mmWave Measurement Campaign using Terragraph Channel Sounders

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The Channel Sounders used for the experiments in this white paper have been granted as part of the Channel Sounder Program of the mmWave Networks Project Group of Telecom Infra Project (TIP). More information on TIP can be found at [1] and on the mmWave Project Group at [2].
The radios used for the experiments are the Terragraph Channel Sounders [3], being an Facebook Connectivity [4] initiative.

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I. Introduction

The goal of this report is to analyze some of the effects that typically occur in different scenarios at mmWave frequencies. To this extent, we use the Terragraph channel sounders operating with the standard 802.11ad and configured at 60.48 GHz, to perform a measurement campaign in several indoor and outdoor scenarios including an empty room, a rich scattering laboratory, and an outdoor bridge with reflecting metal walls. With the measurements collected, we analyze different physical parameters of the communication link, such as path loss, delay spread and SNR post equalization. The measurements taken and the data analyzed reveal some relevant effects particular to those environments in the 60 GHz frequency band, which must be considered for real deployments.

II. Measurement campaign

A. Indoors measurements

In this section, we focus on some of the effects that typically occur in indoor environments and which are relevant to mmWave communications: (i) the effect of blockage; (ii) reflections on different materials; and (iii) the performance in rich scattering environments.

1) Effect of blockage: It is known that mmWave frequencies are very sensitive to blockage compared to the sub-6 GHz band. Thus, blockage from different materials can lead to large attenuation, that can potentially prevent transmission. For this reason, we study two typical cases of blockage that can take place in an indoor office.

- Card-box blockage: for this scenario we locate transmitter and receiver at a distance of 16.4 ft in an empty workbench, see Fig. 1. We perform beam-sweeping as defined by the standard 802.11ad, in which all combinations of virtual sectors in a pre-defined word-code are evaluated. Then, we place a card-box between transmitter and receiver. Fig. 2 shows that contrary to what was expected, we only only observed a power drop of 3 dB.
- Human body blockage. Fig. 3 shows the path loss for a scenario in which a human body blocks the Line-of-Sight (LoS) between transmitter and receiver. In this case, we observe large attenuation, making transmission only feasible through reflections on the walls. This experiment highlights the possibility of using Non-Line-of-Sight (NLoS) paths as an alternative in order to overcome blockage at mmWave frequencies. In addition, by analyzing the large delay spread of the signal blocked by the human body in Fig. 4, we can infer than the signal was probably scattered and arrived at the receiver from multiple delayed paths.

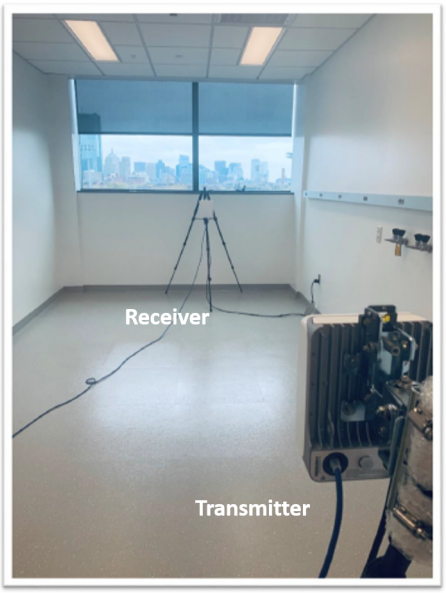


Fig. 1: Workbench set-up, distance of 16.4 ft.

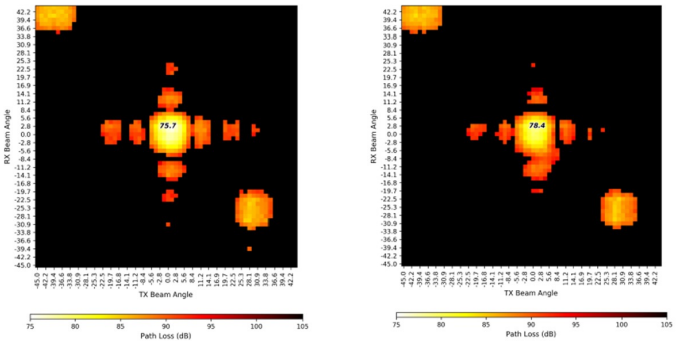


Fig. 2: Path loss for the complete beam scan, when a card-box is located between transmitter and receiver for the setup in Fig. 1

