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Experimental Verification of the Sub-THz Channel Model with Application to IRS-aided Communications

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***Abstract*—By using an experimental setup we measure the wireless propagation channel in an indoor densely-furnished environment in the frequency range [105-175] GHz. We also show how starting from such measurements we can estimate with high precision the position of the transmitter and the delay of multipath components. Our results validate the assumption made in [1] which states that in such propagation conditions, and at such high frequencies, the contribution of non line-of-sight (NLoS) scattered or reflected components is essentially negligible.**

I. Introduction

Because of the ever-increasing thirst for bandwidth of next-generation wireless communication systems, researchers have started considering sub-THz frequencies as a viable option for transferring a huge amount of data. However, the benefit provided by the large available bandwidth at these frequencies comes at the price of severe propagation conditions. Indeed, it is generally recognized that, at sub-THz frequencies, reliable links between transmitters and receivers must be characterized by relatively short distance and line of sight (LoS) conditions [1]. This constraint can be softened by using intelligent reflecting surfaces (IRSs), which can be in LoS with both the transmitter and the receiver and reflect the transmitted signal to overcome obstacles between them [2]. In [1], [2], the optimization of IRS phase coefficients is performed under the hypothesis that the sub-THz channels between BS and IRS and between IRS and UE are purely LoS, possibly with weak wall reflection.

However, to understand the potential benefit of IRSs in the sub-THz band and to support the conclusions of [1], [2], a characterization of the typical propagation channel is needed. In this direction, some attempts have recently been made in indoor scenarios [3], [4] or in outdoor environments [5].

In this paper, we provide experimental measurements of the channel propagation conditions in the frequency band 105–175 GHz, in an indoor densely-furnished environment. We show that the contribution of non line-of-sight (NLoS) scattered or reflected components is essentially negligible, with associated received power tens of dBs below the LoS power.

II. Experimental setup and methodology

Experimental activities took place in the Witel Laboratory of the CNR-IEIIT, the Institute of Electronics, Computer and Telecommunication Engineering of the National Research Council of Italy. The setup consists of a transmitter equipped with a horn antenna with 20dB gain, a precision positioner, and a receiver connected to a spectrum analyzer. The environment and the relative positions of transmitter and receiver are shown in Figure 1.

In the setup, the transmitter, kept with a fixed position and orientation, transmits pure tones at frequencies f_m, $m = 1, \dots, M$, equally spaced in the range $[105, 175]$ GHz. The receiver is mounted on the precision positioner and moves in the (x, y) plane of a 3D Cartesian reference system, along a rectangular grid of $N_x \times N_y$ positions. The origin of the reference system is located at the center of the grid. Specifically, the receiver position (i, j), $1 \leq i \leq N_x$, $1 \leq j \leq N_y$, is given by $\mathbf{p}_{i,j} = (x_i, y_j, 0)$, where $x_i = \Delta_x \left(i - \frac{N_x+1}{2}\right)$ and $y_j = \Delta_y \left(i - \frac{N_y+1}{2}\right)$ where Δ_x and Δ_y are the pitch values in the two directions. The noisy sample of the wireless-channel frequency response, at frequency f_m and at position (i, j) is denoted by $r_m(i, j)$, and is suitably calibrated so as to exclude all contributions of waveguides, cables and connectors, etc. In other words the samples provided by the spectrum analyzer are given by

$$r_m(i, j) = H_m(i, j) + n_m(i, j) \tag{1}$$

where $H_m(i, j)$ is the wireless channel frequency response at frequency f_m and position (i, j), and $n_m(i, j)$ is additive Gaussian noise, assumed independent across frequencies and positions. Given the set of samples

$$\mathcal{R} = \{r_m(i, j), m = 1, \dots, M, 1 \leq i \leq N_x, 1 \leq j \leq N_y\}$$

and for a given frequency f_m, the direction of arrival of the transmitted beam and of possible reflected/scattered replicas can be obtained by a 2D FFT, as often done in radar applications. In particular, let θ and ϕ be the inclination and azimuth of the spherical coordinate system (r, θ, ϕ) whose origin coincides with the origin of the above mentioned Cartesian reference system, so that $(x, y, z) = r(\sin\theta\cos\phi, \sin\theta\sin\phi, \cos\phi)$ and $r = \sqrt{x^2 + y^2 + z^2}$.

(a)

Fig. 1. Experimental setup. (a): side view. (b): TX view.

Then, the beam-domain channel estimate at frequency f_m can be obtained as

$$\widetilde{H}_m(\theta, \phi) = \sum_{i=1}^{\Delta_x} \sum_{j=1}^{\Delta_y} r_m(i,j) \mathrm{e}^{x_i \sin\theta \cos\phi + y_j \sin\theta \sin\phi} \quad (2)$$

Similarly, the discrete-time channel impulse response obtained when the receiver is at position (i, j) can be obtained by inverse-transforming the frequency response $\{r_m(i, j)\}_{m=1}^{M}$, as follows

$$\widetilde{h}(i, j; \tau) = \sum_{m=1}^{M} r_m(i, j) \mathrm{e}^{j2\pi f_m \tau} \quad (3)$$

In the time domain, reflection or scattering phenomena can be revealed by the presence of secondary peaks, of reduced magnitude and delayed with respect to the LoS peak. The delay of the peaks in the impulse response can also be used to estimate the travelled distance of the different paths (or, analogously, the r coordinate of the transmitter and scatterers, which is not captured by the beam-domain analysis). Note that, from the impulse response corresponding to three or more receiver positions, we can perform a 3D localization of the transmitter and of the possible scatterers.

