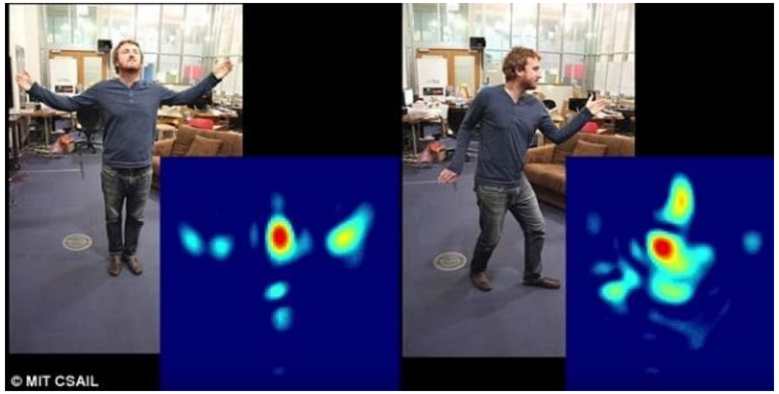
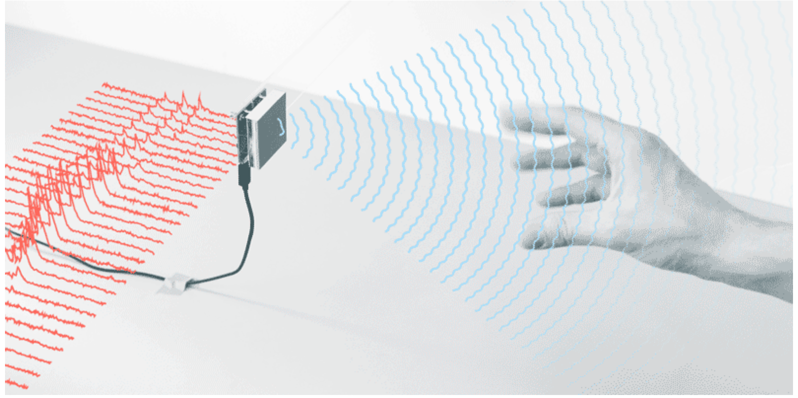
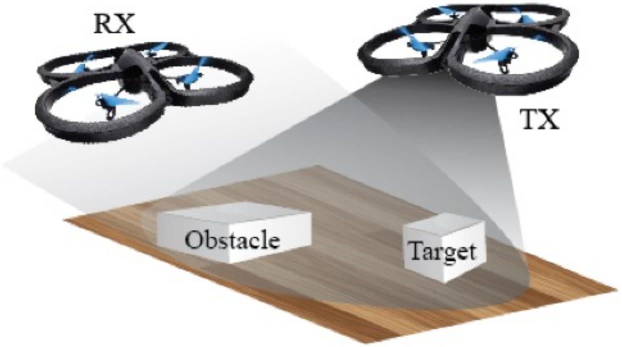
mmWave Sensing

Bringing mmWave sensing to mobile devices

- Reusing 60 GHz mobile devices for gesture recognition, localization/tracking, and imaging



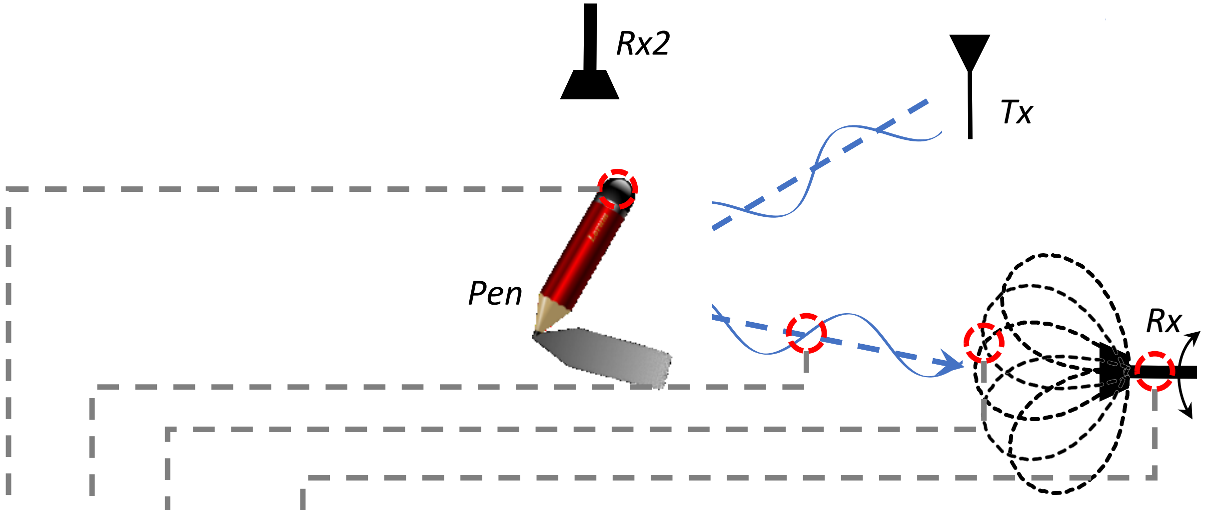




Isn't this the same as radar? No.

