Directional characterization of the 60 GHz indoor-office channel

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Abstract

Directional, dual-link, quad-polarized 60 GHz channel measurements have been carried out in a small-office environment. Purpose of the measurements is to study the directional properties of the channel in view of future multi-gigabit system adopting beam-forming or macro-diversity solutions. The impact of polarization on the characteristics of the channel is also addressed in the study.

1. Introduction

In view of the advent of future-generation wireless communication standards (i.e: 5th Generation) there is certainly a great interest in the topic of multi-Gigabit wireless communication at mm-wave frequencies as proved by recent research activity in both the Industry and the Academy [1-3]. The relatively small size of mm-wave antennas and devices allows in theory the adoption of compact, very high-order MIMO arrays and therefore of narrow-beam, high-performance beam-forming schemes [4,5].

Advanced beam-forming might allow the exploitation of multipath propagation for spatial reuse and multiplexing to achieve high throughput density. Moreover, it allows the implementation of spatial-spectrum management strategies to dynamically "choose" the best paths for transmission, thus overcoming line of sight (LOS) obstruction problems and improving the signal to interference-plus-noise ratio (SINR). This potential however can really be exploited if mm-wave propagation in real environment actually offers independent, spatially separated pathways for multiple concurrent communication links. Unfortunately, the presence of a strong distributed multi-path component (DMC) due to surface-roughness scattering and other phenomena might put into question the actual performance of advanced beam-forming techniques.

Therefore a thorough propagation characterization and modelling study addressing time-domain, angle-domain and polarization-domain dispersion characteristics of the mm-wave radio channel in realistic environment is necessary. Only few studies have addressed the topic so far [6-11]. The problem of characterizing the spatial distribution of multipath and the actual ratio between the DMC and the specular component in different environments is still a very open one.

In the present work directional, quad-polarized 60 GHz channel measurements have been carried out to highlight the multi-dimensional propagation characteristics in a small-office environment. Ray tracing simulation is used to interpret measurement data and to determine the nature of the different propagation contributions (specular vs. DMC). Final goal of the work is to determine the performance of polarization-aware, advanced beamforming or macro-diversity solutions for multi-gigabit indoor wireless systems.

2. Measurement Description

The aim of the present measurement set-up is to investigate the properties of the power distribution, delay spread (DS) and direction of departure (DoD) in a static quad-polarized dual-link in-door scenario at 60 GHz. The M-sequence ultra wide-band channel sounder (UWBCS) used for the measurements consists of one transmitter (TX) and two receiver (RX) channels, RX1 and RX2 [12]. In parallel, simulations on a ray tracing tool developed at the University of Bologna [13] were also conducted for comparison and to assist the interpretation of the measurement results. The scenario is a small office located in the basement of the TU Ilmenau, as depicted in Figure 1. The dimensions, materials and furniture offer a typical scattering environment for similar scenarios. Even though the results of the present measurements correspond to this specific scenario and conditions, they are also valid to be used as reference for the development of stochastic models and parametrization of ray-tracing tools.

The TX was located in a 3D positioner high in a corner of the room emulating an access point. On the other side, both receivers were fixed to perform static measurements. RX1 was deployed over a desk with no line of sight (NLOS), since it was covered by an absorber, hence only scattering components are captured by

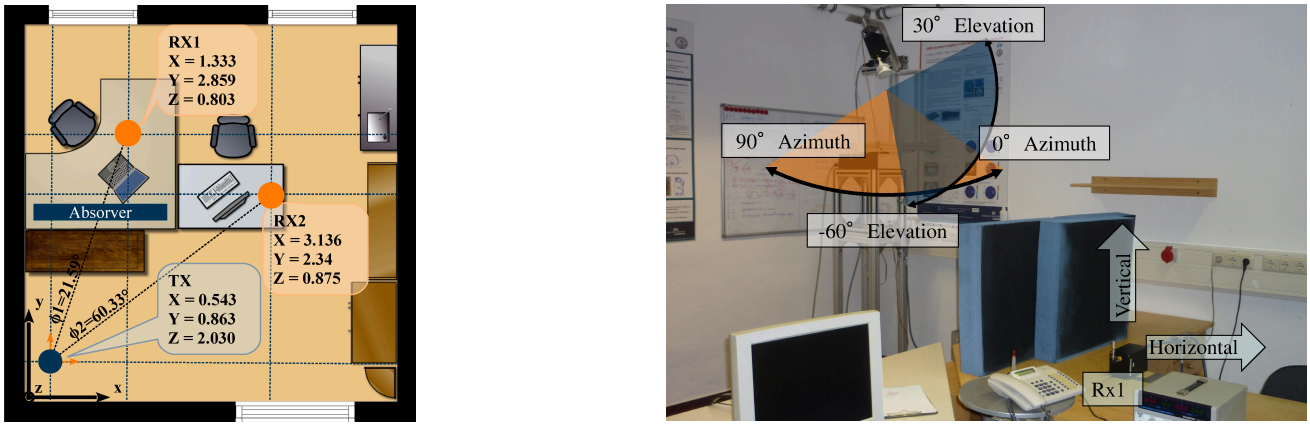

Figure 1: Scenario scheme and picture defining the global axis scheme.

the receiver. On the contrary, RX2 was located with LOS also over a desk at the same height. However, in the present work we are focusing on the results of the NLOS scenario.

