# A Measurement Study of User-Induced Propagation Effects for UHF Frequency Bands

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***Abstract*— Understanding user-induced effects on signal reception across multiple frequency bands is of great scientific and military importance to the wireless industry. Various on-body locations and directional heading of the user are believed to impact the performance of mobile devices, but there has been little work across multiple frequency bands to quantify these user-induced effects. In this work, we perform a measurement study to explore user effects on radio wave propagation with varying line-of-sight conditions and environments across multiple frequency bands, including white space, cellular, and WiFi frequency bands. To do so, we first conduct a baseline experiment that investigates the propagation differences for ground-to-ground communication and tower-to-ground communication. Then, we measure signal quality as a function of the on-body location of the receiver, directional heading of the user with respect to the transmitter, vegetation type, frequency band, and propagation distance. Our assessment reveals that the user directionality can reduce received signal strength up to 20 dB and reduce throughput by 20.9% at most. We also find that the body can act like an antenna, increasing reception by 4.4 dB and throughput by 14.4% over a reference node at the same distance.**

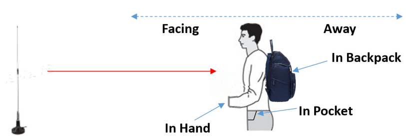
## I. Motivation

Wave propagation knowledge of user-induced effects is of great significance for military communications, cellular network deployments, and device antenna design. The receiver directionality and on-body location caused by human behavior can strongly affect the reception of electromagnetic waves. When there is a change in user behavior, antenna elevation, or scatter distributions, the channel quality can vary, resulting in fluctuations in signal reception within the same environment. Depending on the magnitude of the variation, the received signal strength (RSS) can drastically change the user experience, especially on the outer edges of the propagation range. Many works have investigated the user-induced effects on wave propagation [1] – [6], but most of them lack adequate experimental support, and only focus on a particular environment type at a single frequency band without varying the on-body location and directional heading.

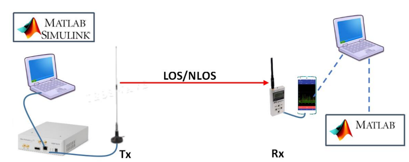
In this work, we perform a measurement study of user-induced effects on wireless reception over a month-long measurement campaign across multiple frequency bands under various conditions characterized by on-body location of the receiver, directional heading, propagation distance, vegetation type, and elevation. We believe that our measurement study has impact on future WiFi and cellular deployments for potential crowdsourcing applications and Ad Hoc networks such as when designing military networks.

## II. Hardware Setup

The experiments are carried out using the Universal Software Radio Peripheral (USRP) N210 as the transmitter controlled a laptop to generate continuous waves at 500, 800, 1800, and 2400 MHz. An omni-directional, multi-band antenna with a typical gain of 4 dBi is implemented at the transmitter. A Nuts About Nets Handheld RF Explorer is working as a spectrum analyzer (SA) to capture received signal strengths (dBm) during in-field experiments per user and the data sets are collected with the Touchstone-Pro mobile application. For each experiment, we collect a minimum of 80 samples. Fig. 1(a) shows our setup with the receivers in the hand and pocket when squarely facing the transmitter, while the backpack is on the opposite side of the transmitter. Fig. 1(b) depicts the hardware setup for our experiments.




(a) On-Body Receiver Locations




(b) Hardware Setup for Experiments

Fig. 1. Measurement Scenario for both LOS and NLOS Environments.

## III. Experiment Design and Conclusion

### A. Baseline Experiment Setup

In baseline setup, the experiments are performed in two practical channels: a ground-to-ground scenario and a tower-to-ground scenario, which enable the study of the effects of transmitter elevation on signal reception, and of controlled user behaviors at diverse user positions. The user always faces the transmitter and the on-body location of the receiver is the hand. The transmitter is located to a height of 1 m above ground in the ground-to-ground setup, while the transmitter antenna is fixed at 10 meters above the receiver antenna to imitate the tower-to-ground cellular networks. For reference purpose, we first conduct measurements in a LOS path where no obvious objects might interfere with the transmission.

*Conclusion:* the Tower-to-ground scenario results in much higher shadowing standard deviations than the ground-to-ground scenario.

### B. Single-User Linear LOS Experiment

The linear LOS experiment is to explore the user-induced effect of a single user on wave propagation. Specifically, we conduct measurements in a selected LOS path and investigate the effects of on-body positioning and directional heading of the receiver with respect to the transmitter. The transmitter and receiver have an unobstructed path between them only affected by various on-body locations, as a function of whether the user is forward facing or reverse, propagation distance, and frequency band under test. Table I provides the quantitative evaluation on user-induced loss for three on-body locations.

