Open up the proceedings of the biggest wireless conferences such as the IEEE GLOBECOM and INFOCOM. A quick look at the accepted papers reveals a sad truth: *a vast majority of wireless research does not involve any experimental work at all*. This problem is most stark in the emergent millimeter wave (mmWave) frequency bands between 30 and 300 GHz. Simply put, the problem is one of access: the wireless research community demands access to more experimental platforms that are affordable and feature advanced wireless transceiver technologies.

Pi-Radio is a startup whose vision is to democratize experimental wireless research in these emergent bands. Pi-Radio is supported by the New York State Center for Advanced Technologies in Telecommunications (CATT), located at the Tandon School of Engineering at New York University. Pi-Radio has been funded by the following federal awards: a) NSF STTR Phase I; b) ARMY STTR Phase I; and c) NSF I-Corps. Our office is located in the Dumbo neighborhood of Brooklyn (NY). We have made a production-grade, technologically advanced, and low-cost Software Defined Radio system for use by the wireless research community.

The baseband sub-system of this SDR is the ZCU111 board, which is based on the Xilinx RFSoC. In addition to the FPGA fabric and ARM cores, the RFSoC contains multiple high-speed DAC/ADCs and soft-decision forward error corrector (SD-FEC) blocks integrated in silicon. The Pi-Radio transceiver (TRX) board mates with the ZCU111, and implements the fully-digital transceiver. Specifically, the TRX board consists of four HMC6300 mmWave up-converters and four HMC6301 mmWave down-converters made by Analog Devices. The RF ports of these chips are routed to separate 1x4 TX and RX linear antenna arrays designed by Aalto University (Finland). The local oscillator (LO) generation is done using the TI LMX2595 synthesizer chip, which uses a high-accuracy reference crystal input. The differential LO outputs are converted to single-ended using an impedance matching circuit. These single-ended LO signals are independently amplified in two stages (using a low noise amplifier cascaded with a power amplifier, both made by Analog Devices). The amplified LO signals are split using 1:4 Wilkinson power dividers made by Knowles Dielectric Labs. This allows phase-coherent LO signals (with programmable drive) to be available at all the mmWave up- and down-converter chips. The antenna arrays are surrounded by large circular *keep-out* areas; these spaces are meant for users to mount their home-brew dielectric lenses if desired.

We have also implemented MATLAB-based drivers for the control and data plane. All hardware schematics and software have been released on GitHub. We are currently implementing a few simple reference examples that users can use as a starting point in their research. This SDR system is shown in Fig. 1. While many of the calibration tasks have been done, we are currently in the process of implementing built-in self test (BIST) and array self-calibration routines. We note that early work on the SDR system (while based on a completely different architecture) was performed at NYU. This early SDR system and an LO sub-system are shown in Fig. 2a and 2b respectively.

The main benefit of a fully-digital transceiver is that it can transmit and receive in N directions simultaneously, where N is the number of antennas (in our SDR, N=4). To demonstrate the benefits of this, we built a simple OFDM-based data link between two nodes, where one is configured as the TX, and the other as a RX. The TX node transmits four streams of information, with each stream transmitted in a different direction. The RX *looks* in all four directions simultaneously. For each RX direction, it attempts to detect and decode each of the four TX streams independently. For clarity of illustration, the four streams of data are color coded (red, green, blue, and cyan). Fig. 3 plots the decoded constellations at the receiver. Each row corresponds to a different RX direction, and each column corresponds to a different TX direction or data stream. Each TX stream has four opportunities to be detected: one for each RX direction. We observe that a fully-digital transceiver allows all TX streams to be detected independently and that the optimal direction for one stream might be very different from the optimal direction for another. This shows the main benefit of a fully digital transceiver: the O(N2) scanning overhead with analog phased arrays is replaced with a one-shot O(1) detection.

Our goal is that the Pi-Radio SDR system can be used by the academic wireless community (as well as skunkwork projects among the affiliates) to perform more experimental work. Universities need to produce more engineers who have real-world prototyping skills. Companies today find it hard to find talent with such real-world skills. This SDR system is our attempt at bringing about the change that we believe the wireless world needs: *democratizing experimental research through affordable and technologically advanced SDR systems.*