Designing Experimental Platforms for Millimeter-Wave Communication and Sensing

Xinyu Zhang

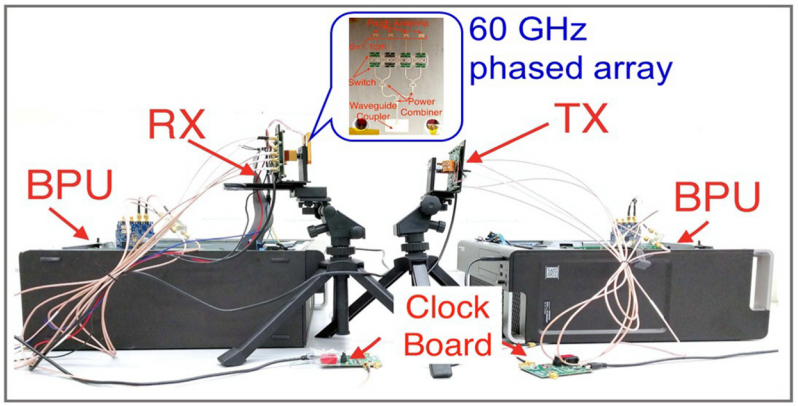
http://xyzhang.ucsd.edu

Department of Electrical and Computer Engineering

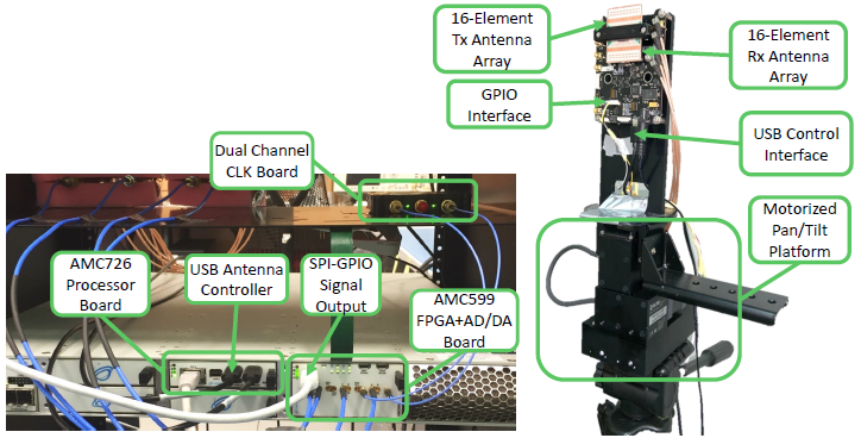
University of California San Diego

Software radios changed the landscape of wireless research

mmWave software radios are still not very accessible

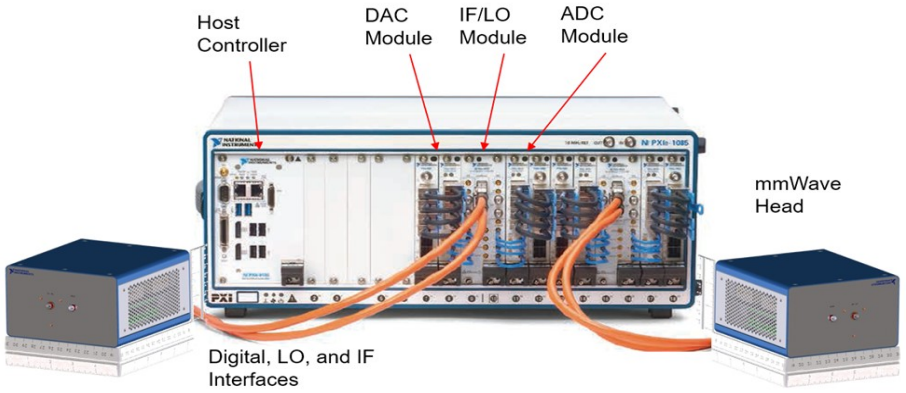


OpenMili Zhang et.al *MobiCom* 2016



mm-FLEX Jesus et.al *MobiSys* 2020

X60 Swetank et.al *WiNTECH* 2017

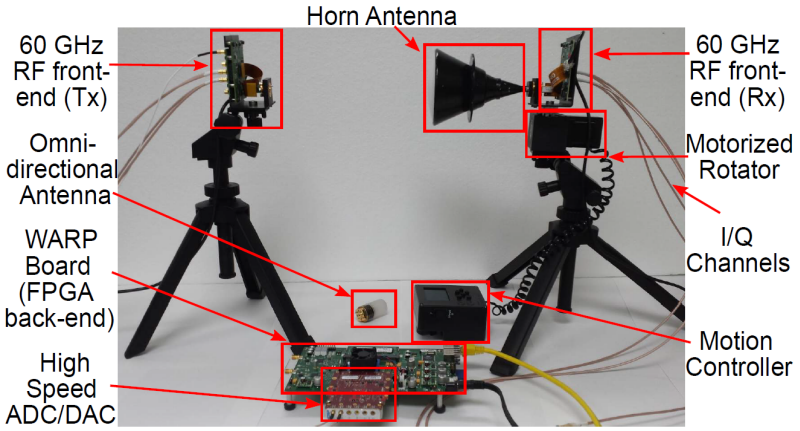


NI mmWave Testbed

Early generation of mmWave software radios

- The WiMi software radio
  - RF front-end: Pasternack 60 GHz frequency converter (PEM-003)
