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A comparative study of near-field blockages in 14 GHz and 140 GHz indoor wireless channels

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Abstract. Further increase in the volume and speed of data transfer requires the use of the subterahertz frequency range as the next stage in the evolution of wireless communication systems. Problems emerge due to large propagation losses of subterahertz signals in the atmosphere and a drop in the output power and sensitivity of subterahertz transceivers. This leads to the necessity of highly directional communication channels. Such channels will rely on the use of antenna arrays in both the base station and the user equipment. Given the inherent limitation to relatively small coverage areas, the deployment of subterahertz systems in indoor environments will emerge as a key aspect of their practical implementation. It is expected that line-of-sight channel blockages by users in crowded premises will significantly affect the communication stability. Signal scattering effects are to be different from those observed at microwaves. Moreover, near-field wireless operation becomes possible and probable. In this paper, we perform a comparative study of near-field blockages in 14 GHz and 140 GHz indoor wireless channels. Different trajectories of the blocking user are studied. A diffraction model describing dynamics of the blockage process is parameterized. The results obtained allow one to enhance the existing cluster models of subterahertz channels and to determine the available time budget for communication systems with real-time blockage avoidance.

Keywords: subterahertz, 6G network, indoor deployment, channel blockage, near-field diffraction, signal time series, signal loss

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Материалы конференции

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Сравнительное исследование ближнепольных блокировок в беспроводных каналах с несущими 14 ГГц и 140 ГГц внутри помещений

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Аннотация. Для дальнейшего увеличения объемов и скорости передачи данных необходимо освоение субтерагерцового диапазона, требующего использования высоконаправленных каналов связи из-за значительных потерь на распространение. Ключевым сценарием становятся помещения, где на устойчивость связи влияет блокировка каналов прямой видимости, а распространение сигнала характеризуется ближнепольными эффектами, отличающимися от микроволнового диапазона. В этой статье мы проводим сравнительное исследование блокировок в ближнем поле в беспроводных каналах внутри помещений на частоте 14 ГГц и 140 ГГц. Изучаются различные траектории блокирующего пользователя, параметризуется аналитическая дифракционная модель, описывающая динамику процесса блокировки сигнала. Полученные результаты позволяют уточнить существующие кластерные модели субтерагерцовых каналов и определить доступный временной бюджет для систем связи с упреждающим методом предотвращения блокировки в реальном времени.

Ключевые слова: субтерагерц, сеть 6G, развертывание внутри помещений, блокировка канала, дифракция в ближнем поле, временной ряд сигнала, ослабление сигнала

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Introduction

At the moment the development of wireless communications is widely conducted and oriented to raising data rate and connection reliability. Increasing throughput is a cornerstone of next-generation wireless networks. Transition to subterahertz (sub-THz) frequencies poses significant challenges, primarily due to huge atmospheric propagation losses and an essential reduction in transceiver output power, which require the use of ultra-directional transceiver systems. In the pursuit of ensuring a stable wireless connection, it is imperative to implement mechanisms that can proactively detect obstructions that arise when the line-of-sight (LoS) is impeded by the human body. Information about the characteristic signal oscillations that occur immediately before blockage and are associated with the diffraction phenomenon near the object can be used for proactive detection methods [1]. In accordance with the standard approaches to modeling

communication channels at the system level, deterministic ray tracing methods are selected, supplemented by emulation of certain stochastic components. Based on them, diffraction models are presented that describe the effect of the human body on the transmission channel when it is blocked [2, 3]. This paper provides an addition to existing models using the classical description of diffraction at the edge of a half-plane using Fresnel integrals [4].