- New opportunities: reusing mobile comm devices for sensing
  - Large-scale phased-array: high directionality and electronic steerability
  - Ubiquity and portability (similar to PC→Smartphone revolution)
  - More applications in IoT space (wireless health, HCI, etc.)
- New challenges: need a redesign of sensing algorithms
  - Radios differ from radars
  - Uncontrolled mobility (different from airborne radar or airport mmWave imager)
  - Sophisticated reflection environment
  - Limited bandwidth and low computational capability

mTrack: reusing 60 GHz devices for passive tracking



1. 60GHz **laser-like** directional beam
2. Flexible **beam-steering** capability
3. 5mm extremely **short** wavelength
4. More **diffusive** on small objects

* "mTrack: *High Precision Passive Tracking Using Millimeter Wave Radios*", Teng Wei, Xinyu Zhang, ACM MobiCom'15

Targeted use cases

- Building new mobile human computer interface through wireless sensing

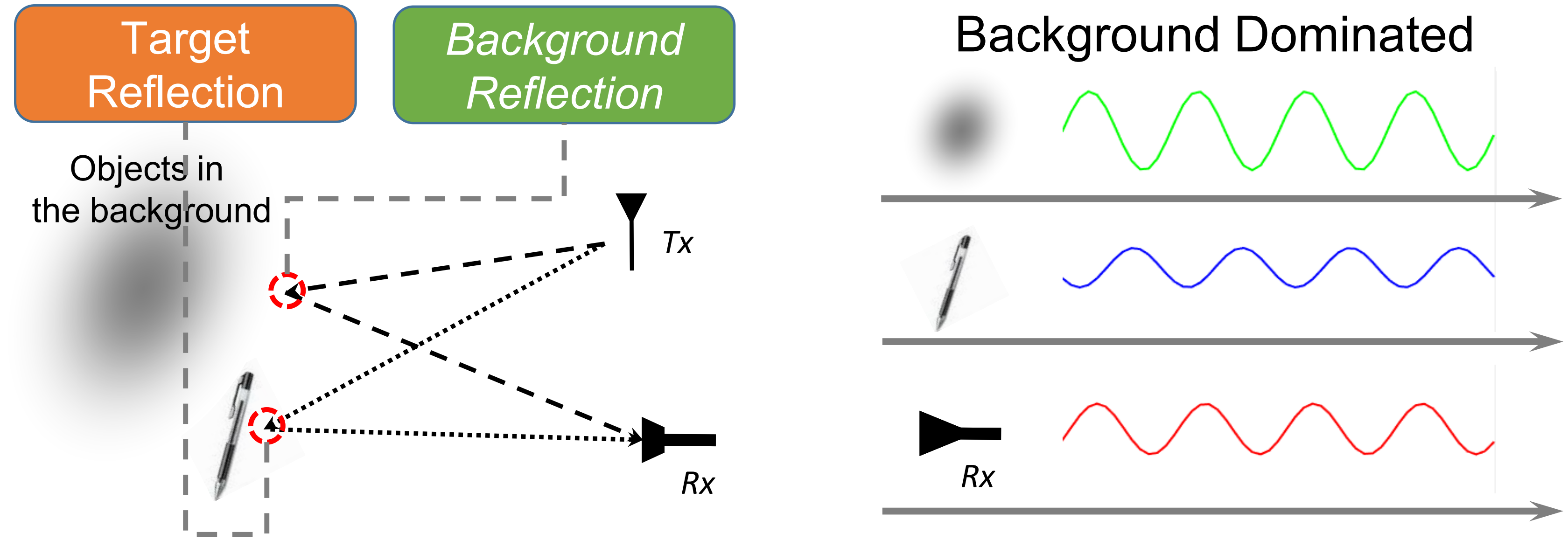
Virtual Trackpad

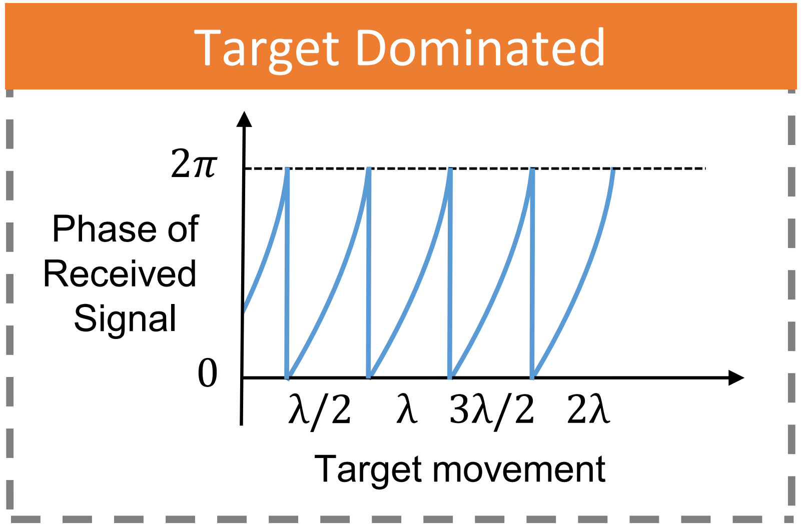
Interactive Display

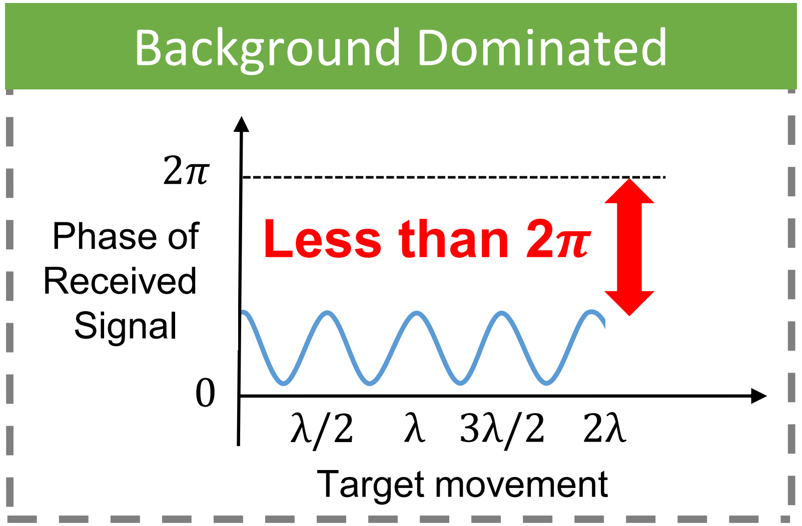
Wireless transcription

- Turn any surface into interactive virtual touchscreen
- Enable a new form of pervasive user-computer interface