  - Baseband: WARP FPGA and 4DSP data converters (150 Msps)
  - Antenna: horn antenna with a waveguide interface

WiMi, 2015

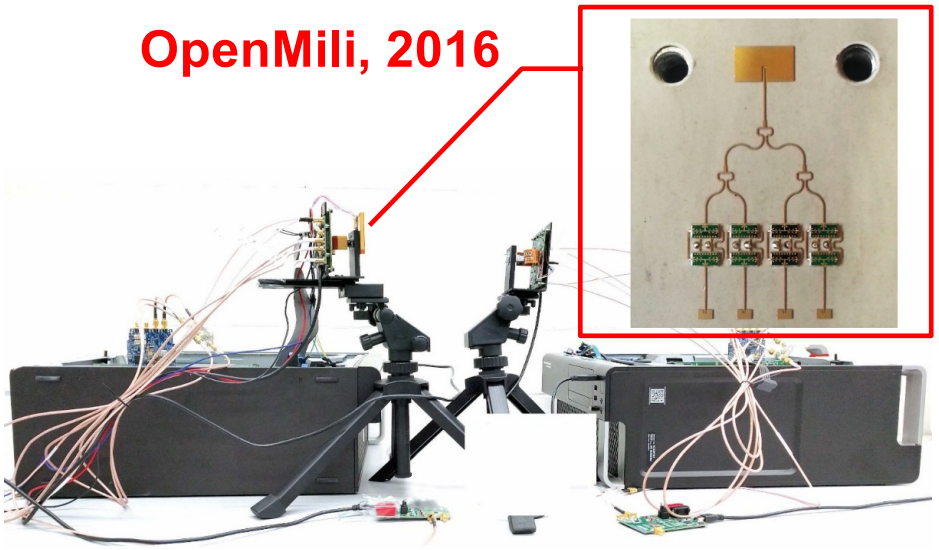


Supported by NSF CRI. Project website: *http://xyzhang.ucsd.edu/wimi*

* "*60 GHz Indoor Networking through Flexible Beams: A Link-Level Profiling* ", Sanjib Sur, Vignesh Venkateswaran, **Xinyu Zhang**, Parameswaran Ramanathan, ACM SIGMETRICS'15

Early generation of mmWave software radios

- The OpenMili software radio
  - RF front-end: Pasternack 60 GHz frequency converter (PEM-003)
  - Baseband: Xilinx KCU105 FPGA development board (1 Gsps sampling rate)
  - Antenna: custom-built phased array (4 elements, 2 bit phase shifter)



