K-factor analysis based on channel measurements from 24 to 40 GHz in a laboratory scenario

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***Abstract*—The *K*-factor is commonly used to model the small-scale fading. In this contribution, the *K*-factor is analyzed in a laboratory scenario based on wideband channel measurements carried out at millimeter-wave (mmWave) frequencies, covering the 24-40 GHz frequency band. The value of the *K*-factor is estimated from the method of moments applied directly to the envelope of the measured complex channel transfer function (CTF). The dependence of the *K*-factor on frequency and distance has been investigated. The results are interesting to understand the selectivity behavior of the wireless channel in this particular scenario at mmWave frequencies.**

I. Introduction

In the context of wireless fading channels, the Rician *K*-factor is a parameter commonly used to describe the small-scale fading in time, space or frequency of the received signal envelope. The Rician *K*-factor is defined as the power ratio of the dominant component to the stochastic multipath contributions (MPCs) [1]. Thus, if the dominant component is attenuated with respect to the rest of MPCs, the *K*-factor decreases. In the limit, when the dominant component disappears, the *K*-factor reaches a value of 0 ($-\infty$ dB). This situation corresponds to the case of maximum channel selectivity, and the received signal envelope fluctuations can be described by the well-known Rayleigh distribution [1]. Therefore, the knowledge of the *K*-factor has an important implication in the design of transmission techniques, such as modulation and adaptive coding techniques [2], diversity schemes [3], and system complexity in massive multiple-input multiple-output (MIMO) systems [4], among others. In [5], under the assumption of wide-sense stationary uncorrelated scattering (WSSUS), the authors demonstrated that it is possible to estimate the *K*-factor in wideband channels from a single-snapshot measurement. This facilitates the analysis of temporal variability at mmWave frequencies based on experimental measurements conducted with traditional channel sounders where stationary channel conditions are required, such as those based on vector network analyzers (VNAs).

In this contribution, we estimate the *K*-factor from wideband channel measurements at millimeter-wave (mmWave) frequencies conducted in a laboratory scenario, covering the 24-40 GHz spectrum. The method of moments working directly with the measured channel transfer function (CTF) is used to estimate the *K*-factor. The relationship between the *K*-factor with both frequency and distance is investigated.

This contribution is organized as follows. Section II briefly describes the channel measurement setup. Section III indicates how the *K*-factor can be estimate from channel measurements. The results are presented and discussed in Section IV. Finally, Section V draws the main conclusions.

II. Channel Measurements Setup

The channel measurements were performed in the frequency domain using a channel sounder based on the Keysight N5227A VNA. The CTF was measured from 24 to 40 GHz, with 8192 frequency samples. The frequency resolution is thus 1.95 MHz, which corresponds to a maximum observable distance of about 153 m, higher than the dimensions of the laboratory environment. Omnidirectional antennas with linear polarization (vertical) were used on the transmitter (Tx) and receiver (Rx) sides. The Tx subsystem was connected to the VNA through a radio-over-fiber link to avoid the high losses introduced by cables at mmWave. The Rx antenna was placed on a two-dimensional positioning system, implementing a 7×7 uniform rectangular array (URA), with a separation between elements equal to 3.04 mm ($\approx \lambda/4$ a 24 GHz). The Tx antenna was placed on a one-dimensional positioning, implementing a 1×10 uniform linear array (ULA), with a separation between elements also equal to 3.04 mm. The ULA was placed at different positions in the laboratory, whereas the URA remained in the same position near one of the walls, emulating the position of an access point. The channel measurements were performed under line-of-sight (LOS) propagation conditions. The ULA-URA distance ranged from 3.16 m to 10.35 m. To ensure stationary conditions, the measurements were carried out at night in the absence of people.

