Demo: Fully-Digital Beamforming Demonstration with Pi-Radio mmWave SDR Platform

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ABSTRACT

Pi-Radio's vision is to democratize wireless research by providing advanced mmWave Software Defined Radio (SDR) platforms to the community at plainly affordable price points. Pi-Radio's v1 SDR features a 4-channel fully-digital transceiver that operates in the 57-64 GHz band. Fully-digital (a.k.a. MIMO) transceiver architectures enable multiple simultaneous TX/RX beams, standing in stark contrast with phased arrays featuring analog beamformers that are capable of transmitting/receiving only one beam at a time. This opens up a whole set of research problems to work on, across virtually every layer of the protocol stack. In this demo, the team will: (1) prove the correct formation of different TX/RX beams by applying geometrically determined beamforming weights, and (2) prove the benefits of fully-digital beamforming by transmitting four independent streams of data with an OFDM-based physical layer.

CCS CONCEPTS

• **Hardware** → *Electromagnetic interference and compatibility*; **Beamforming**; *Digital signal processing*.

KEYWORDS

mmWave, SDR, beamforming, fully-digital

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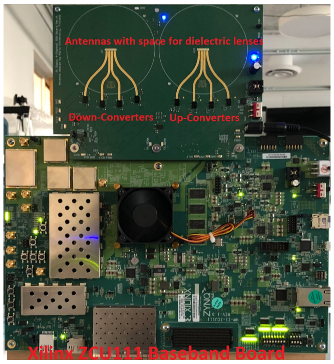

Figure 1: The Pi-Radio v1 SDR being tested at NYU. The bottom board is the Xilinx RFSoC-based ZCU111 evaluation board; the board at the top is the Pi-Radio transceiver board.

1 PI-RADIO MMWAVE SDR V1

Existing mmWave SDRs are either prohibitively expensive, or feature transceiver technologies that are not at the bleeding-edge of wireless innovation. Pi-Radio's vision[1] is to make such systems available to the research community, at reasonable rates. Pi-Radio v1 SDR features a 4-channel fully-digital transceiver that operates in the 57-64 GHz band. Unlike a phased array analog beamformer, a fully-digital beamformer can make n simultaneous beams, where $n = 4$ is the number of antenna ports in our system. This eliminates the need for *scanning*, which incurs a $O(n^2)$ overhead in analog beamforming systems. In contrast, a digital beamformer can achieve synchronization in $O(1)$; this demonstrates the *bleeding-edge* nature of the fully-digital SDR.

The SDR consists of three main parts: a) the Xilinx RFSoC-based ZCU111 baseband board; b) the Pi-Radio 4-channel fully-digital transceiver board; and c) a host computer running various software tool chains. For a detailed description of the platform, please refer to [1–3]. In addition to the hardware, we have also implemented easy to use MATLAB-based drivers and reference examples for this SDR. With just 3 lines of code, the user can: **a)** open and configure the SDR; **b)** run the experiments by transmitting, receiving, and processing the required waveforms; and **c)** close connections and shut down the SDR. A detailed tutorial along with some examples are provided in our website, in the *Getting Started* section [4].

We should give a shout-out to M-Cube, a very impressive (and competing) SDR effort from UCSD [5]; this team shares our passion for democratizing wireless research through affordable and advanced SDR systems.

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[1] Pi-Radio is a spin-off from the New York State Center for Advanced Technologies in Telecommunications (CATT) located at the Tandon School of Engineering at New York University.

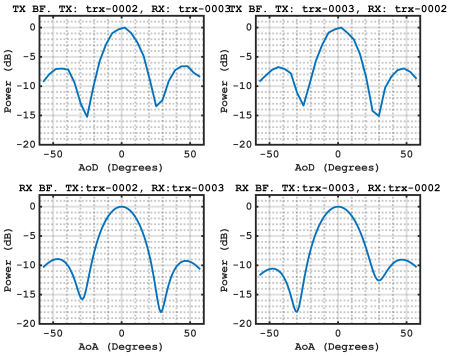

Figure 2: When the two nodes are placed in boresight, the AoA and AoD values are correctly estimated to be 0.

2 DEMONSTRATIONS

In these experiments, we will demonstrate **(1)** the correct formation of different TX/RX beams by applying geometrically determined beamforming weights, and **(2)** the benefits of fully-digital beamforming by transmitting four independent streams of data with an OFDM-based physical layer.

2.1 Beamforming

- Transmit from a single channel on A. Receive on all RX channels of B. Apply multiple beamforming vectors to *look* in all directions;
- Transmit from all channels on A. Then, apply beamforming vectors to scan the transmit beams in different directions using a single RX channel on B;
- Transmit from a single channel on B. Receive on all RX channels of A. Apply multiple beamforming vectors to *look* in all directions;
- Transmit from all channels on B. Then, apply beamforing vectors to scan the transmit beams in different directions using a single RX channel on A.

This demonstrates RX and TX beamforming on both nodes in the link, along with the estimation of the angle of arrival (AoA) and angle of departure (AoD). We first place both nodes (named `trx-0002` and `trx-0003`) directly facing each other and ran the experiment. Fig. 2 shows the TX and RX beam patterns, showing that the AoA and AoD are estimated correctly. Next, we rotated node `trx-0002` counterclockwise by about 15 degrees, and repeated the experiment; the results are shown in Fig. 3, showing that the correct AoA and AoD have been detected. Finally, we returned `trx-0002` to the original position, but rotated `trx-0003` clockwise by about 25 degrees, and the correct AoA and AoD were detected; this has not been plotted for lack of space.

2.2 OFDM-based physical layer

In this experiment, the TX transmits four (the max allowed with 4 antennas) independent streams of data: one stream in each direction. The RX *looks* in all four directions simultaneously. For each RX angle, it attempts to synchronize and decode *each* of the four transmitted streams. We demonstrate that all four TX streams can be decoded in O(1) time, without any scanning or synchronization overhead. This has been illustrated in Fig. 4.

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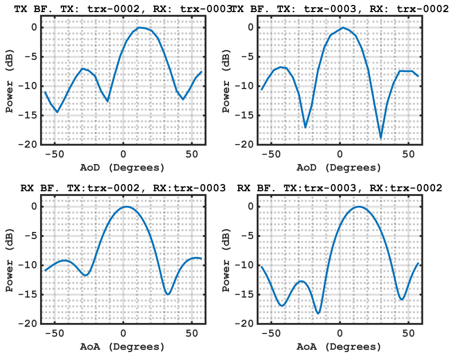

Figure 3: Beamforming demonstration when node `trx-0002` is rotated counter-clockwise by about 15 degrees.

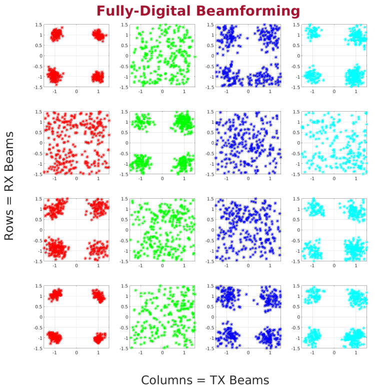

Figure 4: Constellation plots show the received quadrature phase shift keyed (QPSK) symbols at nominal 60 GHz carrier frequency, when decoded in each of four RX directions, with each RX direction decoding data corresponding to four TX directions. The processing was done in MATLAB (non-real-time), and does not include a coding layer.

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