The TX was equipped with a high gain lens antenna (5° beam-width) to offer a high DoD discrimination. The receiver antennas were omni-directional. The TX swept a quarter of a sphere, with an angular step of 2° from 0° to 90° in azimuth, and 30° to −60° in elevation, resulting in 2025 measurements point per TX - RX polarization combination. The polarization was changed by rotating the antennas, keeping the phase centre. The definition of the polarization is selected as follows: for the TX, H defines the linear polarization in the $\vec{i}_\phi$ direction, where $\vec{i}_\phi$ is the versor of the azimuth in the spherical coordinate system. Similarly, V defines the linear polarization in the $\vec{i}_\theta$ direction, being $\vec{i}_\theta$ the versor of the elevation. In the receiver side, V denotes the position of the omni-directional antenna parallel to the z-axis of the Cartesian coordinate system and H parallel to the y-axis, as shown in Figure 1. Since the environment was static, a total of 20 snapshots per measurement point were taken to reduce the noise by averaging. In addition, only the samples 10 dB higher than the noise floor were kept, discarding the other ones by setting the appropriate channel impulse response (CIR) to zero. In the delay domain, a total of 200 samples were selected, corresponding to a distance of 18 m.

3. Results

The presented results correspond to RX1. Figure 2 shows the power vs the DoD for the different combinations of polarization. The power was calculated as the sum of the squared absolute values of the delay components for each DoD. While specific paths or clusters of paths can be identified in different polarizations, e.g. , others are visible only in one of them. This is important from a beam-former point of view, since it shows that independently from the orientation of the antenna, there are always available beams. It is also interesting to notice, that in the TX H - RX H case, and to a lesser extent in the TX V - RX V case, these paths are also widely spread over a large range of possible DoD, increasing the amount of possible sources of signal in case of shadowing. However in the cross-polarized cases most of the paths belong to the low azimuth range, increasing the chance that because of shadowing (e.g. a person standing in front of the access point) the receiver cannot establish a link. This is a clear sign of the advantage of considering polarization in the beam-former, since it increases not only the received power by combining the energy spread over the different polarizations of the same path, but also increases the amount of possible available paths, giving the communication system robustness against shadowing.

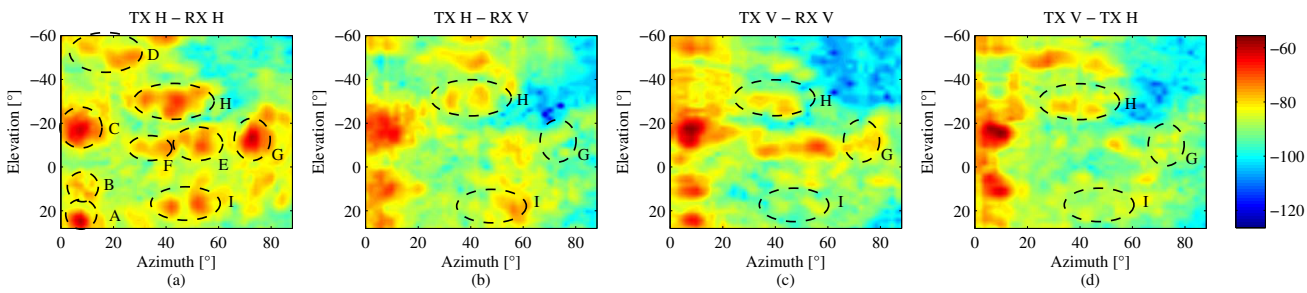

Figure 2: Power vs. DoD. The interpretation of the tagged clusters is given in Table 1.

Ray tracing simulations have been performed in the same environment enabling different kinds of interaction (reflection, diffraction, diffuse scattering) to identify the origin of clusters in Figure 1. Referring to the tags

in Figure 2 (a), the interpretation we have achieved is given in the Table 1. It is evident that while contributions A-C, E, F can be considered "specular components", contributions D, G-I must be regarded as "scattering", even though they appear in Figure 2 as concentrated, specular-like spots. Moreover, a DMC component is evident as a distributed background, probably related to diffuse scattering from rough wall surfaces. In terms of polarization, scatter C for example is present in all the polarizations, indicating a high cross-polarization coupling of the former. On the other side, G - I are only visible in the co-polarized H case, showing a high cross-polarization discrimination (XPD) ratio. To summarize, we are in front of a polarization sensitive channel.

Table 1: Ray tracing assisted interpretation of the cluster.

