Characterization of Non-Stationary Device to Device Channels for Indoor environment

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***Abstract*—This papers studies the non-stationarity behavior of Device-to-Device (D2D) fading channels based on measurements carried out in indoor environment at 2.48 GHz. Tow metrics were used: the Kolmogorov-Smirnov (KS) test and the collinearity metric. It was shown that the equivalent stationarity distance depends on the relative distance between terminals as well as the propagation environment.**

***Index Terms*—Device to Device, stationarity, propagation**

I. Introduction

Device-to-Device (D2D) radio channels are considered as non-stationary channels, i.e. the channel statistics can vary over time, due to the dynamic change of environment around the terminals. To define its stationarity region is of great interest for modeling the time-varying D2D channel characteristics. So far, only the non-stationarity of vehicle-to-vehicle (V2V) channels were explored in literature [1], [2].

This paper assesses the non-stationarity behavior of the measurement based small-scale fading for indoor D2D channels. Two stationarity metrics were considered: the Kolmogorov-Smirnov (KS) test proposed in [3] for on-body channels where the transmitter (Tx) and receiver (Rx) antennas were attached to the same body and the collinearity metric that was developed for V2V channels [1].

II. Indoor D2D Channel Measurement Campaign

A narrow-band D2D channel measurement campaign was carried out in classical offices at CEA Leti at 2.48 GHz. Various indoor environment were considered, e.g. single and multiple rooms, in order to assess the line-of-sight (LoS) and non-line-of-sight (NLoS) conditions. A 4-port VNA was employed to record the full S-parameters. Four people were involved in the measurement and six links were measured in each run. Multiple human mobility were considered including rotation, random movements and straight walking directions. Monopole antennas were used and it was vertically mounted on the right side of a helmet placed on the head of a moving subject. The time step was set to 4 ms providing 2501 points for each realization, considering a measurement time of 10 s. More details about the measurement campaign, post-processing and preliminary results on the channel characteristics can be found in [4].

III. Stationarity Metrics

A stationary process is a process whose its statistical properties do no vary over time [5]. However, a more relaxation notion is usually considered which is a "stationary process up to order m" where the moment characteristics are invariant for each time instant. The small-scale fading characterizes the time-varying part of the channel which depends on the constructive and destructive superposition of the different multi-path components that contribute to the rapid fluctuation over time and it is usually modeled up to order 2. Therefore two metrics were used to qualify the non-stationarity aspect of the small-scale fading for D2D channels: the KS test [6] and the collinearity metric.

The KS test was used in order to assess the stationarity region length of the small-scale fading distribution. The method is based on decomposing the N observations of a realization into M non-overlapping blocks of length L such as

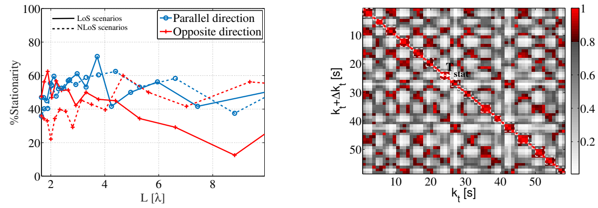
$$N = L \times M \tag{1}$$

However, there is a trade-off between the number of blocks and the length of each blocks. More observations within a block contribute to more accuracy in calculating its empirical cumulative distribution function (cdf), while a large number of blocks will allow for a more robust results. The minimum required length L was set to 100 (1.65λ). Therefore, for similar mobility patterns and a given environment propagation condition, the KS test was employed on each two consecutive blocks in order to study their similarities and the stationarity probability of cdf was then calculated as follows:

$$P(\%\text{CDF stationarity}) = \frac{\sum_{p=1}^{M^*} P}{M^*} \tag{2}$$

where p is a Boolean number that is set to 1 when the two tested blocks are similar (KS test is truth), note that the significance level upon which the KS test decision is made was set to 0.01, $M^* = (M-1) \times N_g$ and N_g is the number of realizations.

