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# The Effect of Small-Scale Mobility on Terahertz Band Communications

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## ABSTRACT

The use of massive antenna arrays for creating extremely directive antenna radiation patterns is considered vital for overcoming high path loss and atmospheric absorption of terahertz links. However, high directivity also results in frequent misalignment of beams due to small-scale/micro-mobility of user equipment (UE), such as shakes and rotations, leading to the spontaneous degradation of SNR level and waste of communications time for the beam searching procedure. In this paper, we make the initial steps to investigate the behavior of terahertz band link characteristics subject to the small-scale mobility of UE. We show that the optimal antenna directivity angle leading to the highest, on average, capacity heavily depends on the micro-mobility pattern of the UE. Further investigations in this area will contribute to the design of robust and high-performance communication systems in the terahertz band.

## CCS CONCEPTS

• **Networks** → **Network reliability**; **Network mobility**; *Network performance modeling*;

## KEYWORDS

Terahertz communications, capacity, micro-mobility, beam steering

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## 1 INTRODUCTION AND BACKGROUND

The small wavelength associated with terahertz (THz) band potentially promise truly massive antenna arrays featuring hundreds on antenna elements at transmit and receive side of a communications link [1]. Such arrays will be capable of creating extremely directional antenna radiation patterns with beamwidth reaching less than several degrees, thus, overcoming path loss and atmospheric absorption of THz band [3].

The use of narrow antenna radiation patterns inherently requires precise beamsteering algorithms to account for both the large-scale mobility and much less predictable small-scale mobility [2]. Small and quick rotations and displacements of user equipment (UE) during the communications process may deteriorate the received signal strength and even lead to outage conditions due to imperfect alignment of beams [5].

When high directivities are used at both ends of a communication link, beamsteering needs to be frequently invoked to restore the beam alignment, which cannot be performed instantaneously. Moreover, the smaller the beamwidth, the more frequently misalignment will occur. Thus, for every practical beam steering solution with known characteristics and UE micro-mobility model, there should be a fundamental trade-off between the antenna directivity angle and the average capacity provided to UE.

In this paper, we characterize the above-mentioned trade-off using field measurements of the UE micro-mobility in several illustrative scenarios. We show that, when accounting for small-scale mobility, a nonlinear dependence appears between the antenna directivity angle and the average capacity of the THz link. The preliminary results of this work will lead to the further investigations in the area, aiming to comprehensively characterize the relation between the small-scale mobility pattern, the characteristics of the beam steering solution, and the system performance.

## 2 SYSTEM MODEL

In this paper, we consider a single point-to-point link between a stationary THz band access point (THz-AP) and a mobile handheld device with THz band connectivity (THz-UE). Both THz-AP and THz-UE are equipped with identical planar 2D antenna arrays with $N(\alpha)$ elements each. We follow a well-adopted propagation model for THz communications reported in [3] and a cone antenna radiation pattern [4], where the gain, $G$, is a function of the antenna directivity angle, $\alpha$: $G = 2/(1 - \cos(\alpha/2))$. We consider a constant noise power spectral density equal to $-174$ dBm/Hz.

The system operates as follows. Once the beam searching procedure is performed at $t_0 = 0$ the beams are assumed to be perfectly aligned. UE micro-mobility process affects alignment and may lead to the SNR degradation at some time $t_1 > t_0$. The beam searching is then initiated again. For simplicity, we assume hierarchical

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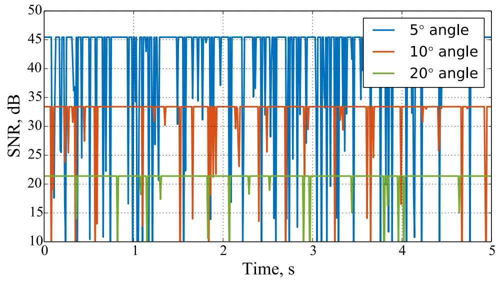


**Figure 1: Sample of the $SNR(t)$ for *Ball game* pattern.**

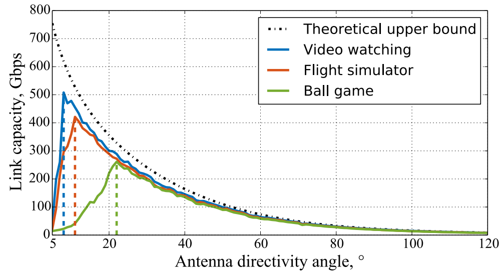


**Figure 2: Time-averaged capacity of the THz link.**

beam search mechansim [2], where the beam searching time, $T_S$, depends on the array switching time $\delta$, the number of transmit and receiver antenna arrays elements, $N_T$ and $N_R$, respectively: $T_S = (N_T + N_R)\delta = 2\delta N(\alpha)$.