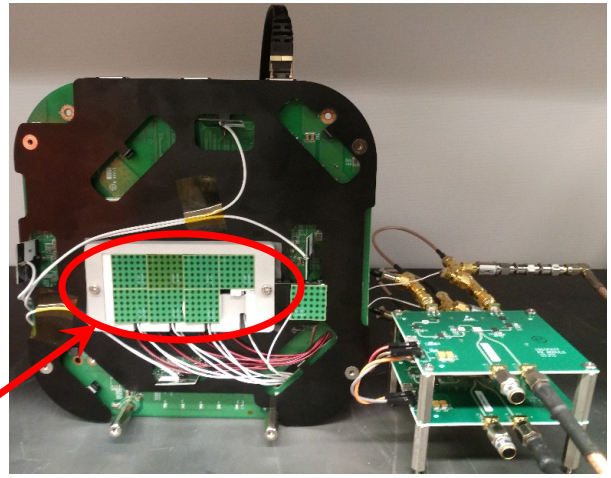
Supported by NSF CRI. Project website:
http://xyzhang.ucsd.edu/wimi

* "*OpenMili: A 60 GHz Software Radio Platform With a Reconfigurable Phased-Array Antenna* ", Jialiang Zhang, **Xinyu Zhang**, Pushkar Kulkarni, Parameswaran Ramanathan, ACM MobiCom'16

A more powerful and affordable mmWave software radio

- M-Cube *mmWave MIMO* software radio
  - RF front-end
    - ✓ Commercial 802.11ad RF front-end
    - ✓ Customized into multi RF chain front-end (up to 8 RF chains), to support MIMO mmWave
  - Antenna
    - ✓ Commercial 802.11ad phased array
    - ✓ 8 phased array panels, 4x8 elements each
    - ✓ Phased array codebook can be reconfigured
    - ✓ Beam pattern selection done through controller FPGA or PC host

M-Cube, 2020



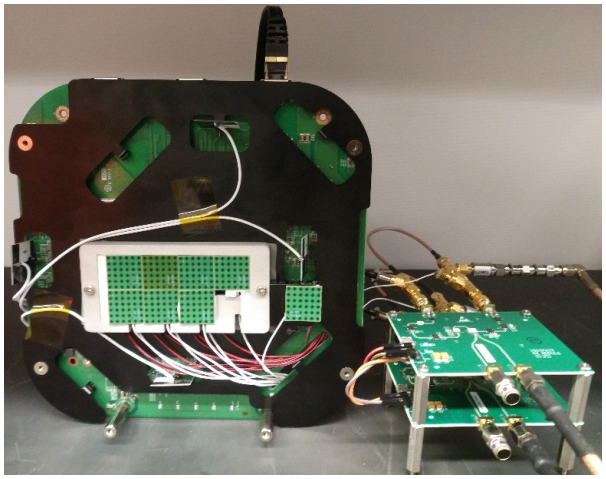
Supported by NSF CCRI. Project website: *http://m3.ucsd.edu*

* "*M-Cube: A Millimeter-Wave Massive MIMO Software Radio*",
Renjie Zhao, Timothy Woodford, Teng Wei, Kun Qian, **Xinyu Zhang**, ACM MobiCom'20, Best Paper Award

A more powerful and affordable mmWave software radio

- M-Cube mmWave MIMO software radio
  - Baseband
    - ✓ Option 1: FPGA+ADC/DAC development board
    - ✓ Option 2: Existing sub-3GHz software radios
    - ✓ Option 3 (under development): Xilinx RFSoC
  - Baseband signal processing modules
    - ✓ OFDM mmWave MIMO communication module
    - ✓ mmWave FMCW radar sensing module (Matlab version available; real-time RFSoC version completed, under testing)

