Channel Measurement and Analysis for Polarimetric Wideband Outdoor Scenarios at 26 GHz: Directional vs Omni-Directional

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Abstract—This paper presents the measurement results and analysis for outdoor wireless propagation channels at 26 GHz over 2 GHz bandwidth for two receiver antenna polarization modes. The angular and wideband properties of directional and virtually omni-directional channels, such as angular spread, root-mean-square delay spread and coherence bandwidth, are analyzed. The results indicate that the reflections can have a significant contribution in some realistic scenarios and increase the angular and delay spreads, and reduce the coherence bandwidth of the channel. The analysis in this paper also show that using a directional transmission can result in an almost frequency-flat fading channel over the measured 2 GHz bandwidth; which consequently has a major impact on the choice of system design choices such as beamforming and transmission numerology.

Index Terms — Millimeter-Wave, propagation channel measurement, directional, RMS delay spread, coherence bandwidth, angular spread, 26 GHz, 5G.

I. INTRODUCTION

Millimeter wave (mmWave) frequencies have been recently adapted in telecommunication standards such as the fifth generation (5G) of mobile networks [1]. In such bands, large chunks of unlicensed spectrum are available and can be used to achieve high data rates. As a result, a lot effort has been focused on developing mmWave communication technology and addressing the related challenges [2], [3]. Since designing wireless communication systems is directly related to the properties of the propagation channel, mmWave measurement campaigns for 5G mobile communications have been conducted across the world by different organizations including Samsung [4], [5], Nokia [6], New York University [7], University of Surrey [8]–[11], Mobile and wireless communications Enablers for the Twenty-twenty Information Society (METIS) [12] and Millimeter Wave Evolution for Backhaul and Access (MiWEBA) projects [13].

Recently, Ofcom, the regulatory organization in the UK, approved 26 GHz channels as a 5G band in the United Kingdom [14]. Although there are many measurement campaigns around the world that have investigated various scenarios for 28 GHz, 32 GHz, 38 GHz and other mmWave frequency bands [15], most of the work for 26 GHz channels have been focused on indoor scenarios [16]–[19]. The amplitude distribution of the channel at 26 GHz with 100 MHz bandwidth

Fig. 1. Block diagram of the channel sounding setup.

for a moving antenna in an indoor scenario is derived in [16]. Indoor measurements for multiple-input multiple output (MIMO) channels at 26 GHz and 200 MHz bandwidth are performed in [17]; and the authors investigated root mean square (RMS) delay spreads in such channels. The diffraction effects for 10, 20 and 26 GHz channels are investigated in [18]. The RMS delay and angular spreads for 26 GHz with 2 GHz bandwidth channels in open office environment are presented in [19]. [20].

At the University of Surrey, we conducted an extensive measurement campaign to measure and analyze several mmWave bands including 26 GHz channels [8]–[11]. Although the models for outdoor mmWave channels are derived in [8], it is necessary to also model the frequency-selectivity and the power angular spreads of the channel in practical systems. For example, the design of beamforming algorithms for mmWave systems, which comes with a lot of hardware constraints [20]–[23], is significantly related to the frequency-selectivity of the channel and the angular spreads of the multipath components in the channel. With this motivation, the current paper presents the measurement results and analysis for wideband outdoor channels at 26 GHz with a 2 GHz bandwidth. In particular, the RMS delay spread, coherence bandwidth and angular spreads are investigated.

TABLE I
SOUNDING SETUP SPECIFICATIONS

Carrier Frequency	26 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
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)	8 m
Height of RX Antenna	1.7 m
TX Antenna Gain	6.8 dBi
RX Antenna Gain	24 dBi

Then, the impulse response of the omni-directional channels are virtually created by superimposing the impulse response of the direction measurements. Comparisons to virtually omni-directional channels are made to highlight the impact of directional transmission on the coherence bandwidth and RMS delay spread of the channel.

II. MEASUREMENT SETUP

At the transmitter, a wideband signal generator (R&S®SMW200A) creates Frank-Zadoff-Chu (FZC) sounding sequence. A vertically polarized semi-directional horn antenna with 78° half-power beamwidth (HPBW) is fixed at 8 m height and transmits the sounding signal which is centered at 26 GHz and has a bandwidth of 2 GHz. The receiver has a directional lens antenna with 5° HPBW and 24 dBi gain. In addition, a R&S®FSW67 signal analyzer and a R&S®RTO1044 oscilloscope are used to down-convert and digitize the signals, respectively. The system block diagram and the summary of the measurement parameters are shown in Fig. 1 and table I, respectively.