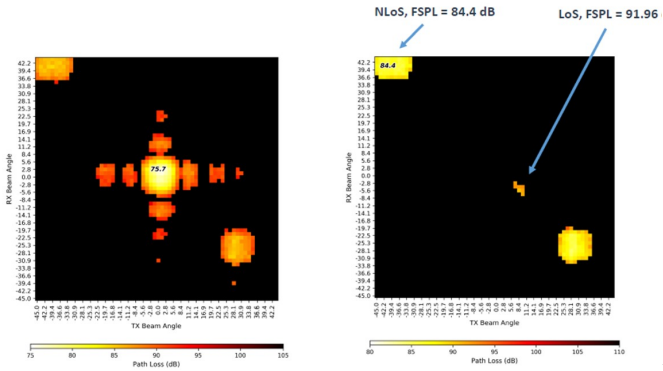


Fig. 3: Path loss for the complete beam scan, when a human body is between transmitter and receiver for the setup in Fig. 1

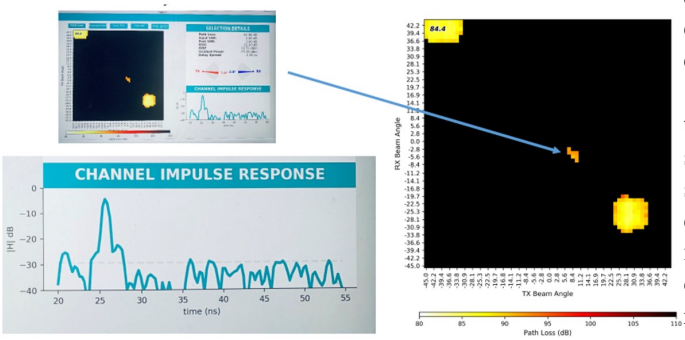


Fig. 4: Delay spread for the signal scattered on a human body

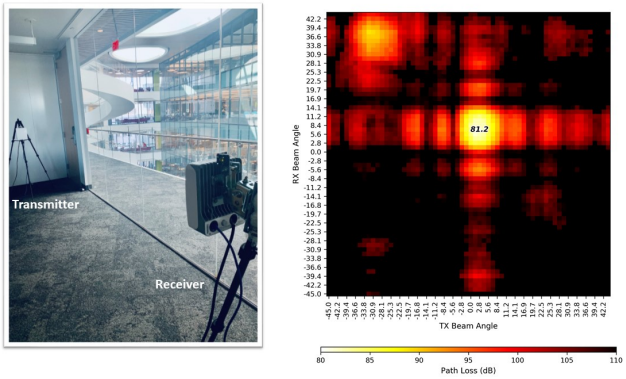


Fig. 5: Path loss for the complete beam scan, evaluated for a reflection on a glass

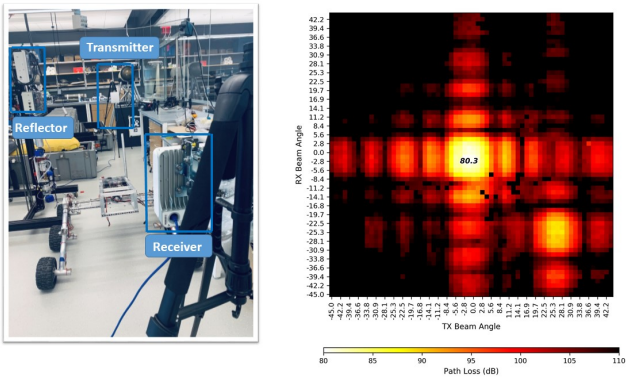


Fig. 6: Path loss for the complete beam scan, evaluated in an environment with rich scattering

2) Reflection on different materials: In this scenario, the goal is to compare the performance of reflection on different materials. To this extent, we compare the path loss for the link reflected on the wall shown in Fig. 2 to the path loss in Fig. 5, which corresponds to reflections on a glass surface. The data collected show that the path loss for the same distance is 3.2 dB higher for the later case and thus, reflections on a wall could be preferred for transmission.

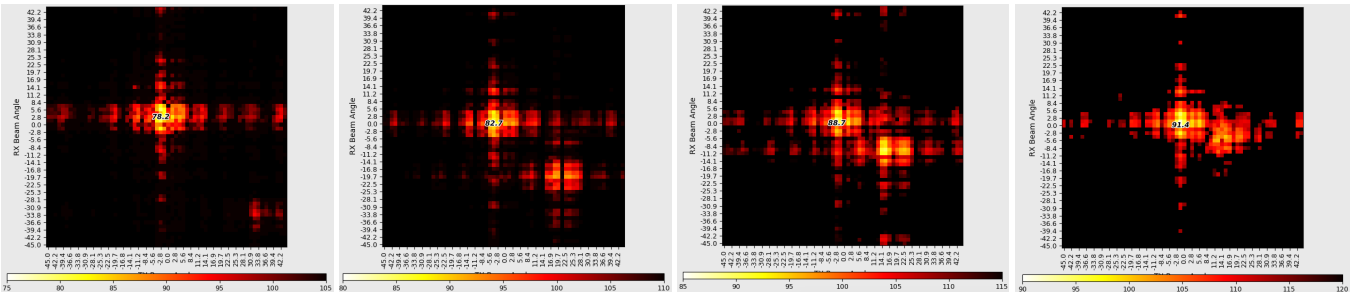
3) Performance in rich scattering environments: In order to analyze the performance in an environment with multiple scatters, we perform several experiments in a laboratory. The setup and path loss for this scenario are shown in Fig. 6. We observe that for a NLoS path, such as as a reflection on a metallic surface, path loss drops 10 dB compared to the Line-of-Sight (LoS) path, highlighting the possibility to use certain reflectors in order to overcome undesirable situations such as strong blockage.