M-Cube, 2020



Supported by NSF CCRI. Project website: *http://m3.ucsd.edu*

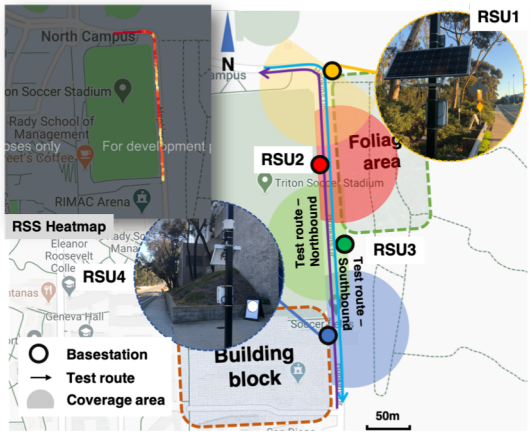
* "*M-Cube: A Millimeter-Wave Massive MIMO Software Radio*",
Renjie Zhao, Timothy Woodford, Teng Wei, Kun Qian, **Xinyu Zhang**, ACM MobiCom'20, Best Paper Award

Comparison of mmWave software radio platforms

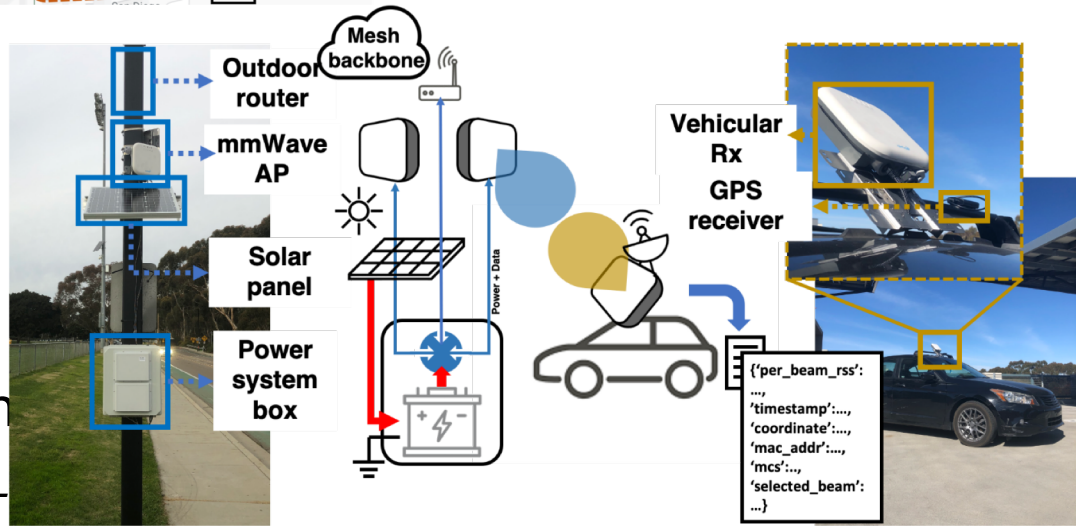
	OpenMilli 2016	X60 2017	Mm-FLEX 2020	M-Cube 2020
Bandwidth	1GHz	2GHz	2GHz	4GHz (with RFSoC)
Phased Array	1	1	1	8 (RF chains)
Array Element	4	12	16	32 (256 in total)
SDR compatible	No	No	No	USRP/WARP etc.
Fast Beam	No	No	Yes	Yes
Cost	$15k(1 by 1)	$150k(1 by 1)	$40k(1 by 1)	$14k (4x4 wide) $3.8k (2x2 narrow)

mmWave V2X Testbed based on M-Cube

- Deployment:
  - 4 basestations on a 1km urban/suburban road.
  - 3GPP Road-side type basestations (RSU).



- MmWave radios
  - Same RF front-end and phased array as M-Cube
  - Customized codebooks and beam control
  - Will use programmable baseban



* Jingqi Huang, Song Wang, Xinyu Zhang, "*Demystifying Millimeter-Wave V2X: Towards Robust and Efficient Directional Connectivity Under High Mobility*", Proceedings of ACM MobiCom, 2020

Summary

- Important to have software radios for research in mmWave sensing and communications
- A long journey of mmWave software radio development
  - Horn antenna → small array → Large MIMO array of phased arrays
  - Expensive, inflexible → Affordable, versatile
- M-Cube
  - First mmWave MIMO software radio, with a massive array of phased arrays
  - Open-source, distributed to the research community

  http://m3.ucsd.edu