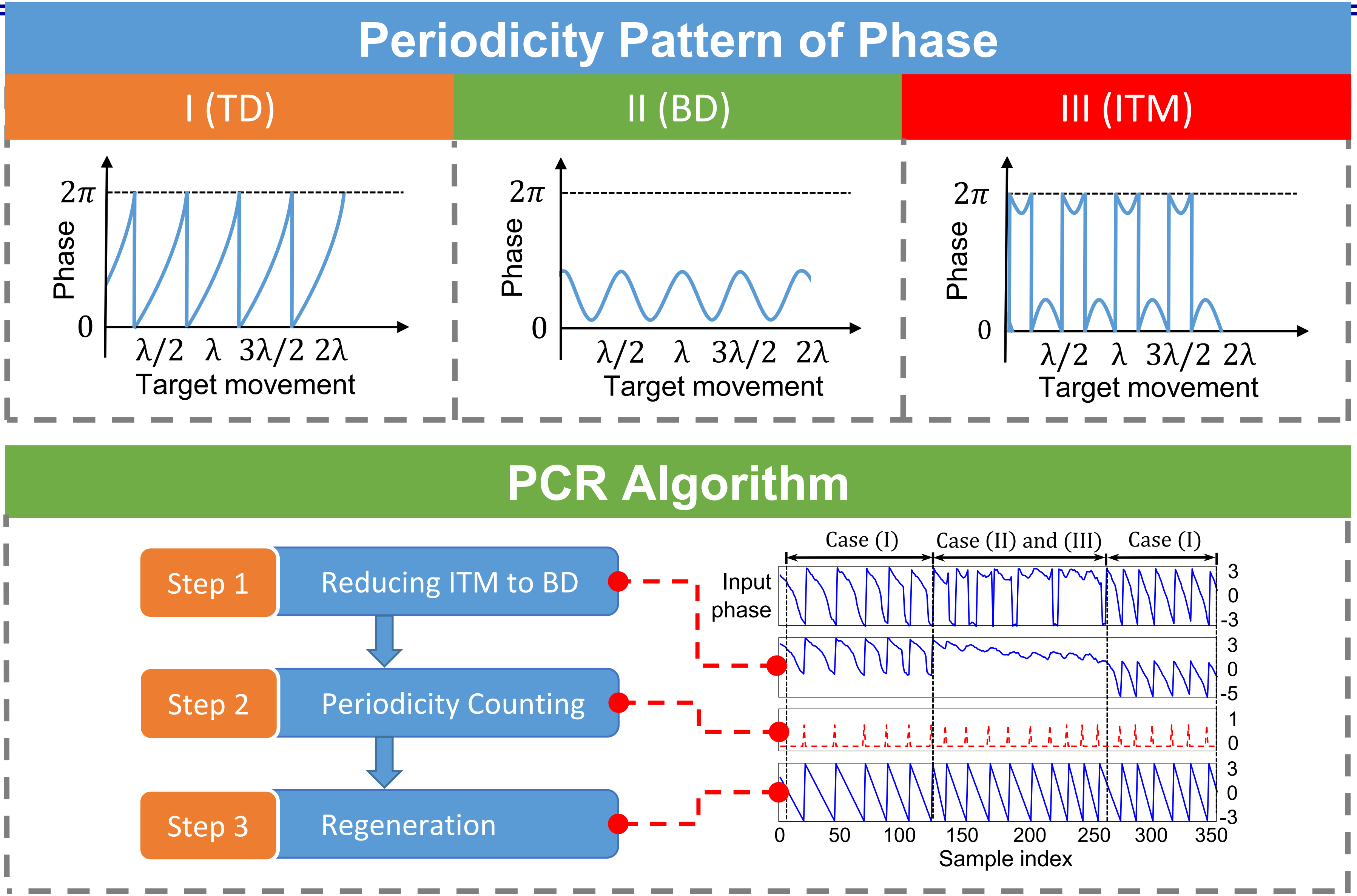
Key challenge: background reflection





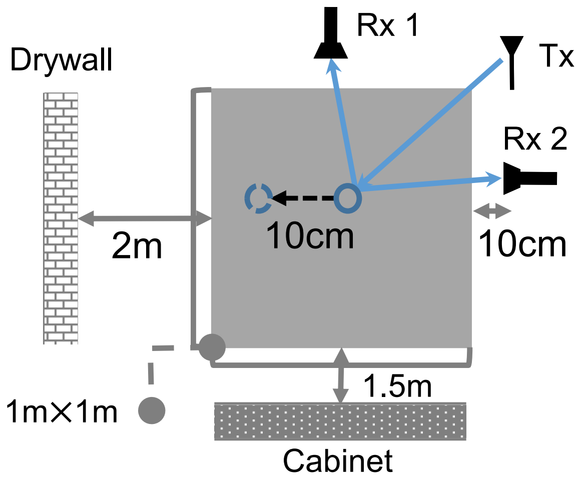


Solution: phase counting and regeneration

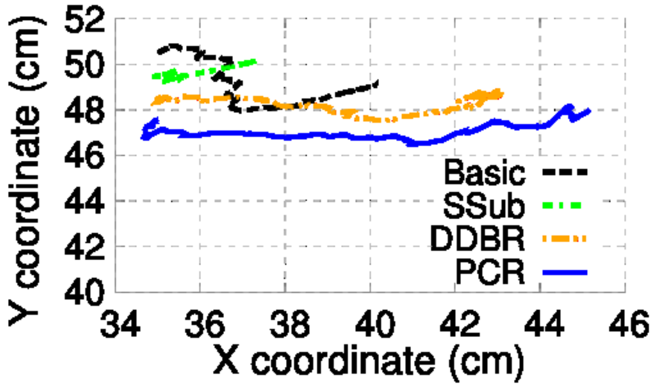


mTrack: performance overview

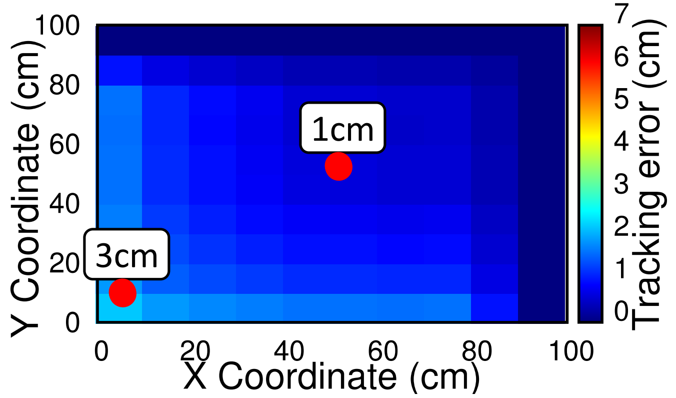
Tracking Setup	Result



Achieve cm to mm-level tracking



Example trajectory of tracking



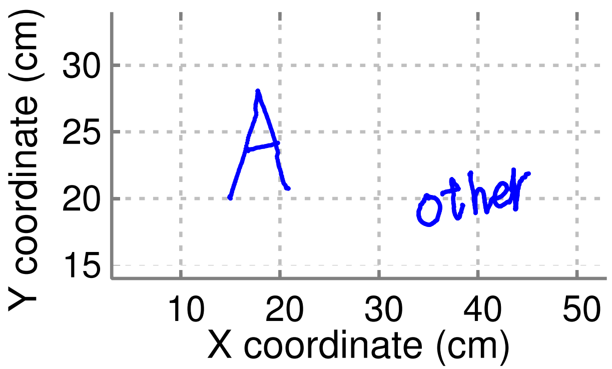
Error map over tracking region

Application and user study

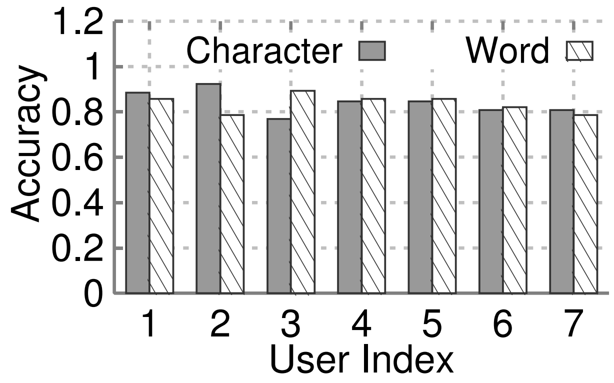
Experiment Setup

- Integrate mTrack into word-recognition application
  - Record hand-writing trace from mTrack
  - Export and control mouse of a PC