Experiment Methodology

In order to assess the received signal level during the dynamic blockage, two experimental setups were employed, operating at carrier frequencies of 14 GHz and 140 GHz. The setups are similar to those detailed by us in [5]. The difference is that the 14 GHz setup does not have final frequency multiplication stage as compared to the 140 GHz setup. The antennas terminating transmitters (Tx) and receivers (Rx) are physically different but have similar beamwidths of $8-10^\circ$. The trajectories of the blocking user under study are a straight line and a circle (both are 1.8 m long), while the height and the length of the Tx-Rx LoS are 1.5 m and 1.1 m, respectively. The blocking user intersects the LoS at the midpoint with an average speed of $u_x = 0.63$ m/s.

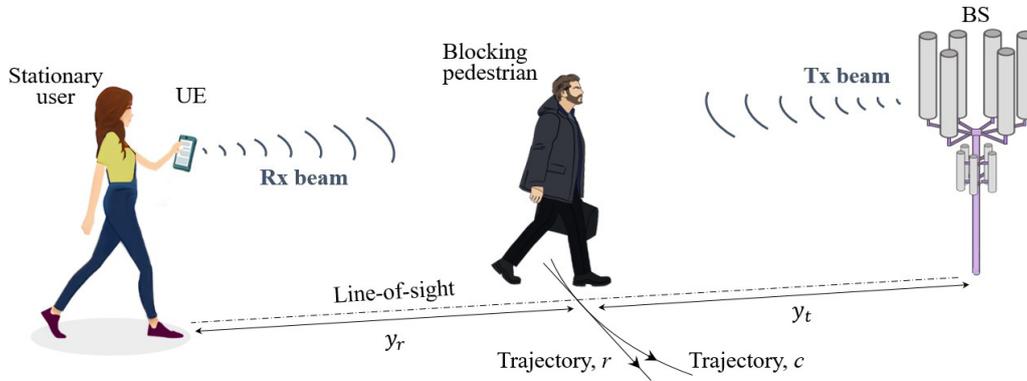


Fig. 1. Geometries of the experiments

Geometry of the experiments is detailed in Fig. 1. And analytical geometry-dependent diffraction models of the dynamic blockage process are shown in Fig. 2, *a, b*. Illustrated knife-edge diffraction models are parameterized and compared against the Rx signals, P_{exp14} and P_{exp140} , obtained in the experiments at $f = 14$ GHz, 140 GHz. Approximation curves, $P_{fit,1}$, are determined directly using Fresnel integrals (1)–(4) described below, treating the human body as an infinite vertical opaque strip 0.2 m wide, Δv , in a horizontal plane and the experiment geometry as measured, i.e., Tx/Rx coordinates relative to the LoS and user trajectory intersection point $y_r = y_t = 0.55$ m (5):

$$C(v) = \int_0^v \cos(t^2) dt, \quad S(v) = \int_0^v \sin(t^2) dt, \quad (1)$$

$$I(v, \Delta v) = \frac{1}{2} \left\{ \left[1 - C\left(v + \frac{\Delta v}{2}\right) + C\left(v - \frac{\Delta v}{2}\right) \right]^2 + \left[1 - S\left(v + \frac{\Delta v}{2}\right) + S\left(v - \frac{\Delta v}{2}\right) \right]^2 \right\}, \quad (2)$$

$$v(t) = \frac{v_1 + v_2}{2}, \quad \Delta v(t) = v_1 - v_2, \quad (3)$$

where

$$v_m(t) = \sqrt{\frac{2f}{c} \left(\frac{1}{y_t} + \frac{1}{y_r} \right)} \left(\frac{u_x t y_t}{y_t + y_r} - \Delta x_m \right), \quad m = 1, 2, \quad (4)$$

$$P_{fit,m}(t) = 10 \lg I(v, \Delta v) - I_0 |_{y_t = y_r}. \quad (5)$$

Here c is the speed of light. In contrast, $P_{fit,2}$ are determined using the LoS lengths, y_r and y_c , and shift factor, I_0 , as fitting coefficients. The fitting is successful in the initial phase of the blockage of interest with the LoS lengths of 0.2 m and 0.36 m for rectilinear (r) and curvilinear (c) trajectories, respectively.

