Surface steers signals for next-gen networks

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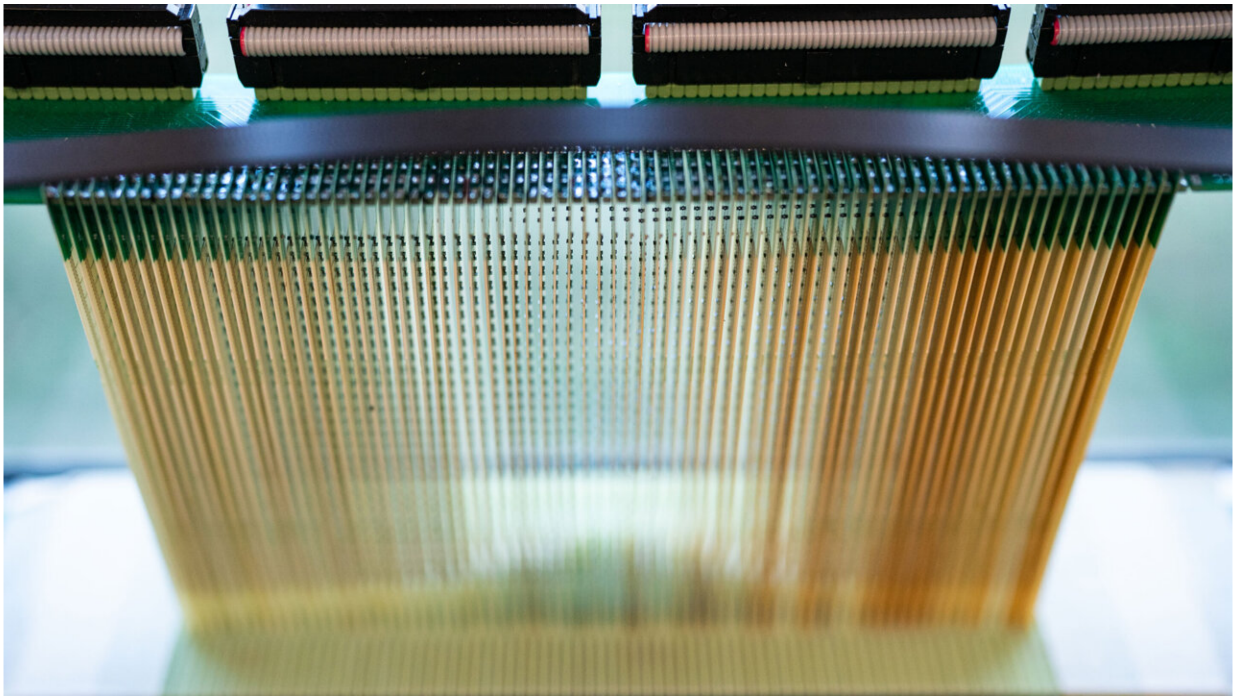
Computer science Ph.D. student Kun Woo Cho is the lead author of a study on mmWall, a new device that steers higher-frequency 5G signals, or mmWave signals, to get around obstacles and improve connectivity. Credit: Tori Repp/Fotobuddy

5G communications' superfast download speeds rely on the high frequencies that drive the transmissions. But the highest frequencies come with a tradeoff.

Frequencies at the upper end of the 5G spectrum hold the greatest amount of data and could be critical to high-resolution augmented and virtual reality, video streaming, video conferencing, and services in crowded urban areas. But those high-end frequencies are easily blocked by walls, furniture and even people. This has been a hurdle to achieving the technology's full potential.

Now, a team led by Princeton researchers has developed a new device to help higher-frequency 5G signals, known as millimeter-wave or mmWave, overcome this obstacle. The device, called mmWall, is about the size of a small tablet. It can steer mmWave signals to reach all corners of a large room, and when installed in a window, can bring signals from an outdoor transmitter indoors. The researchers presented their work on mmWall at the USENIX Symposium on Networked Systems Design and Implementation in Boston on April 19.

