Demo: Metasurface-Enabled NextG mmWave for Roadside Networking

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ABSTRACT

We present **Wall-Street,** a smart surface designed for vehicles to boost 5G mmWave connectivity for passengers. It improves mmWave connections in three ways: (1) it steers outdoor mmWave signals into the vehicle, ensuring all users have coverage; (2) it enables the vehicle to receive data from the current cell while measuring signals from potential handover cells, allowing smooth transitions without interrupting service; (3) during handovers, it combines/splits signals from/to both the current and new cells, creating a make-before-break connection. Our demonstration shows Wall-Street's versatile signal manipulation abilities. These include steering single beams, simultaneously reflecting and transmitting beams for neighboring cell measurements with concurrent communication, and combining or splitting beams for seamless cell transitions.

CCS CONCEPTS

• **Hardware** → **Wireless devices**; • **Networks** → **Network protocol design**; **Physical links**;

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1 INTRODUCTION

Millimeter wave (mmWave) communication, despite its potential for high data rates, faces significant challenges due to its susceptibility to blockage and high path loss [1, 5, 6, 11, 13]. As a result, networks deploy a dense array of small cells, leading to frequent handovers as users move through the coverage area. These handovers occur much more frequently in mmWave 5G New Radio compared to LTE or low-band 5G [4, 9]. The mmWave handover process is more complex than its low-band counterpart. It requires precise alignment of narrow beams between user equipment (UE) and base stations (BS), frequent measurement of neighboring cell signal strengths by the UE, and reporting of these measurements to the serving BS [3, 11, 12]. During this process, the serving cell must suspend data exchange with the UE, significantly degrading the service quality [4, 7, 8].

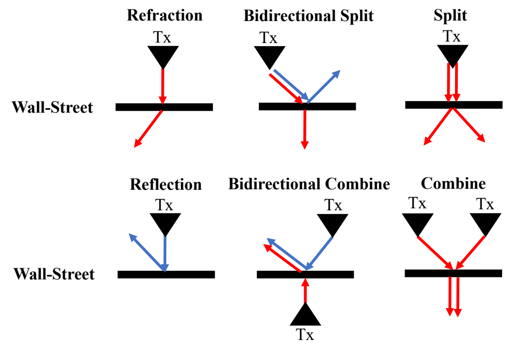

Figure 1: Wall-Street's six operational modes. *Left:* single beam refraction/reflection; *middle:* bi-directional beam spliting/combining; *right:* uni-directional splitting/combining.

To address mmWave communication challenges, we present Wall-Street, a programmable smart surface that manipulates and steers mmWave signals for seamless in-vehicle coverage and reliable communication. Wall-Street builds on the Huygens metasurface (HMS) concept, previously demonstrated at 24 GHz [2], and marks the first HMS implementation at 26 GHz. We strategically deploy Wall-Street on the vehicle, enabling three key innovations.

First, Wall-Street provides in-vehicle mmWave coverage by redirecting outdoor mmWave signals into the vehicle, ensuring consistent coverage for all occupants. This capability addresses the issue of signal blockage by car bodies. Second, Wall-Street enables seamless handover with concurrent communication. Wall-Street reflects synchronization signal bursts (SSB) from neighboring cells to the serving cell while refracting the data communication link between the serving cell and UE. This dual functionality—simultaneous transmissive and reflective beam steering—enables seamless handovers without service interruption. Third, Wall-Street facilitates make-before-break handover. By combining two beams directly to the UE, it enables concurrent transmission of identical data packets from both the old and new cell,