  - MyScript© Stylus for word detection

Example word



Recognition Accuracy



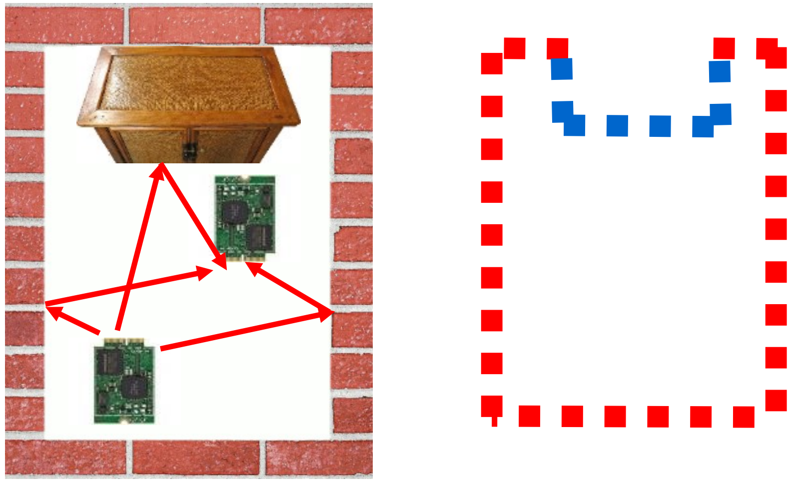
E-Mi: sensing assisted 60 GHz network deployment

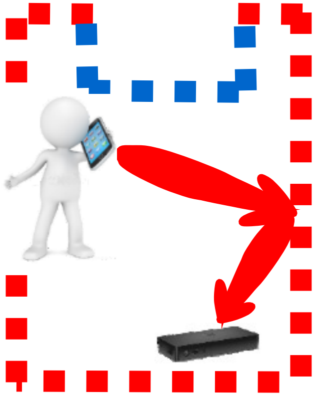
- Reverse engineering

  Reconstruct environment geometry/reflectivity by sampling radio channel

- Forward engineering

  Predict the channel of arbitrarily located links



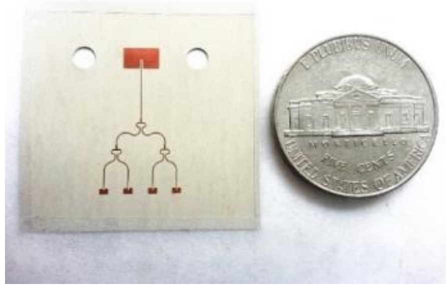


* “*Facilitating Robust 60 GHz Network Deployment by Sensing Ambient Reflectors*”, Teng Wei, Anfu Zhou, Xinyu Zhang, USENIX NSDI’17

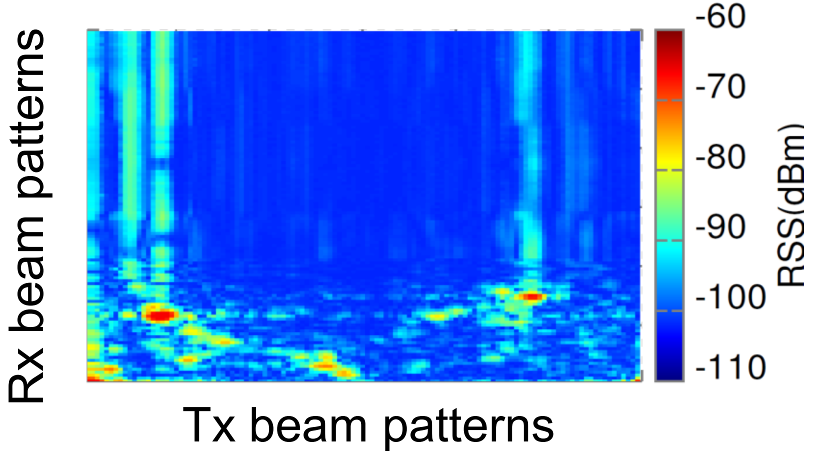
E-Mi: let mmWave radios “see” the environment

