Polarimetric Wideband Directional Channel Measurement and Analysis for Outdoor Small Cell Scenarios at 32 GHz and 39 GHz

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Abstract—Wideband millimeter-wave (mmWave) directional propagation measurements were conducted in the 32 GHz and 39 GHz bands in outdoor line-of-sight (LoS) small cell scenarios. The measurement provides spatial and temporal statistics that will be useful for small-cell outdoor wireless networks for future mmWave bands. Measurements were performed at two outdoor environments and repeated for all polarization combinations. Measurement results show little spread in the angular and delay domains for the LoS scenario. Moreover root-mean-squared (RMS) delay spread at different polarizations show small difference which can be due to specific scatterers in the channel.

Index Terms — Millimeter-Wave, propagation channel measurement, directional, small-cell, RMS delay spread, full polarimetric.

I. INTRODUCTION

There is growing interest in industry and academia to use millimeter wave (mmWave) frequencies where wide spectrum is available for short-range hotspots or small cell operations in dense urban environments [1]–[3]. On the other hand, fundamental knowledge of the channel propagation characteristics in this new frequency bands is vital for a system and network design. By considering these, and the fact that many new environments are considered for mm-wave deployment, necessitate the need for new channel models at different mmWave frequencies [4], [5]. To characterize mmWave channel, there have been several mmWave channel measurement campaigns at various frequency bands, recently. For example, channel measurements at 81 GHz band over 5 GHz of bandwidth for point-to-point communications in a long street canyon environment have been performed in Helsinki, Finland [6]. The results prove that line-of-sight (LoS) component is dominant and also multipath exist in this band (81-86 GHz). Also, several channel measurement campaigns for the 28 GHz have been conducted, and path loss, RMS delay spread, and multipath effects have been studied.

Measurements presented in [7] indicates that higher transmitter (TX) antenna height can increase the coverage compared to the lower heights, due to fewer obstructions. Multipath delay spreads, number of multipath components, and large-scale path loss have been studied by New York Univer-

sity (NYU) wireless research centre at 28 GHz, 38 GHz, and 73 GHz for access and backhaul scenarios and the first 3-D measurement-based mmWave wideband statistical channel impulse model for 28 GHz propagation is presented [8].

Two-dimensional and three-dimensional statistical spatial channel models for across the mmWave bands were developed by NYU and presented in [9] and [10]. According to the literature; there are still several measurements to be carried out at different mmWave frequency bands to investigate channel propagation at mmWave bands. Considering two of the unlicensed mmWave frequency bands; 32 GHz and 39 GHz, this paper presents measured results from wideband feasibility studies conducted in outdoor environments.

To the best of our knowledge, there is only one study on propagation channel at 32 GHz which has been conducted with omnidirectional TX antenna over 1 GHz bandwidth [11]. While there are several studies at 38 GHz band (mainly measurement bandwidth was less than 1 GHz), there are few studies on channel propagation characteristics at 39 GHz. In this paper, we present channel characteristics of 32 GHz and 39 GHz with a wideband directional setup with 2 GHz bandwidth. Another motivation of this channel campaign was to study the effect of the antenna polarization on propagation parameters by considering an appropriate resolution in delay and azimuth for proposing a wideband, directional channel model for 5G small cell scenarios at 32 GHz and 39 GHz. For this purpose, a measurement campaign was performed on the campus of University of Surrey, UK. The scenario of measurement is outdoor LoS small-cell. Details of the measurement process, parameters, and the analysis of the measurement data are presented in the following.

II. MEASUREMENT DESCRIPTION

A. Measurement Setup and Equipment

As shown in Fig. 1, a computer (PC) is used to control the antenna rotator table and spectrum analyzer using LAN. A wideband signal generator (R&S®SMW200A) is used to transmit sounding signal. At the receiver (RX), signal analyzer R&S®FSW67 performs down conversion and base-band sampling of the received signal. The signal generator is

Fig. 1. Automatic channel measurement setup.

capable of upconverting the generated signal to 40 GHz. Due to its outstanding autocorrelation properties, Frank-Zadoff-Chu (FZC) sequence is employed as the sounding signal which provides high autocorrelation properties. The sounding signal is transmitted with the power of 17 dBm over 2 GHz bandwidth. The signal analyzer FSW67 offers a built-in low-noise pre-amplifier and captures I/Q data to be processed by the Matlab based sounding software tool (R&S TS-SGC). An R&S®RTO1044 oscilloscope offers a wide bandwidth ADC conversion to support 2 GHz sounding bandwidth. Baseband digitized data is then sent back to the signal analyzer.

