Millimeter-wave for 5G: Unifying Communication and Sensing

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Salient Features of Millimeter-wave Networks

- Features
  - Abundant spectrum, e.g.,
    - 57 GHz to 64 GHz unlicensed: 7 GHz in total
    - 28 GHz/38 GHz licensed but underutilized: 3.4 GHz in total
    - 71 GHz/81 GHz/92GHz Light-licensed band: 12.9 GHz in total
  - High rate (multi-Gbps) at short range
    - e.g., 7 Gbps in IEEE 802.11ad standard for 60 GHz networking

Millimeter-wave for 5G: Use Cases

- Short-range Applications with high-rate (Gbps) traffic

In-home/store/flight media distribution and miracast

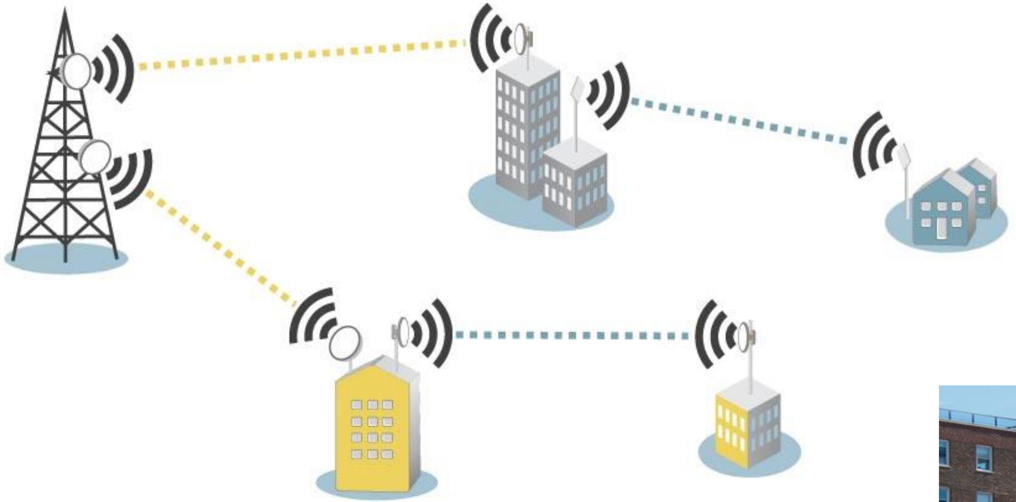
Virtual reality

Kiosk to mobile file sync

Millimeter-wave for 5G: Use Cases

- Short-range Applications with high-rate (Gbps) traffic

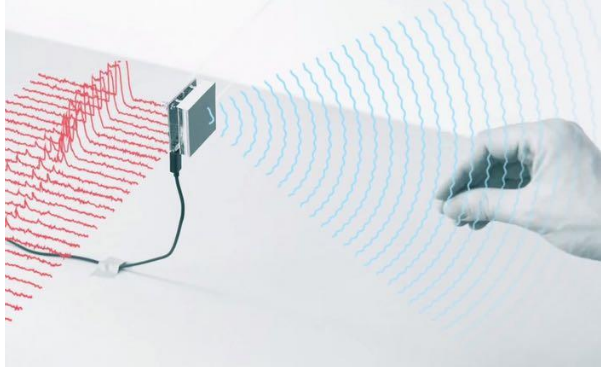
Cellular backhaul/fronthaul



Small/pico cells in dense areas

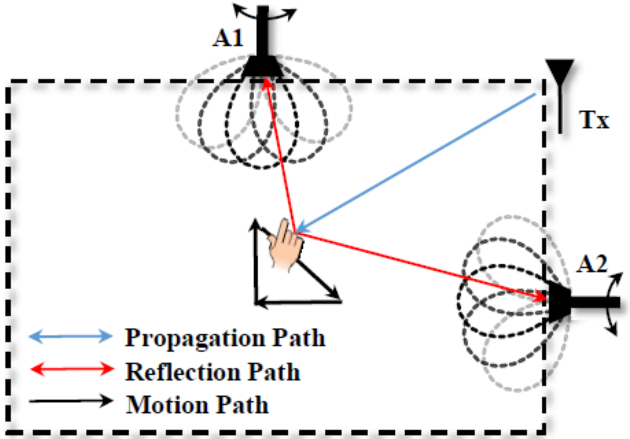
Millimeter-wave for 5G: Use Cases

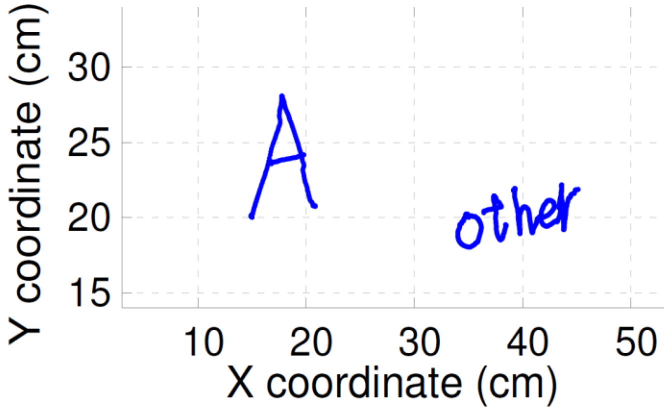
- Mobile sensing applications
  - Google Project Soli