TABLE I
ESTIMATED USER-INDUCED LOSS AFTER LINEAR FITTING

| Location | User-Induced Loss (dB) | 500 MHz | 800 MHz | 1800 MHz | 2400 MHz |
|---|---|---|---|---|---|
| Hand | Min | 9.32 | 2.56 | 2.47 | 0.27 |
| | Max | 13.42 | 7.02 | 15.10 | 19.15 |
| | Mean | 10.73 | 5.48 | 6.81 | 6.77 |
| | St Dev | 0.81 | 0.93 | 4.12 | 6.01 |
| Backpack | Min | 2.81 | 0.65 | 3.36 | 0.35 |
| | Max | 4.96 | 2.96 | 11.11 | 8.55 |
| | Mean | 3.55 | 1.44 | 5.71 | 3.17 |
| | St Dev | 0.68 | 0.73 | 3.10 | 2.89 |
| Pocket | Min | 6.02 | 3.79 | 0.50 | 0.38 |
| | Max | 10.71 | 8.04 | 16.46 | 9.04 |
| | Mean | 7.63 | 5.25 | 5.99 | 3.36 |
| | St Dev | 1.49 | 1.21 | 5.08 | 3.75 |

*Conclusion:* The effects of user behaviors tend to be more critical on received signal strength at relatively close distances. The location in the hand presents the largest user-induced loss out of all locations. Users can act like an antenna and cause signal reception of up to 4.4 dB more than the reference node.

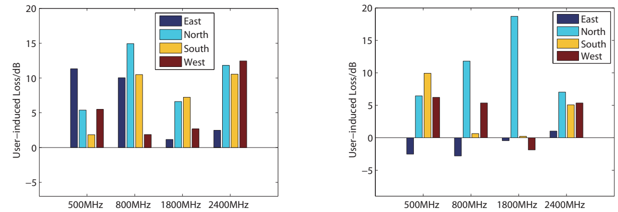
In order to further justify that the user can act as an antenna, we perform extensive experiments to compare the throughput performance implementing a typical OFDM scheme among two directional headings and a reference location.

*Conclusion:* The location of the in-hand facing receiver can achieve an average of 13% (ranging from 11.0% to 14.4%) improvement in terms of throughput than the reference node, and 19% (ranging from 18.1% to 20.9%) improvement than the in-hand receiver that is facing away from the transmitter.

### C. Multiple Users Radial NLOS Experiment

The radial NLOS experiment investigates the effects of cardinal direction forming a radial pattern, as opposite to the single path in linear LOS experiment, and directional heading of the user with respect to the transmitter on signal reception. We conduct the radial experiments with four simultaneous users of resemble size taking samples at each of the cardinal directions in two distinct propagation scenarios: a densely treed environment and a brush environment. Fig. 2 shows the quantitative evaluation on user-induced loss as a function of frequency and cardinal direction for the tree and brush environment.

*Conclusion:* The received signal quality is severely susceptible to environmental impacts and largely depends on frequency. moreover, the forward versus reverse facing directionality loss is more pronounced in the tree environment (6-8 dB) as opposed to the brush environment (3-7 dB). Users can affect received signal strength up to 20 dB.




(a) Tree Area (b) Brush Area

Fig. 2. Estimated User-Induced Loss at 40 m

### D. User Directionality-Aware Propagation Prediction

In order to investigate the user-induced impact of cellular providers crowdsourcing and inferring wireless channel characteristics from users via LTE Key Performance Indicators, we experimentally quantify the role of directional heading of the user with respect to the transmitter on propagation parameters derived from previous discussed linear LOS and radial NLOS experiments. In radial NLOS experiments, we examine the aggregate user effects aligned in all cardinal directions to remove the spatial differences.

*Conclusion:* The directional heading of facing towards the transmitter results in higher path loss exponents than turning away in channel propagation, and user directionality can have more than triple the shadowing effect in a given environment.

## IV. FUTURE WORK

We plan to extend our experiments design to higher frequency band. It is estimated that the impact of user effects will only increase with the growth of frequency bands such as those with millimeter wavelengths. Besides, we are interested in utilizing the user-induced information combined with sensors from mobile devices to improve performance.

## ACKNOWLEDGMENTS

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