26 GHz Indoor Wideband Directional Channel Measurement and Analysis in LoS and NLoS Scenarios

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Abstract—This paper presents details of the indoor wideband and directional propagation measurements at 26 GHz in which a wideband channel sounder using a millimeter wave (mmWave) signal analyzer and vector signal generator was employed. The setup provided 2 GHz bandwidth and the mechanically steerable directional lens antenna with 5 degrees beamwidth provides 5 degrees of directional resolution over the azimuth. Measurements provide path loss, delay and spatial spread of the channel. Angular and delay dispersion are presented for line-of-sight (LoS) and non-line-of-sight (NLoS) scenarios.

Index Terms — 26 GHz, Millimeter-wave, indoor, LoS, NLoS, propagation angular spread, delay spread, 5G.

I. INTRODUCTION

Fifth generation (5G) mobile network is undergoing to develop to overcome high data traffic and escalating request for higher transmission speed and it is anticipated to deploy initially by 2020. Furthermore, in the boundless demand of higher bandwidth for wireless communications, millimeter wave (mmWave) spectrum bands are becoming more interested as lower wireless frequency bands (below 6 GHz) are not free to be used for future needs. Although mmWave bands offers a higher capacity, but little information are at hand about the channel propagation at mmWave carrier frequencies. On the other hand, channel propagation measurements at mmWave frequency bands in outdoor and indoor environments are essential to create statistical channel models to develop new technologies and standards for future wireless communication systems. Many studies have been conducted at mmWave bands in indoor environment, mostly in the 60 GHz band [1]–[4].

On the other hand, fundamental knowledge of the channel propagation characteristics that can predict signal strength and multipath time delays in these new frequency bands are vital to conduct 5G system design precisely. By considering these, and the fact that many new environments are considered for mm-wave deployment, necessitate the need for new channel models at mmWave frequencies. To fill this research gap, there have been several mmWave channel measurement campaigns at different frequency bands, recently.

New York University conducted indoor mmWave channel measurement at 28- and 73 GHz [5]. Rotatable directional antennas have been employed in the channel measurement

where directional and omni-directional path loss models and RMS delay spreads have been studied.

In [6], reflection and penetration loss measurement at 28 GHz is performed and a large penetration loss of 45 dB through an office building is reported. In [7], wideband measurement campaigns have been conducted in the two mmWave bands of 60 GHz and 70 GHz in railway stations, indoor shopping malls, and office environment using VNA over 5 GHz bandwidth. Zhu et al. performed indoor channel measurement and presented large-scale fading channel parameters at 45 GHz using different type of antennas [8].

In [9], 28 GHz indoor channel measurements have been performed by means of the rotatable horn antennas that steered the whole azimuth-plane using VNA channel sounding method. There are still several indoor channel measurements to be conducted at different frequency bands to investigate channel propagation at mmWave bands. Currently, Ofcom proposed 26 GHz band as a pioneer band for 5G in Europe [10].

To study of the channel characteristics at 26 GHz band, wideband and highly directional channel measurements have been performed in indoor environment over 2 GHz bandwidth. The ultimate purpose of this measurement campaign was to acquire a reliable set of data with appropriate resolution to study the line-of sight (LoS) and non-line-of-sight (NLoS) scenarios in indoor environment. RMS delay spreads of channel and power angular spectrum for LoS and NLoS have been studied and details of measurement description, parameters as well as the analysis of the measurement data are presented below.

II. CHANNEL MEASUREMENT CAMPAIGN

The wideband and directional measurement campaign were performed in line with the concept of the next cellular mobile network generation, which employs the highly directional steerable antennas at mmWave operating frequency bands. This measurement campaign targets to explore the delay and angular dispersion of mmWave indoor small-cell propagation channel at 26 GHz over 2 GHz bandwidth.

A. Measurement Equipment and Hardware

A Rohde & Schwarz signal generator R&S®SMW200A is used to transmit continuous wave signal in power of 17dBm.

Fig. 1. Map of the second floor plan of 5GIC with TX and RX locations.

The received signal is recorded by a Rohde & Schwarz signal analyzer R&S®FSW67 to capture I/Q data, later the R&S® TS-5GCS software tool processes received data which enables us to perform channel sounding measurement. FSW and SMW are connected with two cables to be synchronized by a reference frequency, and the measurement is started by a trigger signal. To support bandwidths up to 2 GHz, an R&S®RTO1044 oscilloscope is provided to operate with the FSW. The oscilloscope offers a wide bandwidth D/A conversion. Antenna rotator table, which is connected to the control machine by the fiber optic cables, enables azimuth scanning at RX with a rotation increment step of 5° . A computer (PC) is used to not only control the antenna rotator table, but also control the FSW using the LAN.

B. Transmitter and Receiver Antennas

Wideband and directional lens antenna is used as the receiver side (RX) with same gain in both E- and H-plane of 24 dBi at 26GHz. Half power beam width (HPBM) of the RX antenna is 5° in both planes, which is narrow enough to obtain directional channel impulse responses (CIRs) with high resolution in azimuth of arrival and delay. At transmitter (TX) side, quasi-directional horn antenna with 61° HPBM is used in the channel measurements with gain of 6.8 dBi. Both TX and RX antenna are vertically polarized. Before starting the channel measurements, the SMW was directly connected to the FSW to take calibration data. Specification of the TX and RX antennas and hardware along with measurement equipment and setup are provided in Table I.