Looking into (2), one can readily detect that a probability of 100% means that all two consecutive blocks are similar while 0% imposes that there is no similar consecutive blocks. Thus, a threshold of 20% was decided in order to determine the stationarity length L_{stat}.



(a) KS test

(b) Collinearity metric

Fig. 1: Examples of stationarity test results of indoor D2D channels

The collinearity metric was used to analyze the non-stationary behavior of the Doppler spectrum for D2D fading channels. The method consists on splitting the measurement data, for a given mobility pattern and environment condition, in regions of dimension L using a sliding window of $L/2$. Hence, within each region, the small-scale fading was assumed stationary and the local Doppler spectrum was calculated using the Multitaper power spectral density estimate [7]. The minimum stationarity length was set to L_{stat} given by KS test. Then, the collinearity metric was calculated to assess the similarities between any two estimated Doppler spectra. It gives values between 0 and 1. A collinearity close to 1 results from comparing very similar PSDs, whereas a collinearity close to 0 indicating the dissimilarities between the two compared Doppler spectra. Therefore, an indicative threshold was set to 0.8 in order to identify the degree of similarities between the Doppler spectra and to define the time stationarity region.

IV. Measurement Results

Fig. 1a presents the KS test results of D2D small-scale fading in LoS and NLoS scenarios for parallel and opposite walking scenarios. For LoS scenarios, the KS test is around 50% for parallel direction while for opposite direction when Tx and Rx were moving close to each other, the KS test decreases with the increases of L revealing the non-stationarity behavior of the small-scale fading after 8λ. These observations can be related to the mitigation of the coherent power with the increase of Tx-Rx distance as highlighted in [4]. A stationary behavior can be considered in large sense for NLoS scenario, probably due the large effect of the MPCs presented in such environment and the less impact of the coherent component.

Fig. 1b presents the collinearity test results obtained from opposite LoS direction and Table I lists, for each scenario, the minimum and maximum stationarity times T_{stat}, i.e. $\min_{T_{stat}}$ and $\max_{T_{stat}}$. As seen, the opposite walking LoS scenario reveals explicitly the non-stationarity behavior of the small-scale fading. This is probably due to the fast variation of the coherent path which can impact the Doppler spectrum. Moreover, for a given walking scenario, the small-scale fading obtained from LoS environment exhibits extra non-stationarity behavior compared to the one given by the NLoS environment.

TABLE I: Stationarity time results

Walking patterns	**Propagation condition**	$\min_{T_{stat}}$ [s]	$\max_{T_{stat}}$ [s]
Parallel direction	LoS	1.9 ($7.8\,\lambda$)	11.6 ($48\,\lambda$)
Parallel direction	NLoS	2.9 ($12\,\lambda$)	37.7 ($155.8\,\lambda$)
Opposite direction	LoS	1.9 ($7.8\,\lambda$)	4.8 ($19.8\,\lambda$)
Opposite direction	NLoS	2.9 ($12\,\lambda$)	12.6 ($52\,\lambda$)

V. Conclusion

The non-stationarity behavior of the indoor D2D small-scale fading were studied based on methods proposed in literature for On-body channels [3] and V2V channels [1]. Two metrics were employed, i.e. the KS test and the collinearity metric for the cdf amd Doppler spectrum, respectively. Accordingly, the small-scale distribution depends on Tx-Rx distance considering the LoS conditions whereas non dependency was found for the NLoS environment. Based on the collinerity test, the Doppler spectrum has shown a time variation aspect in the opposite direction LoS scenarios which can be simply related to the rapid variation of the relative distance between terminals which impact the angle of LoS and the coherent power. At this point, it is worth mentioning that the minimun stationarity time was around 1.9 s.

Acknowledgment

The preferred spelling of the word "acknowledgment" in America is without an "e" after the "g". Avoid the stilted expression "one of us (R. B. G.) thanks ...". Instead, try "R. B. G. thanks...". Put sponsor acknowledgments in the unnumbered footnote on the first page.

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