Empirical modeling of diffuse scattering at millimeter wave frequencies

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***Abstract*—Propagation channel models based on ray-tracing techniques can estimate the specular multipath components (MPCs) reaching the receiver antenna, but have difficulties to estimate the diffuse components. In this work, an empirical model to include the diffuse scattering in ray-tracing channel models, or channel simulators, is presented. The diffuse scattering model has been developed from channel measurements at millimeter wave (mmWave) frequencies collected from 25 to 40 GHz in the frequency domain in an office environment.**

I. INTRODUCTION

New enabling technologies for the fifth-generation (5G) and sixth-generation (6G) systems, such as the use of massive multiple-input multiple-output (MIMO), require evaluating the correlation degree between the propagation paths observed by different users. This correlation is directly related to the propagation channel matrix, and for certain environments and frequencies depends not only on the specular contributions, but also on those contributions to reach the receiver through scattering processes. Thus, diffuse scattering is important in indoor environments where there can be many objects (scatterers) interacting with the wave fronts [1]. It has been found that the contribution of the diffuse scattering to the total power is important at frequencies below 6 GHz (sub-6 GHz band) in indoor scenarios [2], reducing as the frequency increases. However, it has been observed that its effect on the channel matrix structure in MIMO systems can be important even at high frequencies. Thus, in [3] an important incidence of the diffuse scattering on the MIMO matrix properties has been observed, and in a more recent work [4], it has been verified that diffuse scattering has a significant impact on channel correlation in massive MIMO systems in highly reflective scenarios at millimeter wave (mmWave) frequencies.

Although channel models and channel simulators are capable of describing the characteristics of specular multipath contributions (MPCs), one of the main problems in modeling diffuse scattering lies in the impossibility of creating geometric models of the propagation scenario with the required resolution as the frequency increases, being one of the main drawbacks when using ray-tracing techniques.

In this contribution, an empirical model based on channel measurements at mmWave frequencies to take into account the diffuse scattering is proposed . This model is easily implementable in channel simulation tools based on ray-tracing techniques.

II. CHANNEL MEASUREMENTS

Propagation channel measurements have been carried out in an indoor office environment in the frequency domain using a vector network analyzer (VNA). Omnidirectional antennas, with vertical polarization, have been used at the transmitter (Tx) and receiver (Rx) sides. The Tx subsystem has been connected to the VNA through a broadband radio over fiber (RoF) link to avoid the high losses of cables at mmWave frequencies. The Rx antenna has been located in a XY positioning system, implementing a 12×12 uniform rectangular array (URA). The separation of the URA elements has been 3.04 mm, less than $\lambda/2$ at 40 GHz ($\approx$ 3.7 mm). The $s_{21}(f)$ scattering parameter was measured from 25 to 40 GHz with 8192 frequency points. The measurements have been taking in both line-of-sight (LOS) and obstructed-LOS (OLOS) propation conditions.

III. DIFFUSE SCATTERING MODELING AND RESULTS

The channel impulse response (CIR), denoted by $h(t, \tau)$, being τ the delay variable and t the time variable, can be considered as the superposition of the total specular and diffuse MPCs that reach the receiver. Thus, $h(t, \tau)$ can be written as:

$$h(t, \tau) = h_S(t, \tau) + h_{DS}(t, \tau), \tag{1}$$

where the term $h_S(t, \tau)$ refers to the specular MPCs and $h_{DS}(t, \tau)$ to the diffuse MPCs. Channel models based on ray-tracing can estimate $h_S(t, \tau)$. However, these models have difficulties, or cannot, estimate the diffuse scattering component $h_{DS}(t, \tau)$.

From channel measurements using an array structure, e.g., the URA described in the previous section, it can be applied array processing algorithms to obtain the parameters of the specular MPCs that reach the receiver, i.e., delay, complex amplitude and direction of arrival. In this way, it is possible to derive the specular component of the CIR, denoted by $\hat{h}_S(t, \tau)$, and from (1), the diffuse scattering component can be estimated as:

$$h_{DS}(t, \tau) \approx h(t, \tau) - \hat{h}_S(t, \tau). \tag{2}$$

Notice that (2) is an approximation since there may be weak specular MPCs that are not detected by the algorithm used in the estimation of $h_S(t, \tau)$. In our work we have use