The measurements took place at the University of Surrey in a canyon-type street under controlled environment. The surface of the surrounding building are mainly made from brick, large pieces of glass and metal, as shown in Fig. 2. The location of the transmit antenna was fixed; however, the receiver was located on a mechanically steerable table and moved away from the transmitter on a straight line over 18 uniformly spaced locations. The initial horizontal distance between transmitter and receiver was 5 m, and it increased to 90 m with 5 m steps. The height of the transmitter and receiver antennas were set to 8 m and 1.7 m above the ground, respectively. For each location, the measurements were performed over 200 snapshots for each of the vertical and horizontal polarizations, denoted by V and H in the following, over a total number of 72 angles which uniformly span 360 degrees. Finally, in all of the measurements, the 0° angle corresponds to the line-of-sight channel.

III. MEASUREMENT RESULTS

A tap-delay-line model is used to present the directional channel impulse response (CIR) $h_{i,j,k}^{D,p}(n)$ where $i \in$

Fig. 2. Measurement environment.

$\{1, \dots, 18\}$, $j \in \{1, \dots, 72\}$, $k \in \{1, \dots, 200\}$ denote the location, angle and snapshot indexes, respectively. Superscript $p \in \{V-V, V-H\}$ present the polarization of the transmit-receive antennas and n is the index of the delay bins. It is noted that the distance, angle and delay resolutions in this measurement are 5 m, 5° and $\Delta\tau = 0.5$ ns, respectively. In order to capture the omni-directional behavior of the propagation channel, a virtually omni-directional CIR $h_{j,k}^{O,p}(n)$ is created by superimposing the directional CIRs over all angles per location; in other words,

$$h_{i,k}^{O,p}(n) = \sum_{j=1}^{72} h_{i,j,k}^{D,p}(n). \quad (1)$$

In the following, “virtually omni-directional” will be simply referred as “omni-directional CIR”.

A. Power Delay Profile and Average RMS Delay Spread of Omni-Directional Channels

For a given CIR $h(\tau)$ where τ denotes the delay, the power delay profile (PDP) is defined as

$$P(\tau) = |h(\tau)|^2. \quad (2)$$

Consequently, the RMS delay spread is

$$\sigma_\tau = \sqrt{\frac{\int_0^\infty P(\tau)(\tau - \bar{\tau})^2 d\tau}{\int_0^\infty P(\tau) d\tau}}, \quad (3)$$

where $\bar{\tau} = \int_0^\infty \tau P(\tau) d\tau / \int_0^\infty P(\tau) d\tau$. Obviously, in the following analysis the continuous model in (3) is converted to discrete model.

With this background and following a similar notation, define $P_{i,k}^{O,p}(n)$, $P_{i,ave}^{O,p}(n) = 1/200 \sum_{k=1}^{200} P_{i,k}^{O,p}$ as the PDP of the omni-directional channels, its average over 200 snapshots and its RMS delay spread at the k -th snapshot, respectively. Figure 3 presents $P_{i,ave}^{O,p}(n)$ and $\tau_i^{O,p} = \sum_k \tau_{i,k}^{O,p} / 200$ for V-V and V-H polarizations. It is noted that “distance” in Fig. 3 is calculated based on $d = i \times 5$ m and it depends on the receiver location. Figure 3.a shows the presence of two

Fig. 3. a. Average PDP for V-V, b. average RMS delay spread for V-V, c. average PDP for V-H, d. average RMS delay spread for V-H.

scatterers within the range of 50 m in addition to the line-of-sight (LoS) component. It is evident from figure 3.a and 3.c that the V-V channel provides higher gains and consequently the Non-line-of-sight (NLoS) components are detectable in this setting compared to V-H. However, 3.b and 3.d indicate that only locations 2 and 3 experience higher RMS delay spread. This translates into the fact that the scatterers in the environment are more significant for these two locations. As stated earlier and evident from Fig. 2, the receiver is surrounded by buildings with glass and metal surfaces which evidently contribute to larger RMS delay spreads. Figure 3 also shows that the average RMS delay spread for V-V channel is higher than V-H due to the number of observable multipath components in the channel.