Wideband, directional horn antenna with 54° half-power beamwidth (HPBW) is used at the transmitter with the gain of 10 dBi at 39 GHz and bandwidth of 13.5 GHz from 26.5 GHz to 40 GHz. V-H, H-V, H-H, and V-V antenna polarizations are conducted where the first symbol refers to the TX antenna polarization and the latter to the RX antenna polarization. A wideband, directional horn antenna is used at the receiver with roughly the same gain in both E- and H-planes. HPBW of the receive antenna is 8° which is narrow enough to capture directional channel impulse response (CIR) with high resolution in azimuth-of-arrival. A precision rotating table is used to scan the azimuth at the receiver with rotation steps of 8°. Before the practical channel measurement, the signal generator was directly connected to the FSW to obtain calibration data. To obtain accurate path loss values, the transmit/receive (TX/RX) antennas are both rotated to be aligned with each other according to their specific three-dimensional coordinates in the LoS scenario. Specification of the TX antenna, RX hardware and equipment are given in Table I.

B. Measurement Environments and Procedures

Outdoor measurements have been carried out in two different environments. First environment (Route 1) was on the pavement close to the 5G Innovation Centre building at the University of Surrey. The exterior of the building is mixed of glass and metal, and the other side of the route is a wide street. The first measurement point was 5 m away from the

TABLE I
SOUNDING SETUP SPECIFICATIONS

Carrier Frequency	32 GHz	39 GHz
Sounding Waveform	Frank-Zadoff-Chu 65535	
RF Bandwidth	2 GHz	
Transmit Power	17dBm	
Delay Resolution	0.5 ns	
TX Polarization	Vertical / Horizontal	
RX Polarization	Vertical / Horizontal	
TX E-Plane HPBW	54°	
TX H-Plane HPBW	54°	
RX E-Plane HPBW	8°	
RX H-Plane HPBW	8°	
Height of TX Antenna (h_T)	5 m	
Height of RX Antenna	1.7 m	
TX Antenna Gain	10 dBi	
RX Antenna Gain	23 dBi	25 dBi

base station with 5 m height, and the last point was 40 m in the first route (Route 1). The second environment (Route 2) is different from the first route as it is surrounded by a different building with a different type of material such as brick, windows, and metal. The width of the canyon street is about 7 m surrounded by buildings which mainly enclosed by glass and metal frames. For each location, TX position is fixed while the RX antenna moves along a straight route with 5 m separation. The number of measurement sites in each cell was set to capture an appropriate statistical sample of the propagation channel. In each point of measurement, RX antenna without changing the elevation setting is rotated in azimuth in small steps of 8°. Also, the measurements have been repeated for different antenna polarizations and 9000 snapshots have been recorded for one polarization at each measurement point. In both routes, the height of TX and RX antenna was kept at 5 and 1.7 m, respectively.

During the measurement, there was no vehicular movement, and human activities were minimized. So the channel was considered as time-invariant.

III. MEASUREMENT RESULTS

Measured CIRs for different polarization at both frequencies are derived with a delay resolution of 0.5 ns and azimuth angular resolution of 8°. At each azimuth angle-of-arrival, 200 snapshots of the CIR are captured and averaged. To get the omnidirectional power delay profile (PDP) at each measurement point, the directional delay profiles are added to all 45 azimuth-of-arrivals.

Fig. 2a and 2c shows the normalized directional received power for Route 1 versus azimuth angle-of-arrival at each measurement point to at 32 GHz and 39 GHz for H-H polarization, respectively. It can be observed from the figures that other than LoS components there are occasional strong components due to reflection or scattering in the channel.

Fig. 2b and 2d also present directional received power at 32 GHz and 39 GHz respectively for H-H polarization on the second route. Similar tendency as Route 1 is observed. In Fig. 2b and 2d for TX-RX = 35 m, lower received power has been observed at LoS. This is due to the presence of a gradient

Fig. 2. Normalized received power at (a) 32 GHz [Route 1], (b) 32 GHz [Route 2], (c) 39 GHz [Route 1], (d) 39 GHz [Route 2], for H-H antenna polarization.

Fig. 3. 32& 39 GHz RMS delay spread CDFs for different polarization [Route 1].

in the street (ramp) when TX-RX separation is 35 m. This changed the elevation angle of the RX antenna making it to misaligned with the TX antenna.

Fig. 3 shows the cumulative distribution function (CDF) for the root mean square (RMS) delay spreads of the PDPs measured over all pointing angles at 32 GHz and 39 GHz for H-V, V-V and H-H antenna polarization for Route 1. The RMS delay spread of the channel τ_{rms} , is calculated as

$$\tau_{\text{rms}} = \sqrt{\frac{\sum_i P_i (\tau_i - \tau_{\text{mean}})^2}{\sum_i P_i}} \quad (1)$$

where, τ_i is the delay of the i th multipath with received power of P_i , and τ_{mean} is the average delay of the multipath.