- Radios: extremely low resolution sensors

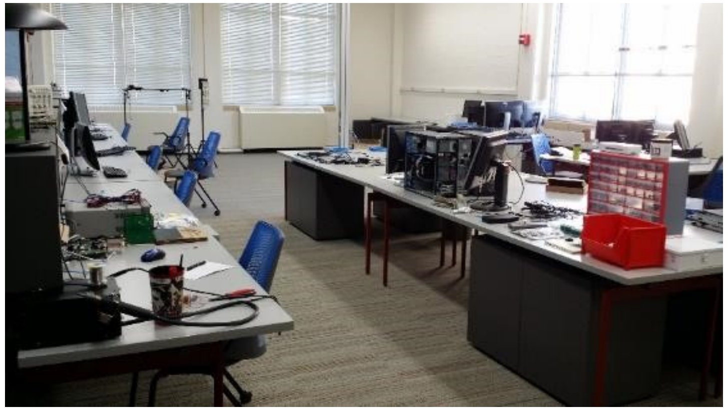
Only a few “pixel sensors” (antenna elements)



From a mmWave radio’s eyes

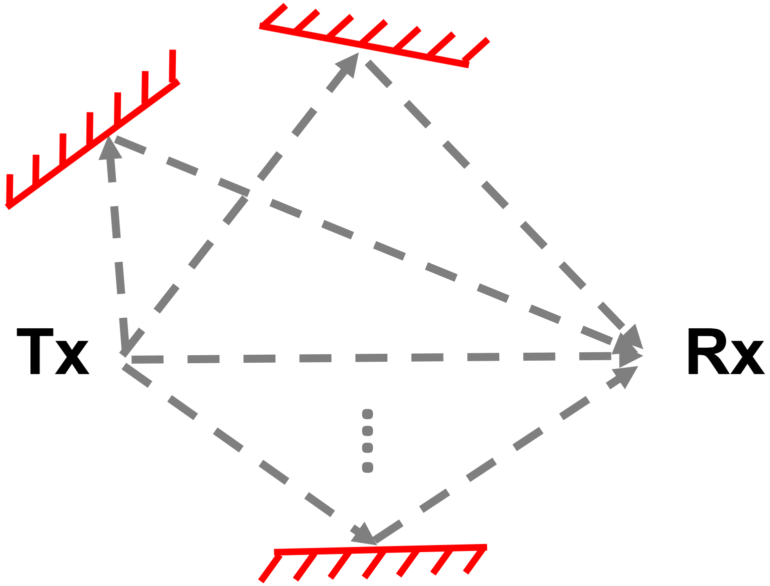


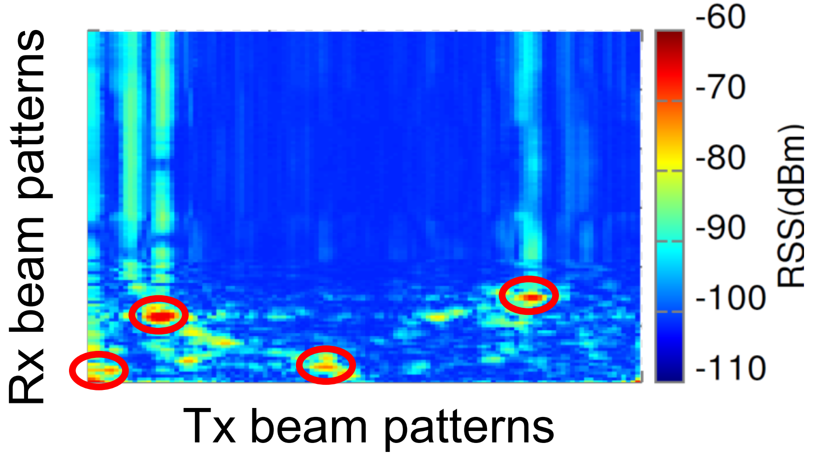
From a camera’s eyes



Achieving super resolution

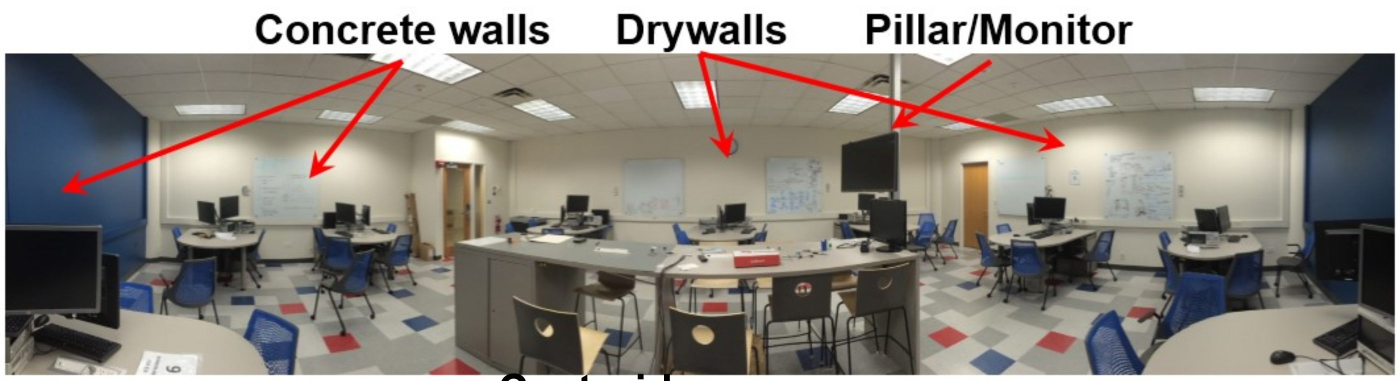
- Model the environment as a sparse set of geometrical structures
- Reconstruct the structure by tracing back the invisible propagation paths
  - Recover geometries of each path: AoA, AoD, length

