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***Abstract*—In this paper we present two indoor measurement campaigns performed using millimeter-waves massive arrays in a corridor and in an office room. In particular, we characterize the delay spread of the backscattered channel responses which can be exploited in future personal radars applications for indoor localization and mapping.**

***Index Terms*—Millimeter-waves channel measurements, massive antenna array, delay spread, personal radar, transmitarray.**

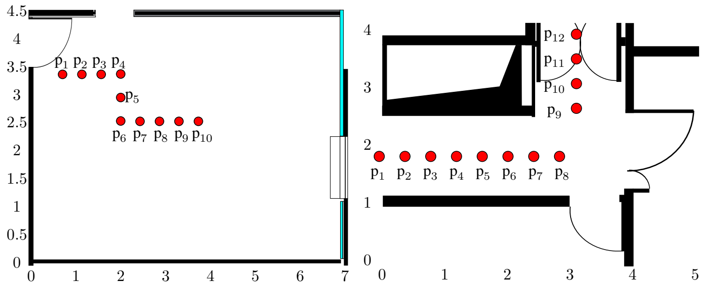
I. Introduction

The concept of smart personal radars has been recently proposed as a solution to map an environment exploiting the compactness and the beamforming potentialities of millimeter-wave (mmW) massive arrays [1]. It is based on the idea of a massive array operating at mmW frequencies that, thanks to the narrow beam formed, is able to electronically scan the surrounding with an angular resolution comparable to that of laser-based radar (i.e. typically 6° of half power beamwidth (HPBW) with 26 dBi of directivity) and with the additional advantage to operate even in non-line-of-sight (NLOS) and poor visibility conditions. From a technological point of view, the adoption of transmitarrays (TAs) for this kind of application has been investigated considering the impact of the antenna radiation properties on the map reconstruction accuracy [2]. The performance of the personal radar system depends on the ability of collecting the environmental backscattered response at the radar interrogation signal and secondly, on the exploitation of such measurements as an input for a mapping algorithm. As a consequence the characterization of the indoor backscattering mmW channel becomes an essential first step.

In this paper we aim at characterizing the delay spread of indoor backscattering mmW channel by exploiting measurements collected in the V-band adopting TAs in two typical office environments (i.e., an office room and a corridor) at CEA-Grenoble premises, reported in Fig. 1. At the best of authors' knowledge, there is not a literature available on this kind of channel, whereas many works deal with the one-way 60 GHz channel such as [3], [4].

II. Measurement Campaign

For the measurements equipment, we considered a set-up composed of a 4-ports Vector Network Analyzer (VNA), 2 mmW frequency converters operating in the frequency range



(a) Office room (b) Corridor

Fig. 1. Plan of the indoor office environment.

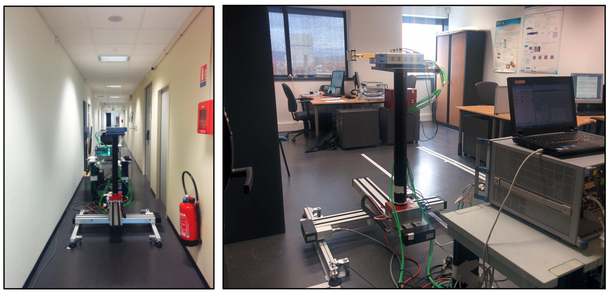


Fig. 2. Photos of measurement campaign in the corridor and office room.

50 GHz-75 GHz, 2 linearly polarized TAs (size 20×20, 1 bit, $F/D = 0.5$) supported by a *X-Y-Azimuth* positioner.

A bistatic configuration has been considered with the TAs spaced apart of 0.16 m in order to mitigate the antenna coupling and to separate the transmitting and the receiving channels. Specifically, as we can see in Fig. 1, where the plan of the office and the corridor are reported, measurements have been collected in 10 and 12 different positions spaced of 0.405 m

For each measurement position, the *X-Y-Azimuth* positioner permits to rotate the radar in the semi-plane from -90° to 90° with a step of 5° (in accordance to the HPBW of the TA used) in order to emulate the beamforming operation, as the considered mmW TA is non-reconfigurable. Fig. 2 shows two photos taken during the measurements campaign.

The 1-bit phase compensation TAs used for measurements are fully described in [2], [5]. Note that it is composed of a focal source (a 10.2 dBi linearly-polarized pyramidal horn antenna working in the E-band) illuminating a planar array

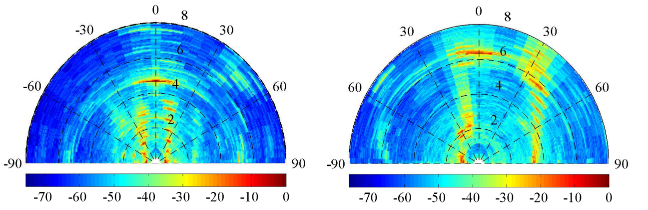


Fig. 3. Radar map results for normalized PDP from radar position p_1 and considering all the steering directions in the corridor (left) and office (right). The maximum radius is 8 m.

