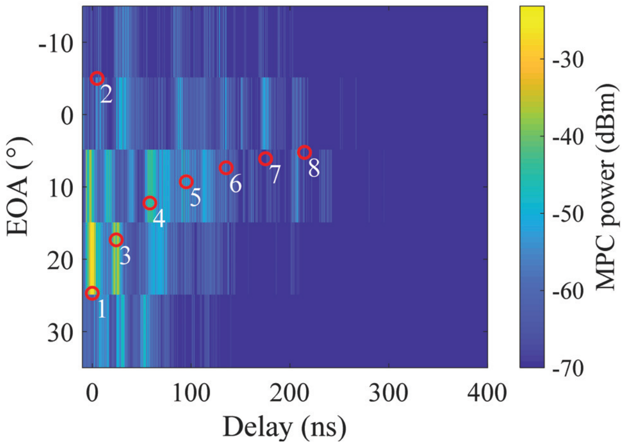

Figure 4. Concatenated PDPs in elevation plane

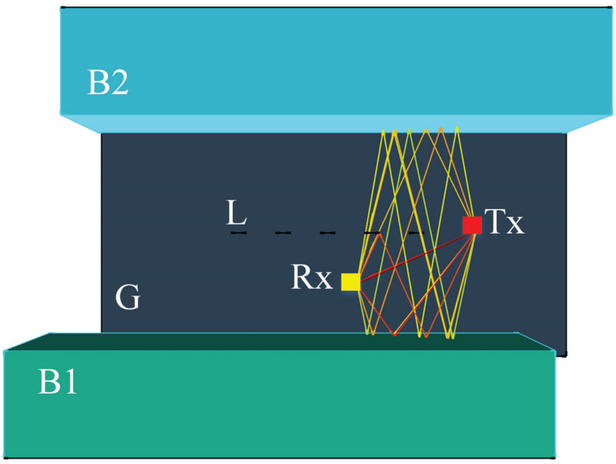

Figure 5. The 3D model and traced rays

The average error of power is around 1.66 dB. The maximum delay difference is 4 ns, and 7 out of 8 rays are with 0 ns delay difference. The maximum angle difference is 10°, and 7 out of 8 rays are correctly matched. The results indicate that the principle MPCs are capture and correctly identified. U1-U3 are the missed principal MPCs, which might be multiple reflections due to the lamps and irregular balconies of buildings.

Table 2. Details of the traced principal MPCs

MPC ID	Route	Differences			
		Power (dB)	τ	AOA	EOA
1	Tx-Rx	0.68	0	0	0
2	Tx-G-Rx	-0.81	0	0	0
3	Tx-B1-Rx	0.87	0	2	0
4	Tx-B1-L-Rx	1.23	0	0	0
5	Tx-B2-B1-Rx	3.22	0	0	0
6	Tx-B1-B2-Rx	0.88	0	0	0
7	Tx-B2-B1-L-Rx	4.20	0	0	0
8	Tx-B2-B1-B2-Rx	-1.10	4	0	0

The buildings of both sides result in reflection paths with up-to 3 bounces, the lamps contribute to two reflection paths. Although the surrounding objects can cause M-PCs with large delay time, by using MIMO technology or directional antennas, the inter-symbol interference can be easily eliminated, while the diversity gain can bring considerable benefits due to the distinguishable angular difference among the principle MPCs.

4 Conclusion

Extracting MPCs and corresponding power-time-spatial domain parameters have significant impacts on clustering and parameter fitting, hence they are fundamental and challenging for mmWave channel modeling. In this work, the direction-scan channel sounding measurement is conducted with 39 GHz microcell configuration in an urban living district. The ray-tracing simulator is employed to assist in analyzing the MPCs. According to the comparisons, the simulation results matched with the measurement in power, delay, and spatial domains. The main propagation mechanisms and interactions among the objects are therefore identified. It is observed that the direct path and the reflection paths with up-to 3 bounces are the principle MPCs. The buildings, ground, and urban furniture like the lamps are significant in generating strong MPCs. The method, observations, and analysis in this work are useful for the design and deployment of mmWave communication systems. In the future, a more generalized joint geometry-electromagnetic RT tuning method will be investigated to effectively tackle the challenges of the high requirement on 3D environment modeling and reducing simulation error.

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