B. Power Delay Profile and Average RMS Delay Spread of Directional Channels

Define $A_{i,j,k}^p = \sum n P_{i,j,k}^{D,p}(n)$ as the aggregated CIRs over all the delay bins at each i -th location, j -th angle and k -th snapshot for polarization p . The angular spread is then defined as

$$\sigma_\theta = \Delta_\theta \sqrt{\frac{\sum_j A_{i,j,k}^p (j - \bar{j})^2}{\sum_j A_{i,j,k}^p}}, \quad (4)$$

where $\bar{j} = \sum_j j A_{i,j,k}^p / \sum_j A_{i,j,k}^p$, and the angular step $\Delta_\theta = 5^\circ$. Figure 4 presents the received powers and the RMS angular spreads averaged over 200 snapshots. For the distances within 50 m in the V-V measurements, there are received signals from almost all directions which result in angular spreads of as high as around 100° , shown in figures 4.a and 4.b. However, the LoS component becomes the major

path for receiving signals after 50 m. The discussion becomes more clear by inspecting the average received signal per angle for each location in the V-H scenario, shown in Fig. 4.c. This effect is expected to be due to the fact that the surrounding of the receiver changes at such distances, as shown by Fig. 2, and the receiver is placed close to brick walls. For the V-V scenario, it is observed that after 35 m, the only detectable path is the LoS component which results in much lower angular spreads. It is noted that the presented results in Fig. 4 heavily rely on the chosen threshold level for noise; and the observable power levels from different angles will be significantly reduced if one increases the threshold levels to e.g., -90 dBm. After careful examination of data, we have intentionally chosen -100 dBm to provide an insight about the propagation channel at 26 GHz against the conventional belief that at such high frequencies the channel is highly directional. In other words, our data indicates that for certain locations, NLoS signals may be received from various directions although they are weaker compared to LoS.

C. Coherence Bandwidth: Omni-Directional vs Directional Channels

For a given CIR $h(\tau)$, let $R_H(\Delta f)$ denote its frequency auto-correlation function where Δf represents the frequency shift. The coherence bandwidth of the channel is then defined as [24]

$$B_{\text{coh}} = \frac{1}{2} \left[\arg \max_{\Delta f > 0} \left(\frac{|R_H(\Delta f)|}{R_H(0)} = 0.5 \right) - \arg \min_{\Delta f < 0} \left(\frac{|R_H(\Delta f)|}{R_H(0)} = 0.5 \right) \right]. \quad (5)$$

Fig. 4. a. Average received signal per angle-location for V-V, b. average angular spread per location for V-V, c. average received signal per angle-location for V-H, d. average angular spread per location for V-H.

Figure 5 presents the CDF of coherence bandwidth for directional and omni-directional channels and different polarizations. The measurement results provide an indication about the impact of using directional antennas in the measurements. For example, the 50-th and 90-th percentile of the coherence bandwidth for omni-directional V-V data are around 280 MHz and 404 MHz compared to 1.3 GHz and 2 GHz for the directional channel, respectively. As it is evident by Fig. 5, the V-H channels result in a significantly flatter frequency response compared to V-V; however, despite this fact, the PDPs in 3 indicate that the received signal levels for V-H scenario are significantly weaker compared to V-V.

IV. CONCLUSION

This paper presented the measurement results and analysis for signals at 26 GHz with 2 GHz bandwidth in a canyon-type street. The results indicated that there can be strong NLoS components from the environment in some scenarios. In particular, the measurements showed that the RMS delay and angular spreads can be as high as 31 ns and 100° when the distance between transmitter and receiver are in the range of 50 m. However, the LoS component was the only dominant path in the channel as the distance between the transmitter and receiver increased. Consequently, the RMS delay and angular spreads become in the range of only a few nanoseconds and degrees, respectively. The measurement results show that the 50 percentile coherence bandwidth of omni-directional channels across all the measured points are around 255 MHz. However, the use of directional antennas increases this value to the whole measurement bandwidth of 2 GHz; resulting

Fig. 5. CDF of Coherence bandwidth for omni-directional and directional V-V and V-H channels.

in a frequency-flat fading channel. Such information about the propagation channel can have a significant impact on the design of beamforming algorithms, the choice of numerology and waveforms in practical mmWave systems.

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