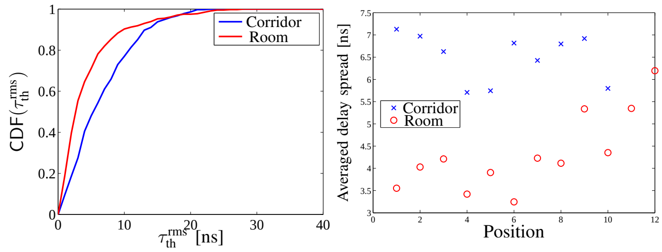


Fig. 4. Left: Obtained RMS delay spread CDFs for the corridor and the office room. Right: average delay spread over steering directions for each position.

with 20×20 unit-cells composed of two patch antennas rotated in order to create a precise phase value to steer the beam [5]. For each position and each TA steering direction, the S-matrix was measured in the frequency domain from 55 to 70 GHz (i.e. the frequencies range corresponding to the TA 3 dB-bandwidth) with a step of 5 MHz [5].

III. Delay Spread Results

For the sake of simplicity, we suppose that, once fixed the steering direction, the angle of departure (AOD)-angle-of-arrival (AOA) is the same for of all the rays due to the TA high directivity. Consequently, the antennas-embedded channel impulse response (CIR) for each radar position can be written as

$$\mathsf{CIR}_i(\tau,\theta)=\sum_{b=1}^{N_{\text{steer}}}\sum_{k=1}^{K_l} h_i(\tau-\tau_k,\theta-\theta^{\text{b}}) \quad (1)$$

with $i=1,\dots,N_{\text{pos}}$, where N_{pos} is the number of radar positions, N_{steer} is the number of steering directions, K_l is the number of rays, τ_k and θ^{b} are the delay and AOD-AOA of the kth ray, respectively.

The power delay profile (PDP) for the ith radar position and the bth steering direction is defined as

$$\mathsf{PDP}_i(\tau,\theta^{\text{b}})=\sum_{k=1}^{K_l}|h_i^{\text{b}}(\tau-\tau_k)|^2. \quad (2)$$

Fig. 3 shows the reconstructed environments from the radar considering a complete angular scan. In both the polar plots, we have considered the radar in position p_1 and we have plotted the sum of the $\mathsf{PDP}_i(\tau,\theta^{\text{b}})$ value over the number of steering directions. Results have been normalized with respect to the maximum PDP value in the corridor (in Fig. 3-(left)) and in the office room (in Fig. 3-(right)). From the two polar plots, thanks to the arrays scanning, it is possible to identify the contour of the corridor and of the room walls.

The root mean square (RMS) delay spread is computed as

$$\tau_i^{\text{rms}}(\theta^{\text{b}})=\sqrt{\frac{\sum_{k=1}^{K_l}|h_i^{\text{b}}(\tau-\tau_k)|^2\,(\tau_k-\bar{\tau})^2}{\sum_{k=1}^{K_l}|h_i^{\text{b}}(\tau-\tau_k)|^2}} \quad (3)$$

where $\bar{\tau}$ is the mean excess delay defined as

$$\bar{\tau}(\theta^{\text{b}})=\frac{\sum_{k=1}^{K_l}|h_i^{\text{b}}(\tau-\tau_k)|^2\;\tau_k}{\sum_{k=1}^{K_l}|h_i^{\text{b}}(\tau-\tau_k)|^2}. \quad (4)$$

Fig. 4 shows the RMS delay spread cumulative distribution functions (CDFs) evaluated as

$$\mathsf{CDF}(\tau_{\text{th}}^{\text{rms}})=\frac{1}{N_{\text{steer}}N_{\text{pos}}}\sum_{i=1}^{N_{\text{pos}}}\sum_{b=1}^{N_{\text{steer}}}\mathbf{1}\left(\tau_{\text{th}}^{\text{rms}}-\tau_i^{\text{rms}}(\theta^{\text{b}})\right) \quad (5)$$

where $\mathbf{1}(x)=1$ if $x\geq0$, 0 otherwise.

As it is possible to observe from Fig. 4, the delay spread does not present large values. We ascribe this effect to the adoption of high directive antennas, which operate as a spatial filter, and to the particular environment configuration especially for what the corridor is concerned. Notably, such results are in agreement with [3], where the authors observed a root delay spread of few nanoseconds, for the one-way channel, when high gain antennas are adopted. Moreover a small difference between the office and the corridor environment can be noticed.

IV. Conclusion

In this paper, the delay spread of two channel measurements campaigns has been derived. To achieve this goal, we first presented the measurements conducted in two indoor environments, and successively we characterized the RMS delay spread. Due to the high gain antennas considered, we found average values comprised between 3 and 7 ns. Further measurements will be conducted in different scenarios, to properly describe all the channel parameters.

Acknowledgments

This research was supported in part by the IF-EF Marie-Curie project MAPS (Grant 659067).

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