III. K-factor Estimation

From the channel measurements, if $H(f_n)$ is the CTF for the *n*-th frequency sample, the *K*-factor can be estimated using the method of moments as [5]:

$$\hat{K} = \frac{\sqrt{G_a^2 - G_v}}{G_a - \sqrt{G_a^2 - G_v}}, \tag{1}$$

where

$$G_a = \frac{1}{N}\sum_{n=1}^{N} |H_n|^2, \tag{2}$$

$$G_v = \frac{1}{N-1}\left(\sum_{n=1}^{N} |H_n|^4 - NG_a^2\right). \tag{3}$$

For each position of the ULA location, the value of the *K*-factor is estimated at each of the 49 (7×7) Rx antenna positions of the URA, taking into account the 10 (1×10)

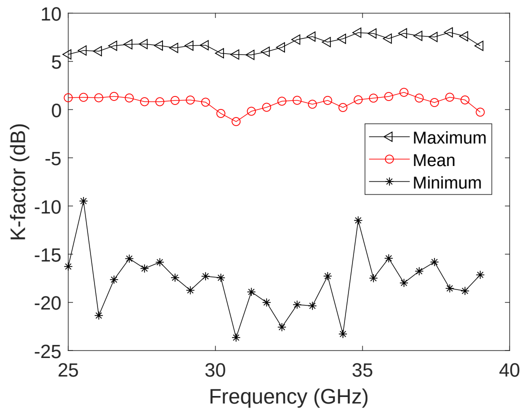

Fig. 1. Minimum, maximum and mean values of the K-factor in terms of the frequency.

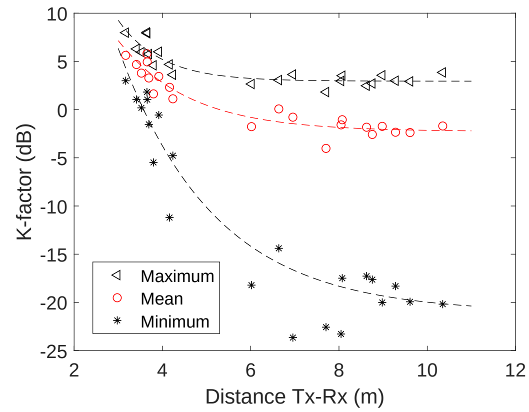

Fig. 2. Minimum, maximum and mean values of the K-factor in terms of the ULA-URA distance.

positions of the Tx antenna in the ULA. Thus for each ULA location a total of 490 (49×10) values of the K-factor are estimated.

IV. Results and Discussion

For a given frequency f_0, the K-factor is estimated over a bandwidth of 2 GHz centered at f_0. That is, $K(f_0)$ is the estimate of the K-factor at the frequency f_0, derived from the frequency samples of the measured CTF in the interval $[f_0 - 1$ GHz, $f_0 + 1$ GHz$]$. The minimum, mean and maximum values of the K-factor in terms of the frequency are depicted in Figure 1. The results show that the mean value of the K-factor ranges from -1.24 dB to 1.79 dB, exhibiting slight fluctuations, around 1 dB. The maximum value of the K-factor also shows small fluctuations with the frequency, with a slightly increasing trend. The maximum value ranges from 5.67 dB to 8.01 dB. On the other hand, the minimum value of the K-factor shows larger fluctuations, ranging from -23.65 dB to -9.48 dB, with no clear trend with the frequency. Figure 2 shows the relationship between the minimum, mean and maximum values of the K-factor in terms of the ULA-URA distance. Note that the value of the K-factor now considers the average value of the estimated values over the whole frequency range, e.g., 25-39 GHz. The results show a clear dependence between the K-factor and the ULA-URA distance, where the K-factor decays exponentially with the distance reaching an asymptotic value.

The values of the K-factor derived in this work are lower than those published in other works at mmWave frequencies for indoor environments. In particular, a mean value of 9.04 dB was obtained in [7] at 26 GHz in a large office, and a mean value of 6.15 dB was derived in [8] at 28 GHz in an open office environment, both under LOS conditions. Our propagation scenario can be considered as a closed environment, where the dimensions are smaller, resulting in a higher number of reflected contributions. As a result, the power associated with the stochastic MPCs increases, resulting in lower values of the K-factor. The comparison with other published works suggests that the mean value of the K-factor is correlated with the dimensions of the propagation environment, decreasing as the dimensions are reduced.

V. Conclusions

In this contribution, the K-factor has been analyzed in a laboratory environment. The results have shown that the mean value of the K-factor has no direct correlation with the frequency within the frequency band considered. However, there is a correlation between the K-factor and the distance, where a decreasing exponential behavior has been observed.

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