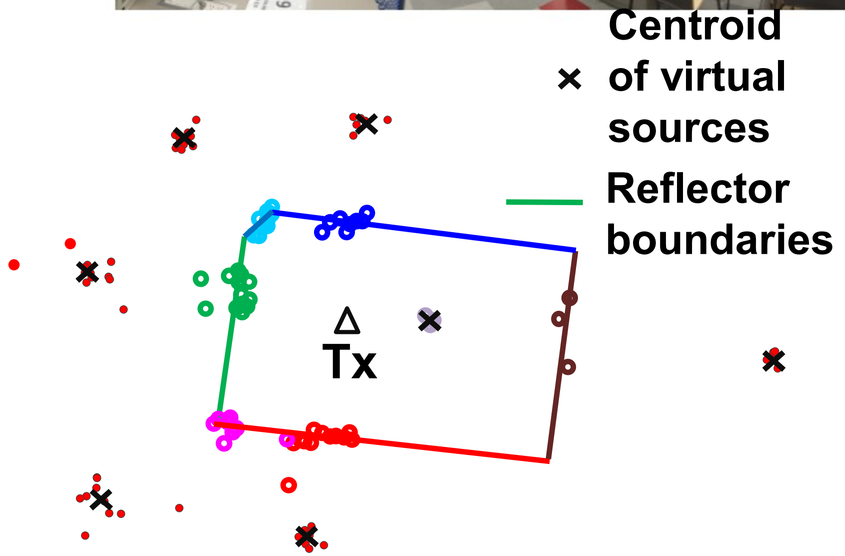


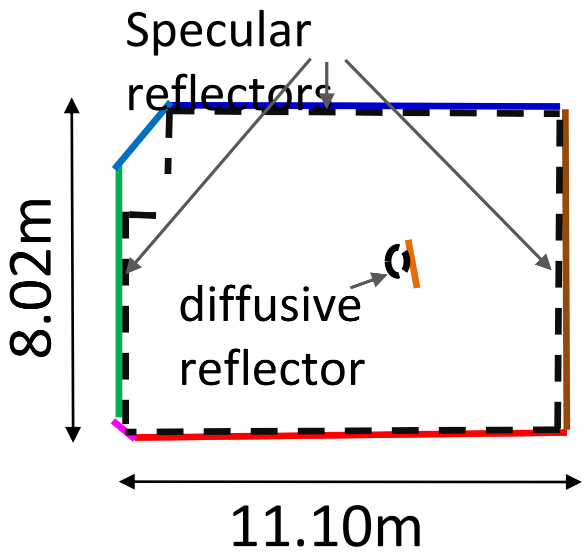


Example

➢ Example: Sparse reconstruction of an office, using only 10 Rx positions



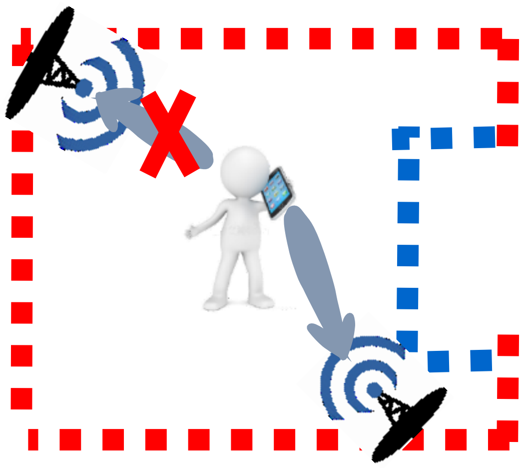




E-Mi: Sensing-assisted mmWave networking

- Reflector-aware multi-AP deployment.
  - Key question:

    For a set of APs in a given environment, how to deploy them optimally so as to maximize the coverage and robustness to blockage?

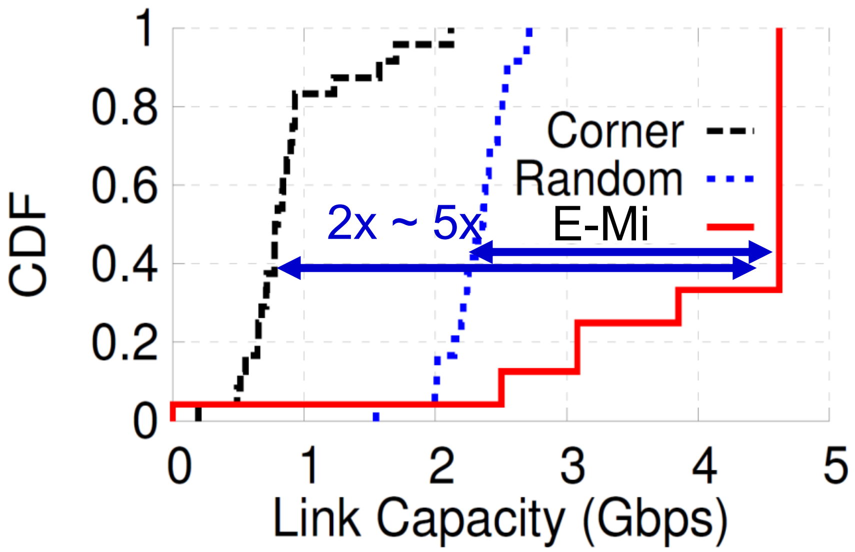


- Solution principle
  - Reconstructing reflector position via wireless channel measurement
  - Predict signal strength distribution for an arbitrary deployment
  - Search for the best topology