III. Experimental results

In Table I, we report the parameters chosen for the experiment. Figure 1 shows the relative positions of transmitter and receiver. As it can be seen, a metal cupboard is placed close to the LoS, possibly generating scattering.

TABLE I
EXPERIMENT PARAMETERS.

Parameter	Notation	Value
Minimum frequency	$f_{\min}$	105 GHz
Maximum frequency	$f_{\max}$	175 GHz
Number of frequency values	M	2001
TX spherical coordinates	(r_T, θ_T, ϕ_T)	(3.25 m, 36°, 348°)
Horizontal pitch	Δ_x	0.8 mm
Vertical pitch	Δ_y	0.8 mm
Number of H positions	N_x	26
Number of V positions	N_y	26

Figure 2 shows the beam-domain channel estimate at frequency $f_{\max}$, for which the pitch is about equal to $\lambda/2$. The plot has been obtained by using (2). As it can be seen, the

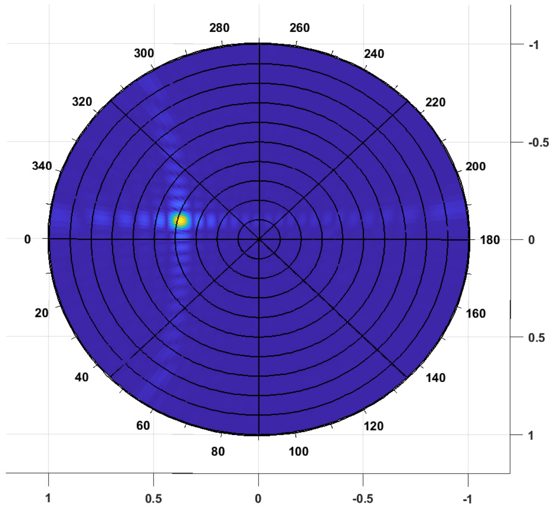

Fig. 2. Beam-domain channel estimate at 175 GHz, shown in spherical coordinates.

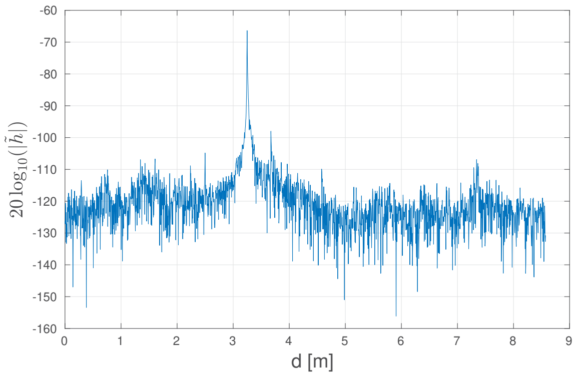

Fig. 3. Impulse response for position (1,1), as a function of the travelled distance.

direction of the main beam is apparent. We can also distinguish the side lobes of the main beam. Instead, no significant contribution is shown from scattering/reflection.

Figure 3 shows the impulse response $\tilde{h}$ obtained using (3) for position (1,1), plotted as a function of the traveled distance $d = c\tau$, where c is the speed of light. As it can be seen, the only impulse that is received has traveled a distance of about 3.25 m, which is in agreement with the measured distance between transmitter and receiver. No other contribution clearly emerges from the noise level, the highest secondary peak being about 30 dB below the level of the line-of-sight impulse.

At least in our setup, the experimental results show that there is no significant power received at sub-THz frequencies from paths other than the direct one, as the highest second peak (whether or not corresponding to an indirect reflected/scattered path) is 30 dB below the main peak. Thus, the assumption of [1], [2], where the channel was assumed to be purely LoS, with at most a faint wall reflection, is confirmed to be correct.

IV. Conclusions

Through an experimental setup,, we were able to measure the characteristics of the indoor wireless channel in the frequency range [105-175] GHz. Using a 2D-FFT technique employed in radar application, we were able to estimate the direction and distance of the transmitter. This technique also allows us to estimate the direction and delay of possible NLoS paths. However, we also show that at such frequency the energy carried by NLoS contributions is negligible, thus validating the assumption made in [1], [2] and helping in the design and optimization of IRS-aided communication systems in the sub-THz band.

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References

[1] A. Tarable, F. Malandrino, L. Dossi, R. Nebuloni, G. Virone and A. Nordio, ”Optimization of IRS-Aided Sub-THz Communications Under Practical Design Constraints,” in *IEEE Transactions on Wireless Communications*, vol. 21, no. 12, pp. 10824-10838, Dec. 2022.

[2] A. Tarable, L. Dossi, G. Virone and A. Nordio, ”IRS Configuration Techniques for Ultra-Wideband Signals and THz Communications,” in IEEE Transactions on Wireless Communications, vol. 24, no. 1, pp. 629-642, Jan. 2025.

[3] K. Tamesue et al., ”300GHz Indoor Propagation Measurement, Simulation and Characterization,” 2022 IEEE 9th International Symposium on Microwave, Antenna, Propagation and EMC Technologies for Wireless Communications (MAPE), Chengdu, China, 2022, pp. 380-385.

[4] M. Lotti, M. Caillet and R. D’Errico, ”Multiband Sub-THz Double Angular Characterization in Indoor Scenario,” IEEE Transactions on Antennas and Propagation, vol. 71, no. 2, pp. 1747-1756, Feb. 2023.

[5] B. De Beelde, E. Tanghe, D. Plets and W. Joseph, ”Outdoor Channel Modeling at D-Band Frequencies for Future Fixed Wireless Access Applications,” in IEEE Wireless Communications Letters, vol. 11, no. 11, pp. 2355-2359, Nov. 2022.