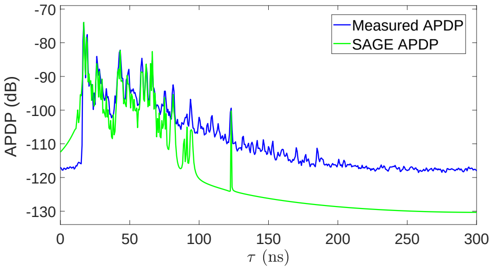

Fig. 1. $APDP$ measured and estimated with SAGE in LOS conditions at 33 GHz.

the Space-Alternating Generalized Expectation-Maximization (SAGE) algorithm to estimate the parameters of the MPCs. This algorithm has been used in the literature to estimate channel parameters from measurements [5]. From $h_{DS}(t,\tau)$, and assuming ergodicity, the averaged power delay profile (APDP) of the diffuse contribution, denoted by $APDP_{DS}(\tau)$ can be estimated averaging the CIR over the $144(12 \times 12)$ positions of the URA. Fig. 1 shows the APDP measured (blue line) at 33 GHz and the APDP of the specular component $\hat{h}_S(t,\tau)$ (green line) estimated using the SAGE algorithm. The differences between both APDPs highlight the need to estimate the diffuse scattering in order to account the total received power. Fig. 2 shows the APDP of the diffuse scattering (blue line). Based on the behaviour observed in the analyzed frequency bands, we proposed the following model to take into account the associated power to the diffuse scattering:

$$APDP_{DS}(\tau) = P_{DS}(\tau) + X_{DS}, \tag{3}$$

where $P_{DS}(\tau)$ describes the mean value in the delay variable, shown by the red line in Fig. 2, and being X_{DS} a random variable to describe the fluctuations over the mean value. The following expression is proposed to model $P_{DS}(\tau)$:

$$P_{DS}(\tau)|_{\text{dB}} = \begin{cases} P_n & \tau < \tau_0 \\ \alpha_{DS} \cdot \tau & \tau_0 \leq \tau \leq \tau_n \\ P_n & \tau > \tau_n \end{cases} \tag{4}$$

where τ_0 is the delay associated to the first MPC that reaches the receiver; P_n represents the minimum value of $P_{DS}(\tau)$, related to the measured APDP and the SAGE estimation; and α_{DS} and τ_n are derived from regression techniques. The distribution function of X_{DS} is estimated by intervals from the measured data, where the tails are approximated using a Generalized Pareto Distribution (GPD), and the central part minimizes the differences with the empirical distribution. Fig. 3 shows the APDP measured at 26 GHz (blue line), the APDP associated to the specular MPCs derived from SAGE (green line), and the APDP estimated taking into account the diffuse scattering (red line). The results show that the introduction of the diffuse scattering permits us to model in some detail the measured APDP, accounting the total power at the receiver.

IV. CONCLUSIONS

A diffuse scattering model based on channel measurements has been proposed in this contribution. This model can be easily incorporated in propagation channel models and channel simulators based on ray-tracing techniques to estimate the propagation characteristics more accurately. Due to the space restriction here to two pages, a full study with more results will be presented at the conference.

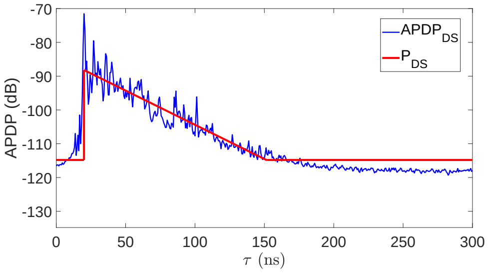

Fig. 2. $APDP_{DS}$ and P_{DS} in LOS conditions at 33 GHz.

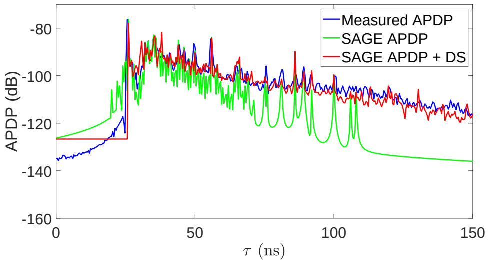

Fig. 3. $APDP$ measured at 33 GHz, $APDP$ estimated with SAGE and $APDP$ estimated with SAGE and considering diffuse scattering.

ACKNOWLEDGEMENT

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