While computers and smartphones often connect to Wi-Fi indoors to get the best data speeds, outdoor 5G base stations could someday replace Wi-Fi systems and provide high-speed connectivity both indoors and outdoors, preventing glitches when devices switch between networks, said Kun Woo Cho, a Ph.D. student in Princeton's Department of Computer Science and the lead author of the research. Boosting 5G signals with technology like mmWall will be crucial to this broader adoption, she said.



The mmWall is an accordion-like array of 76 vertical panels that can both reflect and refract radio waves at frequencies above 24 gigahertz, the lower bound of mmWave signals. Credit: Tori Repp/Fotobuddy

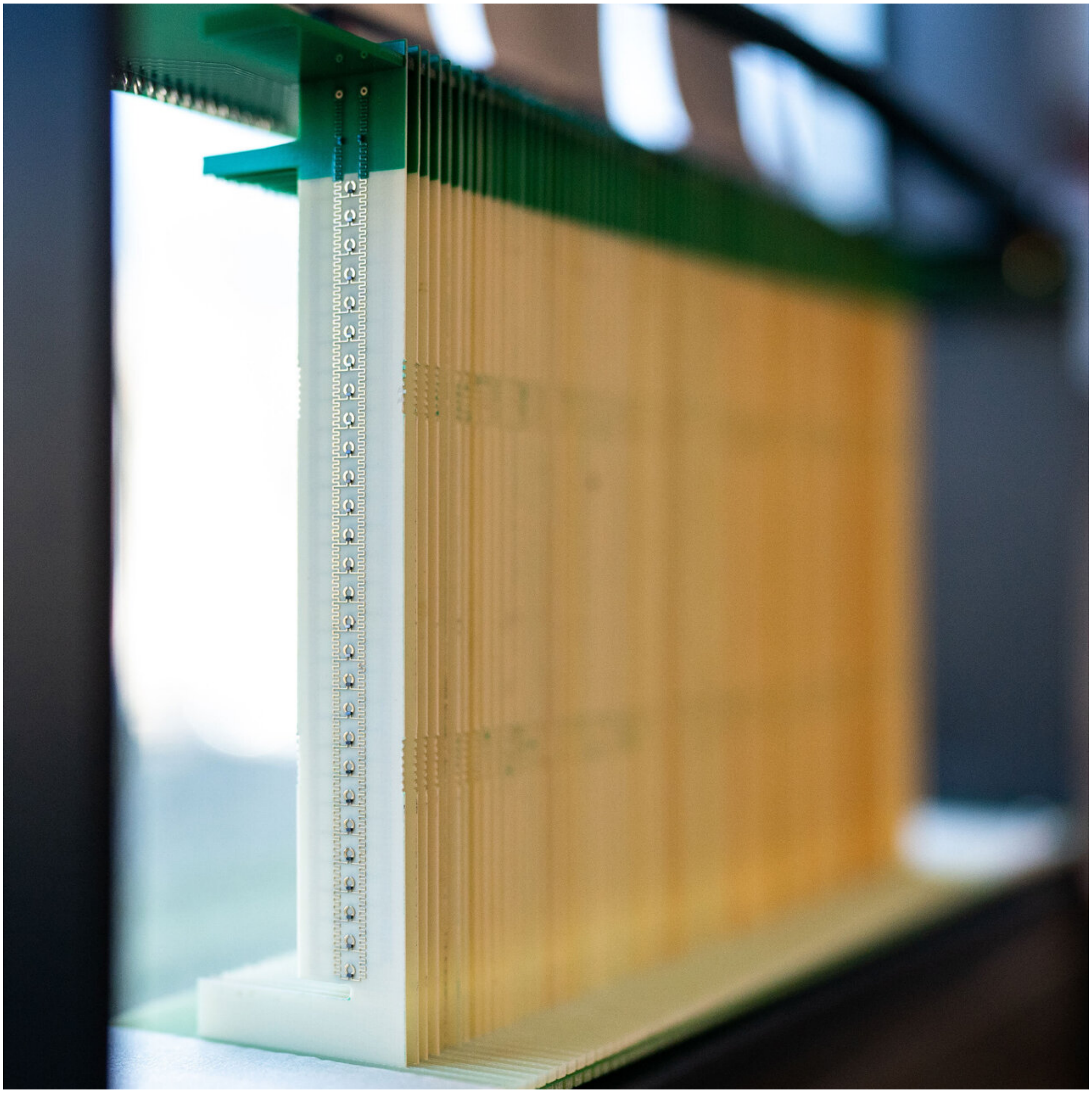
The mmWall is an accordion-like array of 76 vertical panels that can both reflect and refract radio waves at frequencies above 24 gigahertz, the lower bound of mmWave signals. These frequencies can provide a bandwidth five to 10 times greater than the maximum capability of 4G networks. The device can steer beams around obstacles, as well as efficiently align the beams of transmitter and receiver to establish connections quickly and maintain them seamlessly.