Clusters	Description
A	Double-bounce reflection from ceiling and upper wall
B and C	Diffraction/reflection from the upper/lower part of a metal frame of the left window
D	Reflection on the floor under a desk followed by multiple bounces
E and F	Double-bounce reflection from the upper-right corner of the room
G	Scattering from a bookshelf and a metal ladder in the lower-right corner
H	Scattering from objects (computer monitor, transceiver and equipment metal boxes, etc.)
I	Scattering from lamps in the ceiling

Another important characteristic of the propagation channel is the power delay profile (PDP) and DS. The total PDP was calculated as the sum of the PDP measured for each DoD. Figure 3 (a) and (b) show the total PDP for the different combinations of polarization. A difference can be seen between polarizations given by strong components coming from different DoD, consistent with what is observed in Figure 2. The total DS, as well as the total azimuth and elevation spread are listed in Table 2. As expected, the TX H - RX H case has a longer delay spread because of the further strong components arriving later, also seen in the azimuth spread. Furthermore, Figure 3 (c) and (d) illustrates the PDP for azimuth and elevation for the TX H - RX H and TX H - RX V cases. It is interesting to notice these strong different components arriving at different delays around elevation $= -15°$. Moreover, the strong paths seem to be grouped in clusters since they don't appear as single peaks of power, but they have a width in the angular and delay domain.

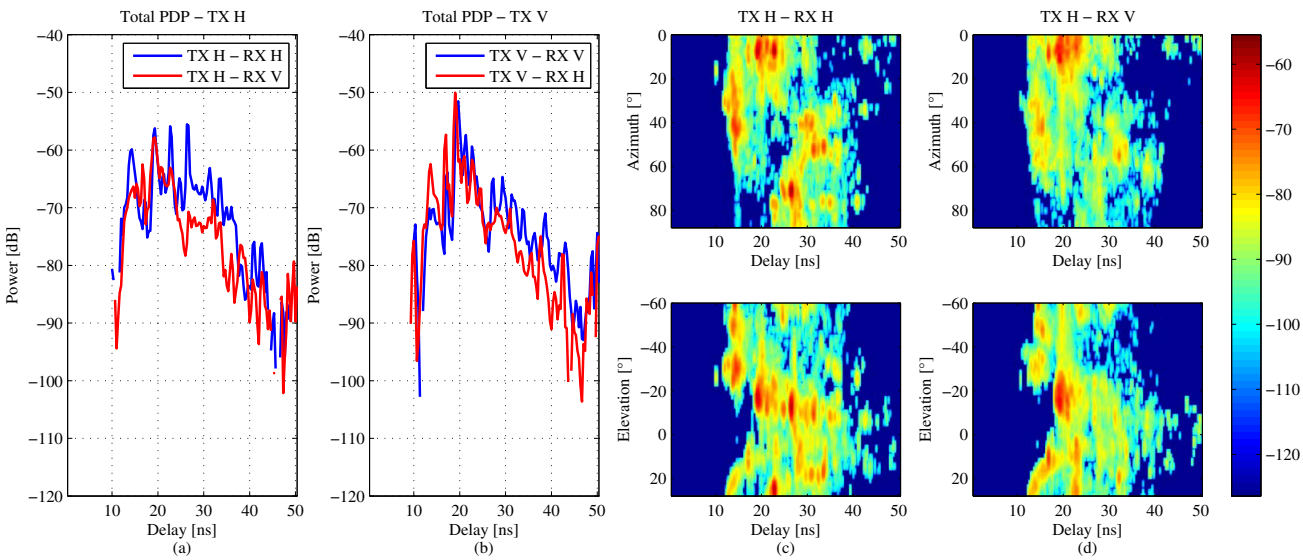

Figure 3: (a) and (b) total PDP considering all the DoD. (c) and (d) marginal PDP in azimuth and elevation for the TX H - RX H and TX H - RX V, respectively.

Table 2: Delay, azimuth and elevation spread for the different polarizations.

	TX H - RX H	TX H - RX V	TX V - RX V	TX V - RX H
Delay Spread [ns]	5.66	4.56	4.13	3.28
Azimuth Spread [°]	28.39	19.58	15.61	12.71
Elevation Spread [°]	21.12	20.23	16.14	16.20

4. Conclusion

The identified strongest paths are clear proof of the need of using beam-forming in NLOS scenarios, furthermore the presence of different paths with different polarizations show the advantage of considering polarization in

the beam-former. From the results it is evident that, compared to lower frequencies, back scattering from objects (PC monitor, ladder, etc.) appear more "specular-like" due to the higher "resolution" of mm-waves. However such contributions should be anyway treated as scattering and modelled through statistical distributions, due to the unpredictable shape, position and presence of such objects. Further work will deal with a more detailed multi-dimensional analysis of measured data and with the study of the correlation between the two different link in dynamic conditions.

5. Acknowdelgment

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