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Measurement Based Path Loss Study for Indoor Device-to-Device Communications at 60 GHz

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Abstract—**This paper empirically investigates the path loss for indoor 60 GHz device-to-device (D2D) channels. In particular, we consider signal propagation between two user equipments (UEs) which are operated in close proximity to the human body within an indoor environment. Two key UE operating modes were studied: (i) making a voice call and (ii) carrying a device. It has been found that the obtained path loss exponents were often much less than those anticipated in free space (i.e., $n = 2$) particularly for non-line of sight scenarios.**

I. INTRODUCTION

Millimeter-wave (mmWave) frequency bands will play an increasingly important role in future wireless networks, driven in part by the need to satisfy the demand for higher data rates [1]. Within the mmWave frequency bands, the unlicensed 60 GHz band is particularly attractive as it contains approximately 7 GHz of spectrum worldwide, laying the foundations for multi-gigabit data rates. In recognition of this, significant interest in the use of mmWave technologies for emerging wireless applications, e.g., wearable [2], device-to-device (D2D) [3], vehicular [4] communications, has been generated. In particular, for D2D communications, operating user equipment (UE) within the 60 GHz band has many advantages such as spectrum availability, small size of antenna (an attractive feature for handset design), and low interference.

Several studies of the mmWave D2D channel have been reported in the literature. For instance, the authors of [5] investigated the path loss behavior for mmWave D2D communications in an urban environment using ray tracing simulations. Here, it was found that the path loss exponents for the line-of-sight (LOS) and non-LOS (NLOS) conditions were found to be 1.88 and 4.49, respectively. In [6], the performance of clustered D2D mmWave networks was examined in terms of the coverage probability and area spectral efficiency. It was demonstrated that there existed an inverse correlation between the coverage probability and the number of the transmitters (TXs) as well as the maximum area spectral efficiency was achieved when the optimal number of the TXs was chosen.

While these studies have provided important insights into different aspects of mmWave D2D communications, they are restricted to the simulations. Additionally, they have only considered scenarios where the UEs have been isolated from the human body and have been used in an outdoor environment. Therefore, this work provides an empirical investigation of the path loss for indoor 60 GHz D2D channels while considering different UE use cases.

II. MEASUREMENT SYSTEM AND EXPERIMENTS

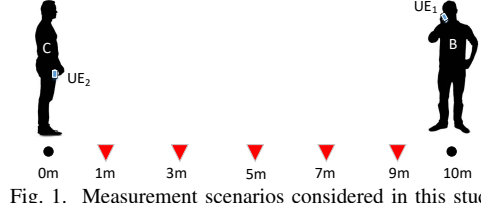The hypothetical mmWave UE used for the TX consisted of a Hittite HMC6000LP711E module and its details

Fig. 1. Measurement scenarios considered in this study.

can be found in [7]. On the other hand, the hypothetical mmWave UE used for the receiver (RX) consisted of a Hittite HMC6001LP711E module, which features a +7.5 dBi antenna in-package. The 50 MHz intermediate frequency (IF) signal outputted by the RX module was recorded using a v1.4 Red Pitaya data acquisition platform described in [7]. This implementation provided an effective channel sampling frequency of 2 kHz and a receive bandwidth of 86 kHz.

The measurements were performed in an indoor seminar room with dimension of 7.92 m × 12.58 m which is located on the 1st floor of the ECIT Institute, Queen's University Belfast in the United Kingdom. The seminar room was unoccupied for the duration of the measurements. The TX-UE was held at different body locations by person A (an adult male of height 1.83 m and mass 80 kg) according to two UE positions which are likely to be representative of everyday UE usage. These were: (1) the right-head region to imitate making a voice call; (2) the right-front pocket of his clothing to imitate carrying a device. Herein, and for brevity, these UE usage cases are denoted as *head* and *pocket*, respectively. To investigate the D2D channels between the TX-UE and two RX-UEs simultaneously, person B (an adult male of height 1.68 m and mass 63 kg) and person C (an adult female of height 1.65 m and mass 51 kg) held the respective UE at their head and pocket, respectively (see Fig. 1). Person A firstly faces towards person B (head) at the separation distances of 1 m, 3 m, 5 m, 7 m and 9 m, i.e., TX-to-head LOS and TX-to-pocket NLOS. Then person A faces towards person C at the same separation distances, i.e., TX-to-head NLOS and TX-to-pocket LOS.