"Wireless transmissions at these higher frequencies resemble beams of light more than a broadcast in all directions, and so get blocked easily by humans and other obstacles," said senior study author Kyle Jamieson, a professor of computer science who leads the Princeton Advanced

Wireless Systems Lab (PAWS).

The mmWall surface is the first to be able to reflect such transmissions in such a way that the angle of reflection does not equal the angle of incidence, sidestepping a classic law of physics. The device can also "refract transmissions that hit one side of the surface through at a different angle of departure, and is fully electronically reconfigurable within microseconds, allowing it to keep up with the 'line rate' of tomorrow's ultra-fast networks," said Jamieson.

Each panel of mmWall holds two meandering lines of thin copper wire, flanking a line of 28 broken circles made of thicker wire, which constitute meta-atoms—materials whose geometry is designed to achieve tunable electrical and magnetic properties. Applying controlled electrical current to these meta-atoms can change the behavior of the mmWave signals that interact with the mmWall surface—dynamically steering the signals around obstacles by shifting their paths by up to 135 degrees.



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"Just by changing the voltage, we can tune the phase," or the relationship between the incoming and outgoing radio waves, said Cho. "We can basically steer to any angle for transmission and reflection. State-of-the-art surfaces generally only work for reflection or only work for transmission, but with this we can do both at any arbitrary angle with high amplitude."

The process is analogous to light waves slowing down when they pass through a glass of water, said Cho. The water changes the direction of the light waves and makes objects appear distorted when viewed through the water.

Cho mathematically analyzed different parameters of the meta-atoms' geometry to arrive at the optimal size, shape and arrangement for the copper meta-atoms and the pathways between them, which were fabricated with standard printed circuit board technology and mounted on a 3D-printed frame. In designing mmWall, the team aimed to use the smallest possible meta-atoms (each has a diameter of less than a millimeter), in order to optimize their interaction with mmWaves, as well as to simplify the device's fabrication and minimize the amount of copper. The mmWall also uses only microwatts of electricity, about 1,000 times less than Wi-Fi routers which use an average of about 6 watts.

Cho tested mmWall's ability to transmit and steer mmWave signals in a 900-square-foot lab in Princeton's Computer Science building. With a transmitter in the room, mmWall improved the signal-to-noise ratio at nearly all of the 23 spots tested around the room. And when the transmitter was placed outdoors, mmWall again boosted signals all around the room, including in roughly 40% of spots that had been completely blocked without the use of mmWall.

In addition to Cho and Jamieson, authors include Mohammad Mazaheri and Omid Abari of the University of California-Los Angeles, and

Jeremy Gummeson of the University of Massachusetts-Amherst.

More information: Abstract: [mmWall: A Steerable, Transflective Metamaterial Surface for NextG mmWave Networks](),

Provided by Princeton University

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