In (1) a threshold of S dB below the maximum peak must be applied to the individual values of the averaged PDP to distinguish the multipath components from the noise [12]. Note that the value of S , directly affects the value of τ_{rms} . Commonly used values of S which can be found in literature include 15, 20, and 30 dB below the maximal which set the threshold 5-30 dB above the noise floor depending on the measurement position. In this paper all RMS delay spread values for H-H and V-V antenna polarization are calculated by considering only paths that exceeded 35 dB threshold below the maximum peak ($S=35$ dB) so that the PDPs will have a wide dynamic range and fair comparison between two different frequency bands as their noise floors have different values. In this case, it can be observed from Fig. 3, that 90% of the measured RMS delay spreads are less than 33.3 ns and 40 ns at 32 GHz for H-H and V-V antenna polarization respectively, which is an indication that 90% of the energy arrived at RX in less than 40 ns at 32 GHz for all measured arbitrary pointing angles. For 39 GHz, it is apparent that 90% of the RMS delay spreads are below 22.6 and 23.6 ns for H-H and V-V antenna polarization respectively.

To calculate RMS delay spreads for H-V antenna polarization, 20 dB threshold has been applied due to short dynamic range in this case, and as it is expected, their values are small for H-V antenna polarization at both bands. 5.4 ns and 4.2 ns were calculated for 32 GHz and 39 GHz respectively, which are smaller than H-H and V-V cases because cross-polarized signal components are generated by depolarized multipath due to reflection and diffraction. As it can be seen from Fig. 3, the RMS delay spread at 39 GHz is smaller than at 32 GHz for each polarization which is similar to results reported in [8] when comparing RMS delay spreads of 28 GHz, 38 GHz, and 73 GHz. The difference is due to the fact that greater energy is scattered at lower mmWave frequencies. On the other hand, wavelengths at 39 GHz are smaller than at 32 GHz which cause more diffuse scattering during propagation that results in weaker path making it not detectable in the receiver.

To illustrate this point; Fig. 4 is presented to show the omnidirectional power delay profile at Route 1 for various polarization combinations at 32 GHz and 39 GHz. It is observed that the spread of the channel in the delay domain is limited as expected for mmWave scenarios, for the copolarized channels V-V and H-H. Moreover, there was hardly any cross polarization component in the channel.

Fig. 5 shows the CDF of RMS delay spread at 32 GHz and 39 GHz for different antenna polarizations (H-V/H-H /V-V) at Route 2. It must be noted that the RMS delay spread H-H is less than V-V at both frequencies. Also the RMS delay spread for H-V is much less than that of other polarization as is expected at both mmWave frequency bands. Similar to Route 1, RMS delay spread values at 39 GHz are less than that at 32 GHz. 90% of the measured RMS delay spreads are less than 41.35 ns and 56 ns at 32 GHz for V-V and H-H scenarios respectively, showing that 90% of the energy arrived at the receiver less than 56 ns at 32 GHz for all measured arbitrary pointing angles with different antenna polarization. 39.8 ns

Fig. 4. Omnidirectional power delay profile at each measurement point at (a) 32 GHz (H-H), (b) 32 GHz (H-V), (c) 32 GHz (V-V), (d) 39 GHz (H-H), (e) 39 GHz (H-V), and (f) 39 GHz (V-V) [Route 1].

Fig. 5. 32 & 39 GHz RMS delay spread CDFs for different polarization [Route 2].

and 32.6 ns has been calculated for V-V and H-H scenarios at 39 GHz respectively. 4.1 ns and 3.4 ns were calculated from measured results for H-V antenna polarization at 32 GHz and 39 GHz respectively. RMS delay values at Route 2 are greater than that at Route 1 due to more scatter in the environment.

IV. CONCLUSION

Wideband directional mmWave outdoor propagation channel measurements for small scenario at 32 GHz and 39 GHz for various polarizations are presented. The delay resolution is 0.5 ns while high gain directional antenna with 54° HPBW at transmitter side, and mechanically steerable antenna with 8° HPBW at receiver side have been used. Measurement in two different environments which include different type of building were performed on campus of University of Surrey. Channel characteristics such as power angular spectrum as well as RMS delay spread are presented and discussed. It is found that LoS components are dominant, but there are also occasional strong components due to specular reflections from buildings. The RMS delay spread of the directional received signal shows a small delay spread around the dominant received signal components. Also, in both Routes, it was observed that RMS delay spread values for H-H polarization are less than that of V-V configuration. The main reason is due to the way the signals with different polarization are de-polarized in the channel. As main reflectors are vertical in the measurement environments, for V-V polarization configuration, less depolarization occurred compared to the H-H scenario. Note that transmitted signal with H-polarization has electric field parallel to the plane of incidence (perpendicular to the vertical reflectors plane), so the chance of depolarization is increased. However, if a vertically polarized wave is incident on a

(a)

(b)

Fig. 6. Measurement environment (a) Route 1, (b) Route 2.

vertical reflector, the reflected wave remains mainly vertically polarized. Finally, in H-H configuration de-polarization will affect the number of observed multipath arriving at RX due to polarization mismatch between transmitted signal and reflected signals observed at RX. So the RMS delay spread are smaller than that for V-V configuration.

ACKNOWLEDGMENT

We would like to acknowledge the support of University of Surrey 5GIC (<http://www.surrey.ac.uk/5gic>) members for this work. Also, authors would like to thank Rohde and Schwarz for the support during the channel measurement campaign.

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