  - mTrack: tracking passive objects at mm precision

    “*mTrack: High Precision Passive Tracking Using Millimeter-wave Radios* ”, Teng Wei, Xinyu Zhang, ACM MobiCom’15





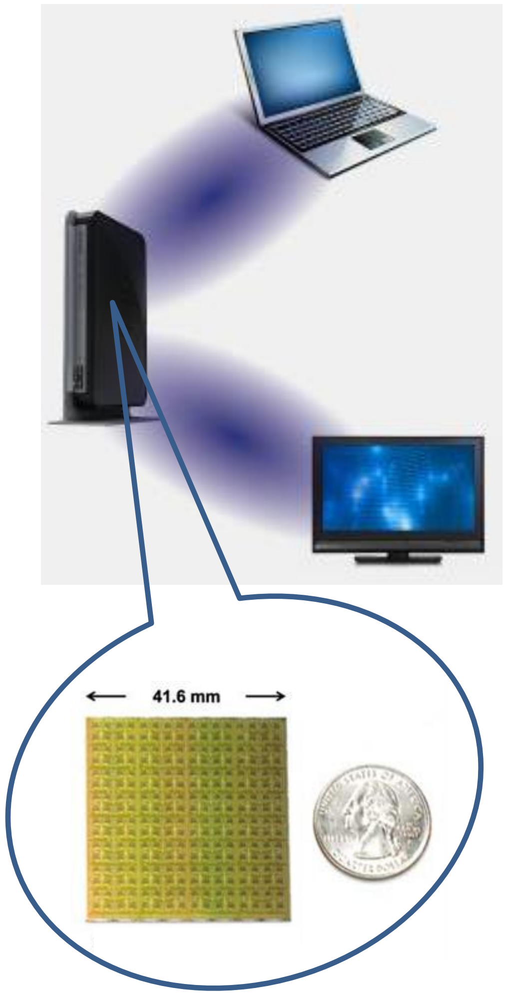
Unifying Millimeter-wave Communication and Sensing

- Millimeter-wave mobile sensing applications can piggyback on communication interfaces

- Sensing functions can enable robust and efficient millimeter-wave networking
  - More details to follow

Millimeter-wave Networking Via Flexible Beams

- Use highly directional antennas to overcome propagation loss
  - Improves range, but sacrifices coverage
  - Introduces new challenges: blockage, mobility
- Use electronically steerable antennas to overcome the challenges
  - Small form-factor
  - Real-time beam switching
- Still hard to guarantee continuous connectivity
  - Strongly dependent on context