TABLE I
26 GHZ WIDEBAND CHANNEL SOUNDING SPECIFICATION

Sounding Waveform	Frank-Zadoff-Chu 65535
RF Bandwidth	2 GHz
Transmit Power	17 dBm
Delay Resolution	0.5 ns
TX E-Plane HPBW	78°
TX H-Plane HPBW	61°
RX E-Plane HPBW	5°
RX H-Plane HPBW	5°
Height of TX Antenna (h_T)	2.7 m
Height of RX Antenna	1.5 m
TX Antenna Gain	6.8 dBi
RX Antenna Gain	24 dBi

C. Measurement Environments and Experimental Procedures

Propagation measurements were performed on the second floor of the 5G innovation center (5GIC), University of Surrey, U.K. The second floor is a typical office environment surrounded by different obstructions such as offices, doors, desks, chairs, elevator, walls made of glass and drywalls. Fig. 1 displays the detailed floor plan and measuring arrangement of the measurement environment. TX antenna is placed 2.7 m above the ground to emulate common indoor hotspot locations, and RX antenna is placed 1.5 m above the ground, which is at a typical handset level height. The TX antenna is fixed and as shown by the green dots in Fig. 1, RX antenna moves along a L-shaped path for LoS scenario. For NLoS scenario, 7 measurement points shown by orange dots in Fig. 1, have been selected. In each point of measurement, RX antenna is rotated along the azimuth in small steps of 5° without changing the elevation setting. The separation distance between TX and RX was varied between 4 to 28 m with adjacent separation of 2 m for LoS. The scenario was arranged in such a way to ensure the stationarity of the channel. No human activity existed during the channel measurements, so the channel can be considered as time-invariant. Fig. 2 shows the LoS measurement when TX-RX separation is 24 m.

Fig. 2. LoS Measurement when TX-RX = 24 m.

Fig. 3. (a) LoS absolute directional received power versus azimuth angle of arrival at each measurement point, (b) NLoS normalized directional received power versus azimuth angle of arrival at each measurement point, (c) LoS Omnidirectional power delay profile at each measurement point, (d) NLoS Omnidirectional power delay profile at each measurement point.

III. MEASUREMENT RESULTS

The CIRs are derived with a delay resolution of 0.5 ns (measurement bandwidth = 2 GHz) and azimuth angle of arrival resolution of 5° . At each measurement point, 14400 CIRs (200 snapshots $\times$ 72 ($360^\circ/5^\circ$) angles) were acquired at the receiver but to filter out the small scale fading of each single CIR, measured CIRs are averaged over each direction on the azimuth at each measurement point to form a power delay profile (PDP).

A. LoS Scenario

To simplify the characterization of the channel power dispersion, a set of parameters can be extracted from the PDP. The angular dispersion is expressed with the angular spread

from the power angular spectrum (PAS), which characterizes how the signal power varies over an angle. Fig. 3 (a) displays the LoS directional received power versus angle of arrival at each measurement point to present the angular dispersion at 26 GHz for V-V antenna polarization. From Fig. 3 (a), it can be observed that not only LoS components are strong (shown at $= 0^\circ$), but also, there are other strong components at other angle of arrival mainly referring to the reflections from different clusters in the environment when RX antenna is rotated towards them. To get the omnidirectional PDP at each measurement point, the directional delay profiles are added over all 72 azimuth-of-arrivals. Fig. 3 (c) also, shows the LoS omni-directional received power versus delay at each measurement point to present delay dispersion of the channel.

(a)

(b)

Fig. 4. NLoS measurements (a) RX close to the edge of the wall [50λ], (b) RX far from the edge of the wall [90λ].

B. NLoS Scenario

To measure the channel in NLoS scenario, propagation measurement have been conducted in 7 different points. RX antenna positions were selected at different distances from the edge of the walls (equal to multiples of a wavelength). Directional received power at different measurement points has been presented in Fig. 3 (b). It can be seen that when RX antenna is sufficiently close to the edge of the obstacle, strong multipath component can be observed at the receiver, possibly owing to both diffraction and LoS path. Fig. 3 (d) presents the omni-directional NLoS received power that exhibits delay dispersion due to reflections and diffractions. Fig. 5 shows a comparison between 2 different NLoS measurement points at different distances from the edge of the obstacle. It is found that, when RX antenna is close to the edge of the obstacle, strong received power is observed at the receiver.

Fig. 5. PDPs of NLoS scenarios.

IV. CONCLUSION

Indoor wideband directional channel measurements were conducted to obtain channel characteristics at the 26 GHz band in LoS and NLoS scenarios. Channel characteristics such as angular and delay dispersion are presented and discussed. It is found that LoS components are dominant and there are other strong specular reflections in the receiver from other directions. Also, small delay spread around the dominant received signal components was observed. In NLoS scenarios, we observed strong multipath component at the receiver owing to reflection, diffraction and a combination of diffraction and LoS rays. This is dependent on the distance of receiver and transmitter antennas at the edge of the wall or obstacle, along with the azimuth-angle-of-arrival depending on the rotation of the receiver antenna.

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