The metrics of interest are SNR as a function of time, $SNR(t)$, and the average Shannon capacity, $E[C]$, where $C = B\log(1 + SNR(t))$.

## 3 FIRST-ORDER MEASUREMENT CAMPAIGN

For the field measurements, the iPhone 5SE acted as an UE and Sensor Kinetics Pro software has been used to capture the small-scale movements and rotations of the device during the trials. The user was staying still during the entire trial (no large-scale mobility) and constantly holding the device with two hands.

Three illustrative small-scale mobility patterns were selected:

- *Video watching*. The UE was used to watch Youtube video.
- *Flight simulator*. The UE was used to play the flight simulator game, where the control is performed via the device rotation.
- *Ball game*. The UE was used to play the game, where the user aims to hold the ball on the surface for as long as possible. The control is performed by movements and rotations.

The duration of all trials was 1 min. The average capacity results for each of the patterns were averaged over 20 different samples.

## 4 PERFORMANCE EVALUATION

The obtained measurement results of the UE small-scale mobility have been further used to model the SNR and capacity of the THz link between THz-AP and THz-UE, following the considerations from Section 2. For the numerical study, the 50 GHz-wide band of 275-325 GHz was selected. The distance of the communication link was set to 2 m and the transmit power, $P_{Tx}$, to 0 dBm.

Fig. 1 reports a sample of $SNR(t)$ for the *Ball game* pattern and three different values of the antenna directivity angle, $\alpha$: 5°, 10°, and 20°. As one may observe, each of the antenna directivity angles has the maximum SNR level, reached when the antenna radiation patterns are perfectly aligned. These values are 45.45 dB, 33.41 dB, and 21.39 dB, respectively, so the smaller $\alpha$ leads to higher maximum SNR due to the higher antenna gains. Meanwhile, the smaller $\alpha$ also expectedly leads to more frequent and severe $SNR(t)$ degradations due to UE small-scale mobility, as also shown in Fig. 1.

On its turn, Fig. 2 reports on the time-averaged capacity of the modeled THz link as a function of $\alpha$ for three selected small-scale mobility patterns and a theoretical upper bound for a static link. This figure illustrates that each of the taken patterns has its own 'optimal' value of antenna directivity angle: for all the smaller values of $\alpha$, the spontaneous degradation of SNR starts dominating the extra gain and the average capacity rapidly decreases. For the selected set of patterns, these values are around 8°, 11°, and 22°.

It is important to note that after these points ($\alpha$ smaller than the 'optimal'), the capacity starts degrading very fast and a few degrees difference may easily lead to orders of magnitude lower capacity. Therefore, the proper adjustment of the beamwidth following the changes in the mobility pattern is extremely important for the design of high-rate and reliable THz communications, so the small-scale mobility models should be further investigated and integrated into suitable performance evaluation methodologies.

## 5 CONCLUSIONS AND FUTURE WORK

This paper aims to bring an interest to the important effects of small-scale UE mobility on the performance of THz band communications. Particularly, the trade-off between the antenna directivity angle and the capacity of the THz link is investigated by a combination of the field measurements and link level simulations. The performed assessment and reported results illustrate that the typical small-scale mobility of a handheld device may have a severe impact on the SNR and capacity of THz communications, thus, calling for further research in the area.

The future work may include, among others, accounting for small-scale mobility in the performance evaluation, design of beamwidth adjustment mechanisms and small-scale mobility-aware beam tracking solutions. The study can be further elaborated by introducing the PHY/MAC-layer signaling and considering possible packet drops due to the temporal outage caused by the small-scale mobility.

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