B. Outdoors measurements

We performed an outdoor measurement campaign to characterize the propagation as a function of the presence of natural reflectors. In particular, in this case we considered a bridge with high metal walls, as shown in Fig. 7a. We tested the default configuration of the sounder, i.e., full transmit and

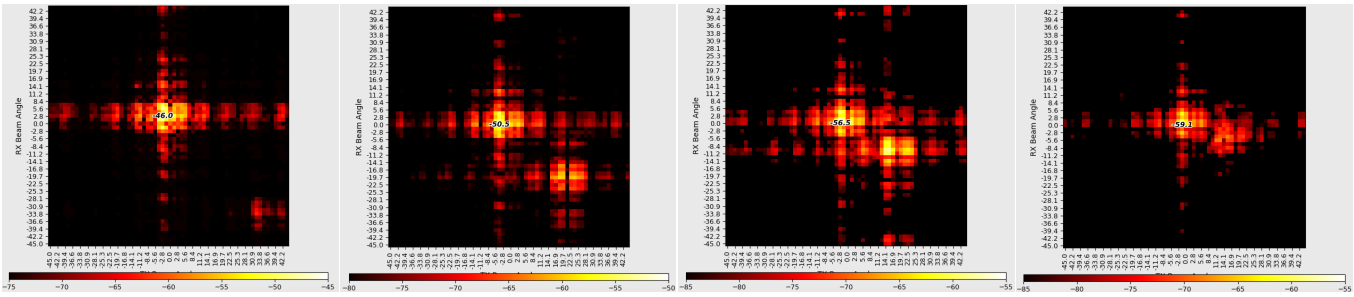
(a) Bridge setup. (b) Setup for the reflection test.

Fig. 7: Measurement setup.



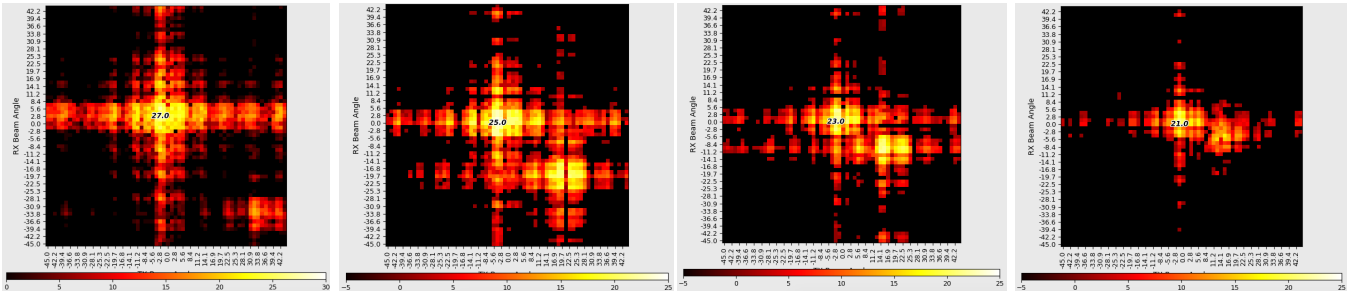
(a) $d = 12.5$ ft. (b) $d = 25$ ft. (c) $d = 37.5$ ft. (d) $d = 50$ ft.

Fig. 8: Pathloss at different distances, for the complete scan in the bridge scenario shown in Fig. 7a.



(a) $d = 12.5$ ft. (b) $d = 25$ ft. (c) $d = 37.5$ ft. (d) $d = 50$ ft.

Fig. 9: Received power at different distances, for the complete scan in the bridge scenario shown in Fig. 7a.



(a) $d = 12.5$ ft. (b) $d = 25$ ft. (c) $d = 37.5$ ft. (d) $d = 50$ ft.