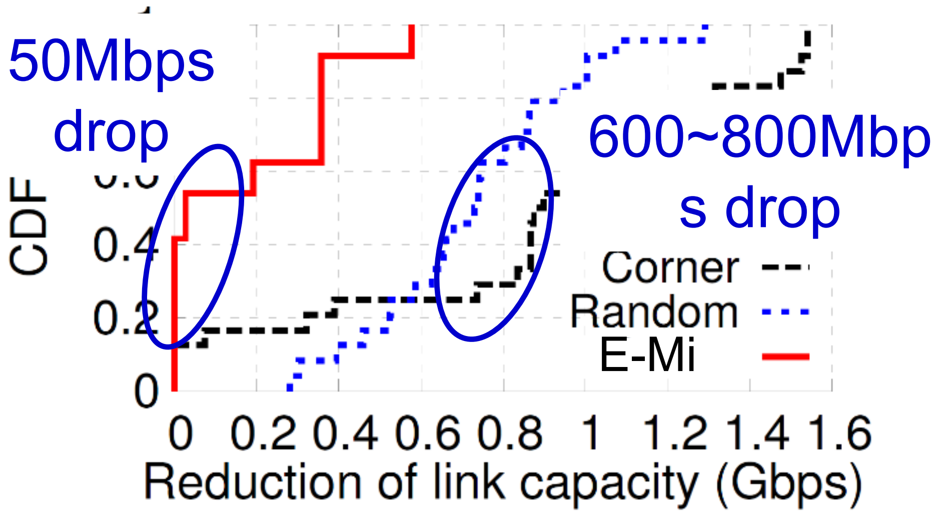
Prototyping and experimental results

- 2x to 5x higher performance than empirical deployment!

Link capacity distribution



Link capacity reduction under random blockage



The impact of sensing on networking

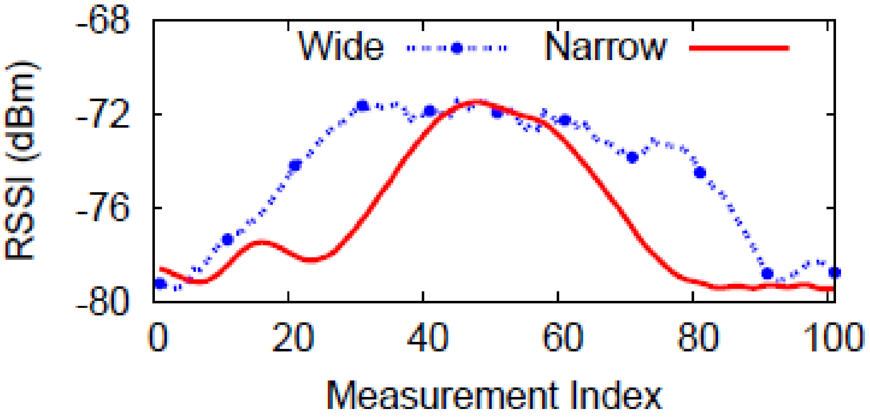
Site survey, or war-driving……

The impact of sensing on networking

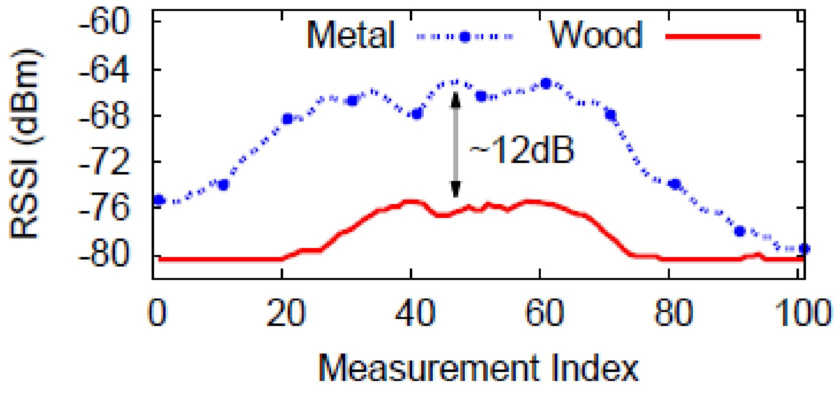
- War-driving is infeasible for mmWave networks
  - Beam steering + human blockage:
    infinite combinations!
- E-Mi: a rigorous way of mmWave network planning
  - A computational wireless sensing model for network performance prediction
  - Many more possibilities:
    Environment aware beam adaptation;
    Intelligent reflector placement for wireless data centers;
    ……

Mobile mmWave imaging

- Estimating object distance, curvature, boundary, and surface material
  - Fix TX, while moving RX to different locations; both using single-beam
  - Use reflected RSS patterns to distinguish object geometries/materials