16x16 phased-array

The Need for Millimeter-wave Sensing

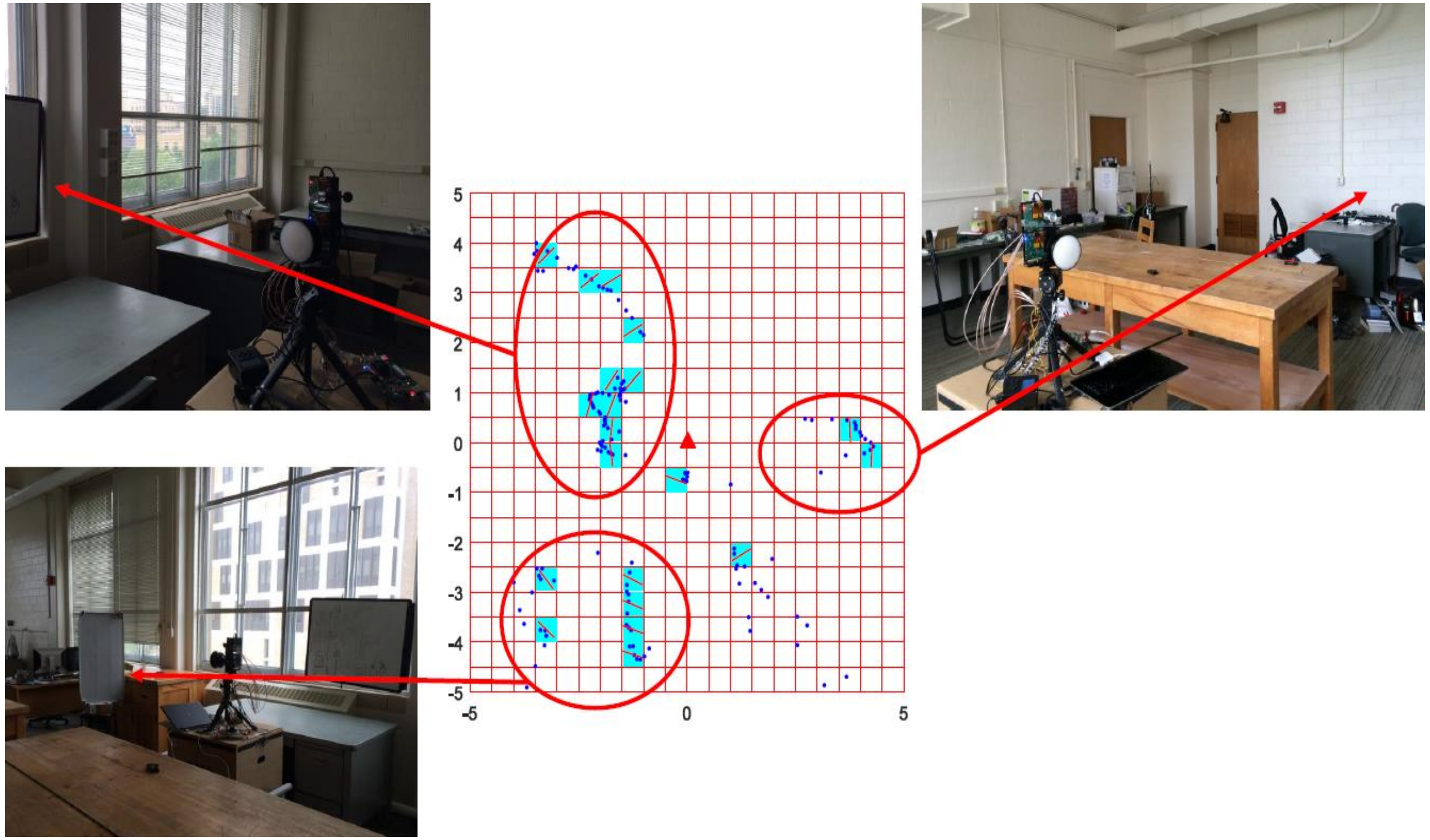
- Effectiveness of beam adaptation depends on context

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

- If radios can sense the context, the sensing results can facilitate network management and protocol adaptation
  - Millimeter-wave radios are born to be a good sensor

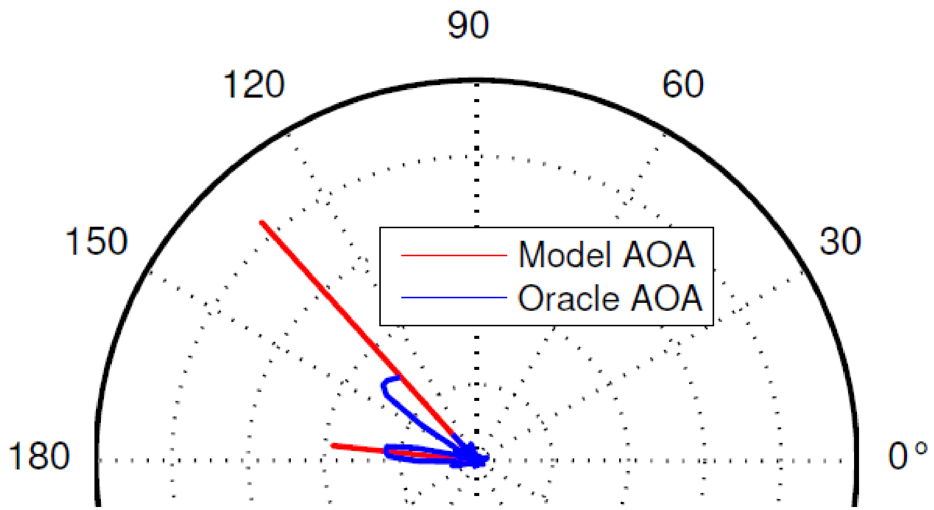
Examples of Facilitating 60 GHz Networking via Sensing

- Environment “sounding” to facilitate node deployment
  - Sense reflector position/orientation and density of human activities
  - Use such prior information to determine where to place access points



Examples of Facilitating 60 GHz Networking via Sensing

- Sensing spatial correlation for fast beam adaptation
  - Link quality of different beam directions are correlated
  - If we can predict the quality of other beams by looking at one of them, then we can avoid the huge probing overhead