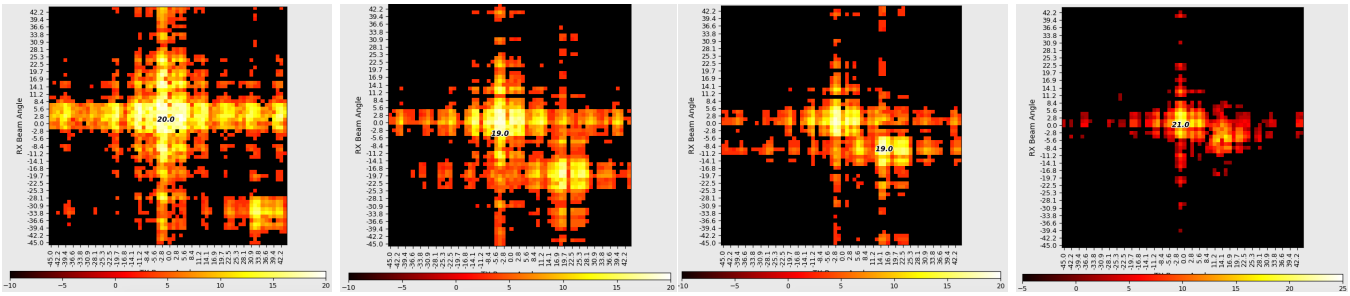
Fig. 10: STF SNR at different distances, for the complete scan in the bridge scenario shown in Fig. 7a.

receive mask with 64 beams at each endpoint, modulation and coding scheme 1. The main experiment consists of a complete beam sweep at 4 different distances ($d \in \{12.5, 25, 37.5, 50\}$ ft), for which we collected the pathloss, the STF and post-equalization SNR, and the received power.

1) Effect of path loss: Fig. 8 reports the pathloss at the four different measurement distances. As expected, given that the two radios are in LoS conditions, it is possible to identify a clear cluster of directions that minimize the pathloss, corresponding to the center of each figure, i.e., to the transmit and receive beams that steer toward the LoS direction at 0°. Moreover, the pathloss increases with the distance. The most interesting phenomenon, however, is the presence of a reflected path over one of the metallic walls of the bridge, and the different contributions it provides to the pathloss. Given that the distance between the radios and the metallic wall is constant, the angle of the reflection changes and becomes wider as the distance between the two sounders decreases. Besides, while at larger distances the contribution of the reflected path is roughly equivalent to that of LoS path, for $d = 12.5$ ft the reflection is at least 10 dB worse than the LoS path (Fig. 8a). A similar behavior can be observed in Fig. 9 for the received power.

2) SNR considerations: The STF (or Input) SNR and the post-equalization SNR are shown in Fig. 10 and Fig. 11, respectively. While the STF-based SNR has a behavior similar to that of the received power and the pathloss, the post-equalization SNR is approximately constant at different distances for the LoS direction and the reflected path.

3) Effect of reflections: Finally, we tested the setup shown in Fig. 7b, in order to understand if it is possible to receive a signal only through the reflection of the bridge metallic wall.



(a) $d = 12.5$ ft. (b) $d = 25$ ft. (c) $d = 37.5$ ft. (d) $d = 50$ ft.

Fig. 11: Post equalization SNR at different distances, for the complete scan in the bridge scenario shown in Fig. 7a.

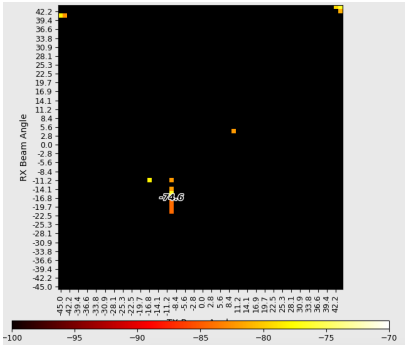


Fig. 12: Received power for the scenario shown in Fig. 7b.

The two radios are at a distance $d = 12.5$ ft from the wall, which, however, is not directly facing them (it presents a slight curvature). Fig. 12 reports the received power for a full scan, and it can be seen that is around -75 dB for the strongest reflected path. However, only a few beam pairs receive power in this setup.

Outdoor experiments demonstrated that the performance of the bridge deployment is significantly different with respect to that of the indoor experiments. However, the reflections introduced by the metal walls of the bridge are beneficial to improve the radio link reliability and performance. This makes it possible to have non-negligible SNR values even at larger distances whilst the carrier frequency being affected from environmental effects typical of outdoor deployments, e.g., a high oxygen absorption.

III. Conclusions

In this report, we characterized the behavior of the mmWave communication link at 60 GHz for different environments. From the measurement collected, we showed that rich scattering environments offer alternative NLoS paths that may help overcome large attenuation due to human body blockage. Additionally, we measure the path loss for reflections on materials of different nature, and highlight the need to evaluate the specific environment in order to select the best NLoS paths for communication.