Results and discussion

An assessment of the time signatures in the signal dynamics is made, since for the development of next-generation stable wireless links it is important to determine the actually available time budget that allows avoiding connection loss when routing a radio signal under blockage conditions. In the experiments at 14 GHz, the pre-blocked state is not expressed, it lasts 400 ms and is followed by a slow signal drop by 1.5 dB. Even though, we observe a bit error rate of 8% in the quadrature amplitude modulation (QAM) scheme with 64 states. At 140 GHz, the signal attenuations are significantly higher and reach 13–17 dB. Fig. 2, c , d provides statistics on the signal temporal metrics.

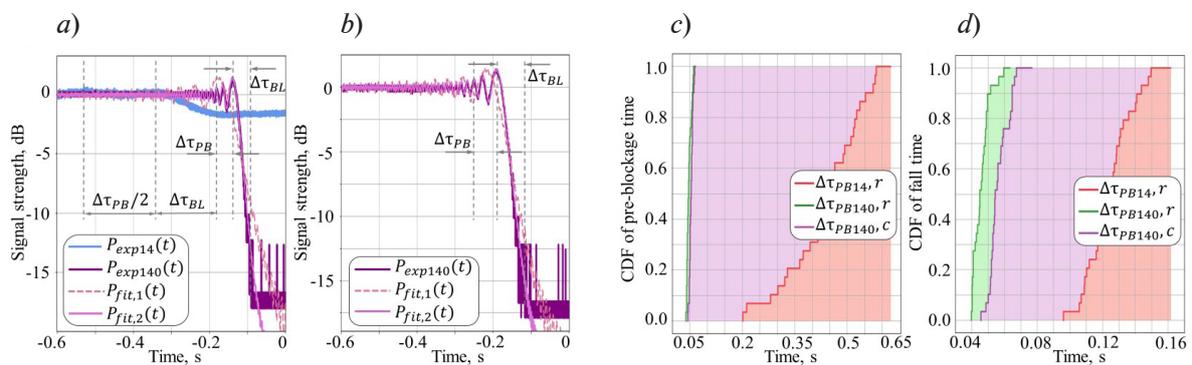


Fig. 2. Parameterized blockage model for rectilinear trajectory (a), curvilinear trajectory; cumulative distribution function (CDF) (b) for pre-blockage time (c), signal fall time (d)

Based on the results of a series of 60 independent measurements, it was found that the average time of the pre-blocked state, Δt_{PB} , is 51 and 54 ms for rectilinear and curvilinear trajectories, respectively, and the fall time, Δt_{BL} , is 52 and 57 ms, respectively. The parameterized analytical diffraction blockage model fits experimental data P_{exp140} well, providing a normalized root-mean-square error of only 2.6–4.4% for both studied trajectories. As an analytical model, it requires minimal computational resources while maintaining high accuracy, enabling integration into high-fidelity cluster models of sub-THz communication channels.

Conclusion

This study presents a comparative analysis of near-field blockage effects in indoor wireless channels at 14 GHz and 140 GHz. Despite the modest 1.5 dB attenuation at 14 GHz causing an 8% bit error rate for 64 QAM, blockage at 140 GHz leads to severe signal degradation with 13–17 dB attenuation. To characterize the behavior of the near-field signal, a parameterized diffraction model based on Fresnel integrals was developed. At the same time, the analytical model agrees well with the experimental data, demonstrating a root-mean-square error of only 2.6–4.4%. Key time characteristics, such as the pre-blocked state time (51–54 ms) and the signal fall time (52–57 ms), were determined for different trajectories of the blocking user. These results enable accurate time budget estimation for proactive blockage detection in next-generation communication systems. The obtained results can be integrated into cluster models of subterahertz channels, which helps to enhance the design procedure and performance analysis of stable wireless networks with directive data links.

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