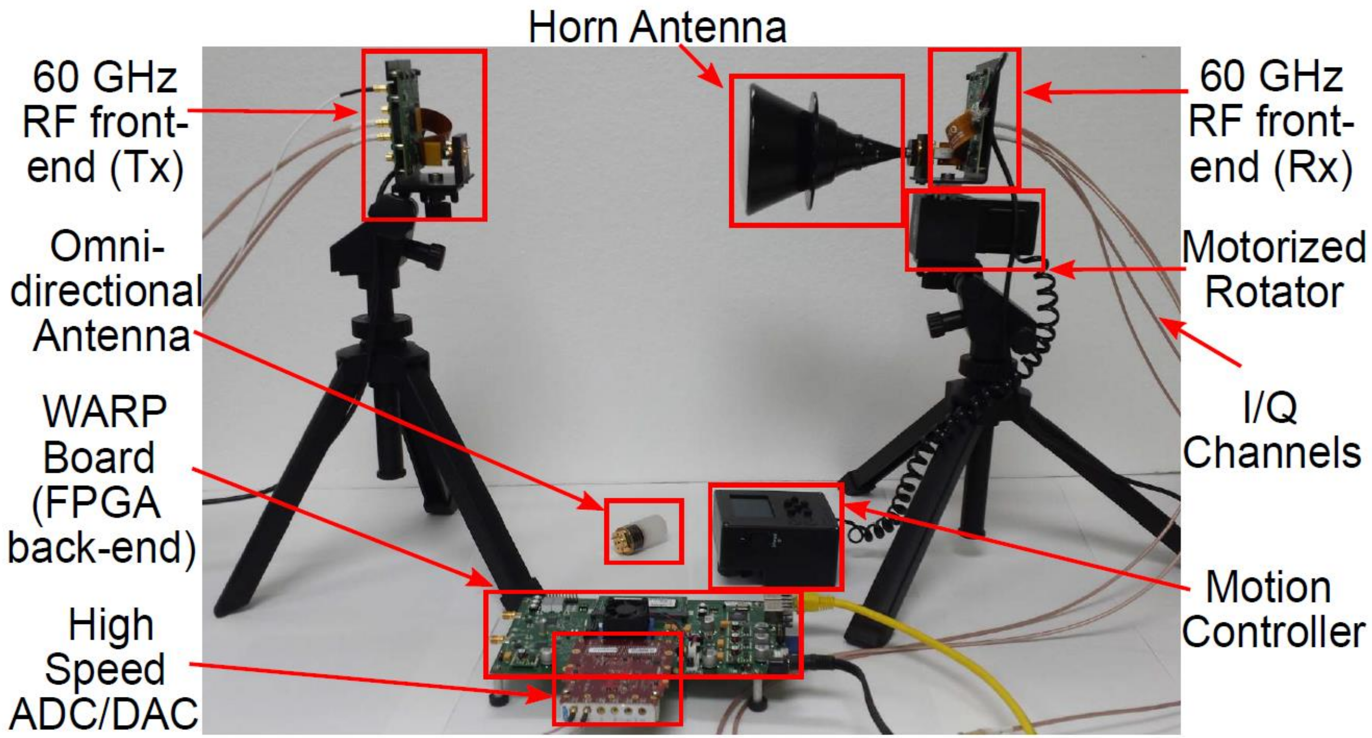


Experimental Support for 60 GHz Sensing/Networking

- Existing experimental facilities
  - Communication: simulation and analytical/empirical model
  - Networking: transport/application layer measurement using COTS 60 GHz devices
- Need for a flexible testbed
  - Environmental effects are non-stationary, hard to be reproduced using simulation/analysis

Experimental Support for 60 GHz Sensing/Networking

- WiMi (Wisconsin Millimeter-wave software radio)
  - Reconfigurable 60 GHz transmitter/receiver
  - Programmable sensing/imaging radar



Experimental Support for 60 GHz Sensing/Networking

- WiMi (Wisconsin Millimeter-wave software radio)
  - Antennas with different beam patterns and steerable motion control system

  - Baseband: Vertex-6 FPGA plus high-speed AD/DA, 245.76Msps sampling rate; programmable waveform generator/processor

  - RF front-end: Vubiq V60WDG03, 57-64GHz frequency upconverter/downconverter with ~2GHz analog bandwidth; adjustable output power (up to 10 dBm)

Experimental Support for 60 GHz Sensing/Networking

- WiMi
  - Open-source hardware and software, supported by the NSF CRI program
  - http://xyzhang.ece.wisc.edu/wimi
- WiMi 2.0
  - Ultra wideband (>1 GHz), millimeter-wave MIMO, programmable phased-array antenna

Summary

- Millimeter-wave communication holds great potential
  - Suitable as part of 5G, for short-range high-rate applications
- Unifying millimeter-wave communication and sensing
  - Standalone mobile sensing applications using millimeter-wave communication interface
  - Enabling robust and efficient millimeter-wave networking via millimeter-wave sensing
  - Need strong experimental verification before deployment