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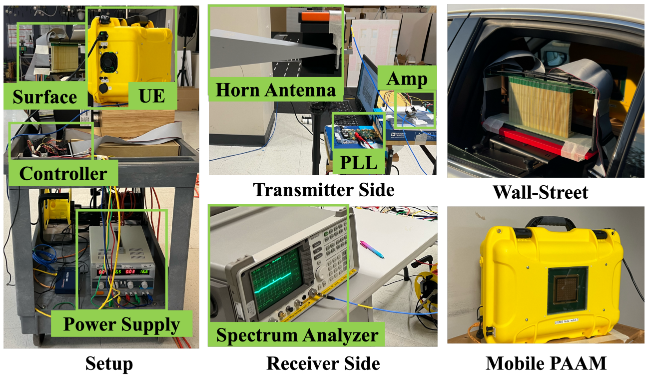
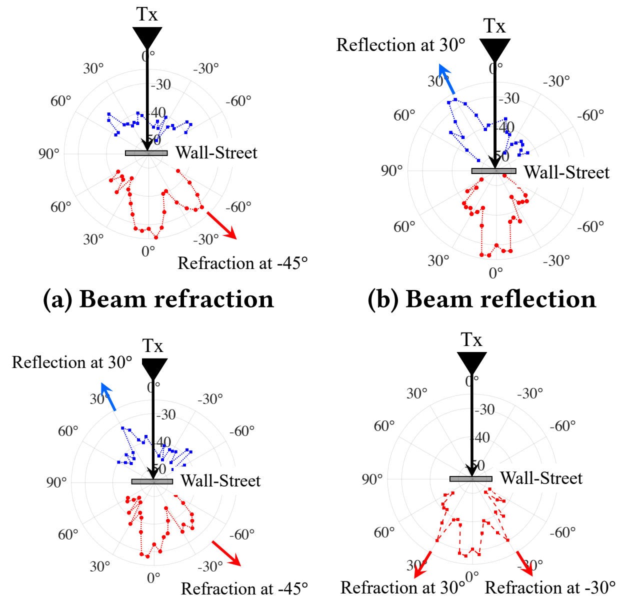


Figure 2: Demonstration setup for beam pattern measurements. *Left*: the surface setup; *middle:* the transmitter and UE setup; *right:* the receiver setup.



(a) Beam refraction **(b) Beam reflection**

(c) Bi-directional split **(d) Uni-directional split**

Figure 3: Wall-Street's beam pattern examples over four operations. Both Tx and Rx are 2 meters apart from the surface. There is a peak around 0°due to signals bypassing around the surface.

enhancing handover reliability.

Wall-Street has flexible signal manipulation capabilities, including single beam steering, simultaneous beam reflection and transmission, and beam combining and splitting. We demonstrate Wall-Street operating in six modes (Fig. 1).

2 DEMONSTRATION SETUP

Figure 2 shows our demonstration setup, including the Wall-Street surface, transmitter, receiver, and a mobile mmWave Phased-Array Antenna Module (PAAM) from the COSMOS testbed [10]. All devices operate at 26 GHz.

- **Wall-Street.** It comprises 76 boards with each board independently controlled by two 40-channel AD5370 16-bit DACs. The DAC provides a variable 0 to 16 V control voltage to the unit cells. To speed-up the steering process, one channel supplies voltage to two adjacent boards, allowing the two DACs to manage all boards independently. Both DACs connect to a Raspberry Pi's Serial Peripheral Interface (SPI) via GPIO.
- **Mobile PAAM.** For the UE, we use the mmWave software-defined radios (SDRs) integrated with the IBM mmWave PAAM. For demo, this portable PAAM alternates the transmitter and receiver role depending on different operational modes, as described in Fig. 1.
- **Transmitter Side.** For the transmitter, we use the phase-locked loop (PLL) frequency synthesizer ADF4371 in conjunction with a variable gain amplifier HMC997LC4 and a 25 dBi transmit horn antenna.
- **Receiver Side.** For the receiver, we use the same antenna at the receiver with a spectrum analyzer.

Figure 3 shows Wall-Street's beam patterns under four exemplary operational modes: (a) beam refraction at -45°, (b) beam reflection at 30°, (c) bi-directional beam splitting $-45°/30°$, and (d) uni-directional beam split at $-30°/30°$. For dual-beam operations, we equally divide the power between two beams. We color reflection in blue and refraction in red. To measure the beam pattern, we place the transmitter and receiver two meters away from Wall-Street and record the received signal in dB as we move the receiver from $-60°$ to 60° with respect to Wall-Street. The spectrum analyzer noise floor is at approximately -52 dB. Since we did not conduct this experiment in an anechoic chamber, the beam passes around the surface, resulting in a high peak around 0°. We observe above 25 dB gain compared to the noise floor for single beam reflection and refraction. For beam splittings, each beam provides approximately 20 to 22 dB gain. While these measurements are acquired at a single 26 GHz frequency, Wall-Street can operate at two different channels (*e.g.*, one beam at 26 GHz and another at 26.1 GHz). Also, Wall-Street can flexibly adjust the power ratio between two beams. Visitor can arbitrary select the operation as well power ratio for dual-beam operations. Also, visitor can choose different steering angles.

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