(b) Narrow vs Wide

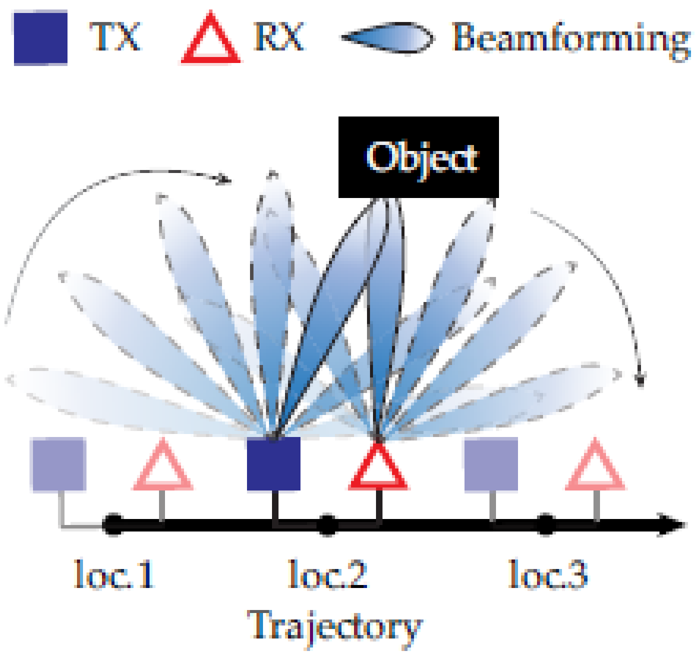


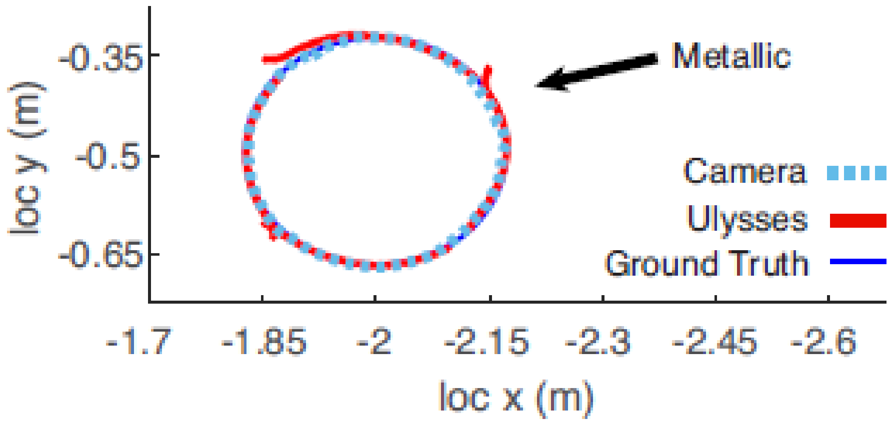
(c) Metal vs Wood

* "*Reusing 60 GHz Radios for Mobile Radar Imaging*",
Yanzi Zhu, Yibo Zhu, Ben Y. Zhao and Haitao Zheng, ACM MobiCom'15

Mobile mmWave imaging

- Ulysses: leveraging beamforming to improve signal diversity
  - Moving co-located TX/RX following predefined trajectory



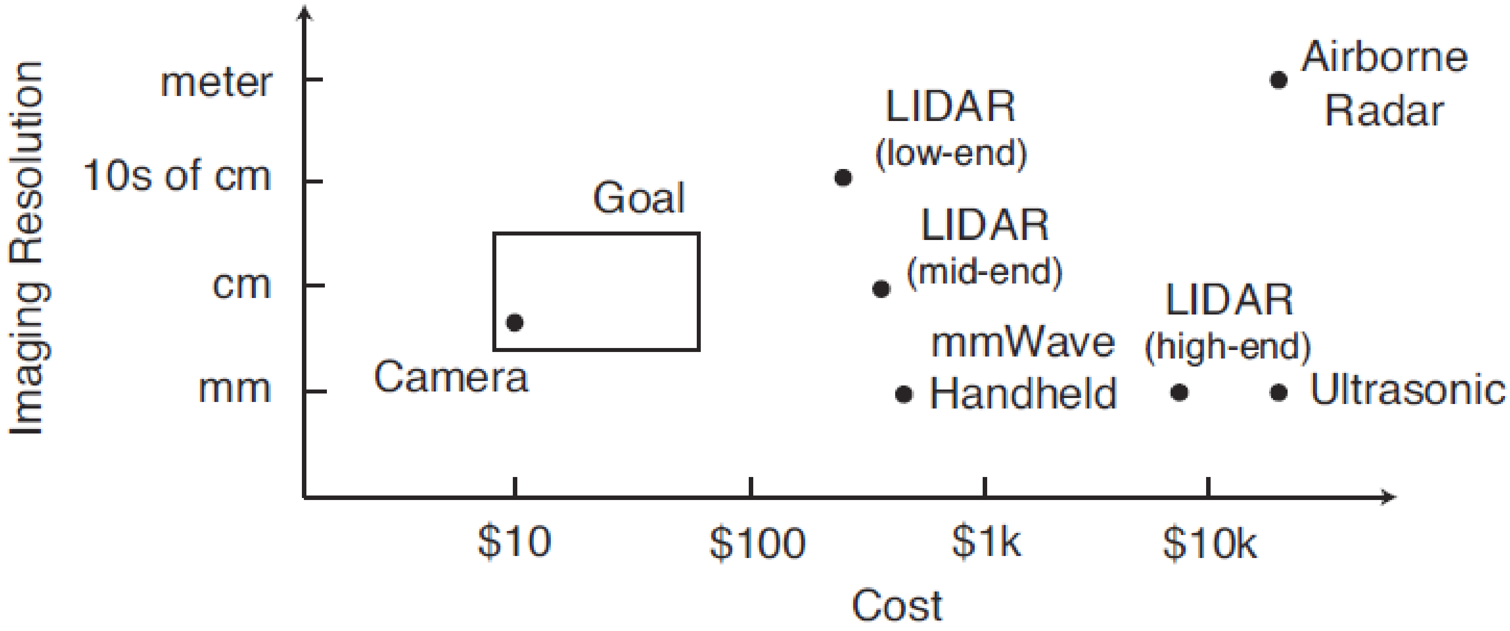


Imaging result of a metal cylinder

* "*Object Recognition and Navigation Using a Single Networking Device*", Yanzi Zhu, Yuanshun Yao, Ben Y. Zhao and Haitao Zheng, ACM MobiSys'17

Mobile mmWave imaging

- Potentials and ultimate goals
  - Low-cost: < $50 (a typical 802.11ad tri-band NIC)
  - High-resolution: cm level (possible with large bandwidth and large phased-array)
  - Ubiquitous: 60 GHz phones/tablets already exist



References

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

* “*Facilitating Robust 60 GHz Network Deployment by Sensing Ambient Reflectors*”,
Teng Wei, Anfu Zhou, Xinyu Zhang, USENIX NSDI’17

* “*Reusing 60 GHz Radios for Mobile Radar Imaging*”,
Yanzi Zhu, Yibo Zhu, Ben Y. Zhao and Haitao Zheng, ACM MobiCom’15

* “*Object Recognition and Navigation Using a Single Networking Device*”,
Yanzi Zhu, Yuanshun Yao, Ben Y. Zhao and Haitao Zheng, ACM MobiSys’17

* “*60 GHz Synthetic Aperture Radar for Short-Range Imaging: Theory and Experiments*”,
B. Mamandipoor, G. Malysa, A. Arbabian, U. Madhow and K. Noujeim, Asilomar, 2014

* “*Capturing the Human Figure Through a Wall*”, Fadel Adib, Chen-Yu Hsu, Hongzi Mao, Dina Katabi, Fredo Durand, ACM SIGGRAPH Asia, 2015