III. RESULTS

The path loss, P, is a measure of the signal attenuation between the TX and RX as a function of the separation distance. It is commonly modeled using the classical power law in logarithmic form as follows

$$P\,[\text{dB}] = P_0 + 10\,n\log_{10}\left(d/d_0\right) + \gamma\,[\text{dB}] \qquad (1)$$

where P_0 represents the path loss at the reference distance (d_0), n is the path loss exponent which indicates the rate at which the path loss increases with the separation distance

D2D Channels	Path Loss		Shadowing									
			1 m		3 m		5 m		7 m		9 m	
	n	P_0 (dB)	μ	σ_{dB}	μ	σ_{dB}	μ	σ_{dB}	μ	σ_{dB}	μ	σ_{dB}
H2H LOS	1.40	41.17	0.03	4.40	0.07	3.50	0.08	3.70	0.07	3.24	0.08	4.19
H2H NLOS	0.97	49.66	0.08	3.64	0.10	3.40	0.11	3.04	0.10	3.22	0.11	3.04
P2H LOS	0.90	39.09	0.03	3.21	0.01	1.62	0.06	4.35	0.09	3.78	0.05	3.75
P2H NLOS	0.69	51.92	0.11	3.29	0.10	3.29	0.09	3.43	0.09	3.45	0.07	3.75
H2P LOS	0.68	51.64	0.13	2.29	0.13	2.51	0.13	2.14	0.14	2.17	0.15	3.80
H2P NLOS	0.32	50.49	0.11	3.40	0.13	2.70	0.12	2.46	0.12	2.46	0.11	2.64
P2P LOS	0.61	49.28	0.01	1.46	0.04	2.21	0.11	2.52	0.12	2.39	0.12	2.46
P2P NLOS	0.11	53.20	0.14	2.06	0.13	2.51	0.12	2.51	0.13	2.31	0.12	2.71

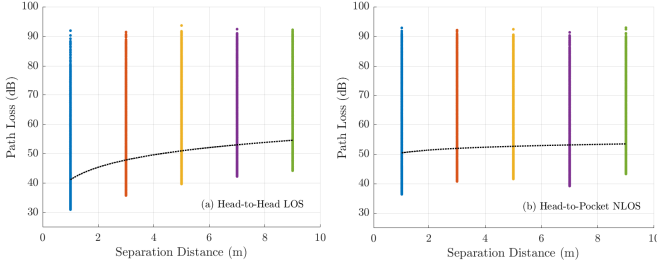Fig. 2. Scattered measured data along with the path loss fit for the (a) head-to-head (H2H) LOS and (b) head-to-pocket (H2P) NLOS.
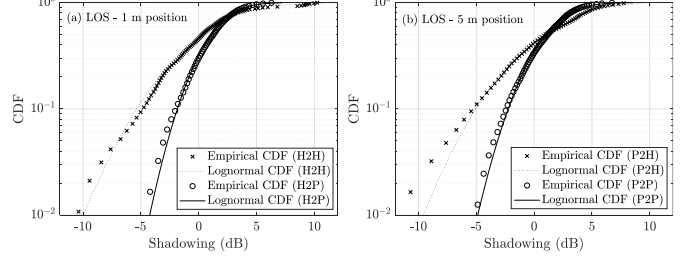

Fig. 3. Empirical CDFs of the shadowing observed in (a) H2H and H2P LOS channels at the 1 m position and in (b) P2H and P2P LOS channels at the 5 m position along with the corresponding lognormal CDF fit.

(d) between the TX and RX and γ denotes shadowing. It is worth highlighting that the reference distance was 1 m in this study. The path loss parameters, P_0 and n, were estimated using linear regression (see Fig. 2) and these are shown in Table I. The path loss exponents were found to be smaller than those observed in [5]. This is most likely due to the different environment considered and the impact of the human body shadowing. More precisely, the measurements presented in [5] were performed in an outdoor urban environment, meaning that it was likely that fewer contributing signal components existed compared to indoor environment considered here. Regarding the human influence, for the NLOS cases, the body shadowing dominates the channel (i.e., a bulk power loss at each measurement location) and thus the received signal is less dependent upon the separation distance between the UEs. Additionally, for all of TX-UE cases, the P_0 and n values for the TX-to-head channels were observed to be greater than those for the TX-to-pocket channels.

Shadowing (γ) was determined independently at each measurement location. To abstract the shadowing from the raw data, the mean path loss was firstly removed from the measurement data and then the small-scale fading was taken out by averaging the resultant data over a distance of ten wavelengths. Table I provides the parameter estimates (μ and σ_{dB}) for the lognormal distribution obtained using maximum likelihood estimation. Overall, the μ values were close to zero and σ_{dB} values range from 1.46 to 4.40. Additionally, the σ_{dB} values for the TX-to-head links were greater than those for the TX-to-pocket links. As an example of the model fitting, Fig. 3 shows the empirical cumulative distribution functions (CDFs) alongside the lognormal CDFs for (a) the H2H and H2P LOS links at the 1 m position and the pocket-to-head (P2H) and pocket-to-pocket (P2P) LOS links at the 5 m position.

IV. CONCLUSION

Indoor D2D channel measurements have been performed at 60 GHz to investigate the observed large-scale fading characteristics including the path loss and shadowing. It has been found that the path loss exponents were smaller than those reported in the open literature. Over all of the considered cases, the lognormal distribution has been shown to well describe the shadowing experienced in mmWave D2D links.

ACKNOWLEDGEMENT

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