A Journey with mmWave research

The Networking Channel
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Developing the Science of Networks

Discussion Topics

- Important **open research questions** for wide-spread adoption
- **Lessons learned** from first deployments
- Availability of **real-world measurement data**
- **Testbeds and platforms** for practical mm-wave research
  - Making testbed facilities more accessible to the research community
  - How can we establish and maintain large software facilities

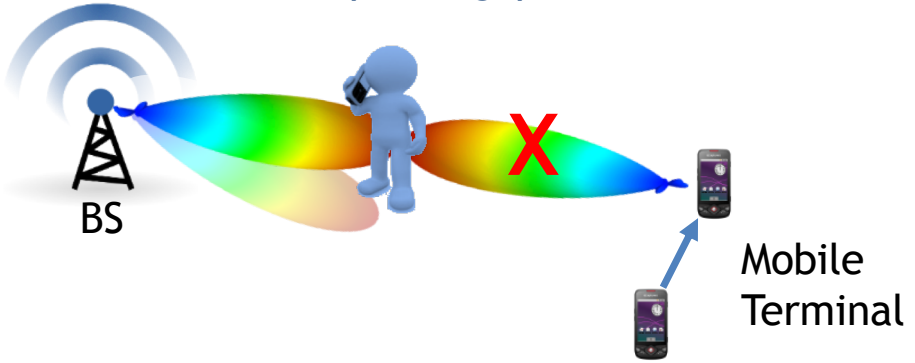
Where Are We Now?

- Mm-wave offers multi-Gbit/s per user data rates
  - Part of 5G/6G and IEEE 802.11ad/ay standards
  - First generation of hardware has demonstrated feasibility (cost, hardware complexity, energy consumption, device integration, …)
  - But no widespread adoption of IEEE 802.11ad

https://5gophers.cs.umn.edu/

- First deployment experience
  - Verizon 5G mm-wave (also T-Mobile, AT&T)
  - Facebook Terragraph project

- Single link beam-training works well even for mobile scenarios
  - As long as there is no blockage



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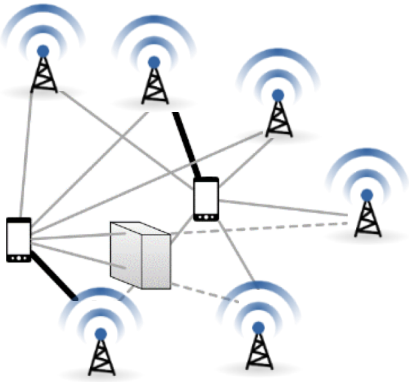
What is Missing?

- Network resilience (with low overhead)
  - Fast handover to deal with limited coverage
  - Fast (self-) blockage detection and recovery
  - Multi-connectivity, efficient failover to sub-6 GHz

- Efficient algorithms for large, dense deployments
  - Many BSs, channel quality only known *after* beam training



- Localization, tracking, sensing systems
  - Joint communication and sensing

- Real-world experience with more complex and compelling use cases!

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A Quick Glance at Tools

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MIMORPH: Open-Source Platform for MIMO Experimentation

Now:

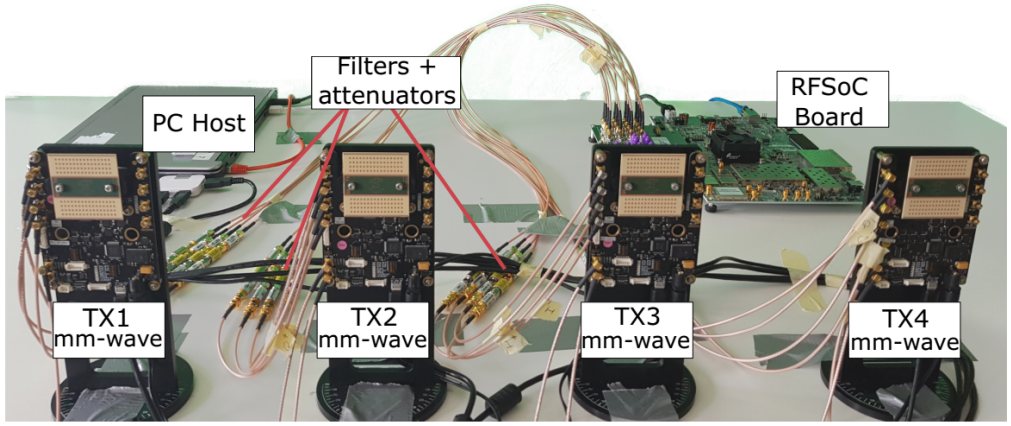
- Support for 4x4 mm-wave with 2GHz of bandwidth and 8x8 sub-6 GHz MIMO
- Simultaneous mm-wave and sub-6 GHz operation
- Real-time (ns-level) beam steering
- Offline frame generation and decoding in C++/Matlab
- Packet detection and channel estimation on the FPGA
- Full-duplex capable

Based on Xilinx RFSoC

Future:

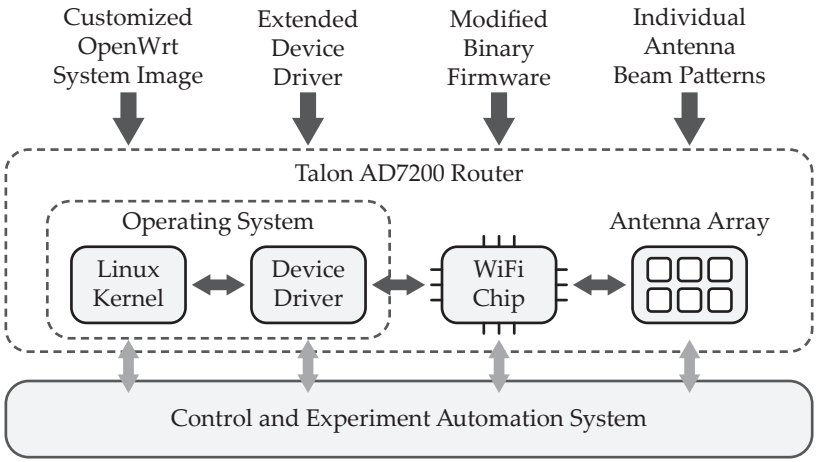
- Flexibly move functionality between software and the FPGA
- Real-time transceiver (802.11ad/ay and 5G+)
- Joint communication & radar
- Scale to 8x8 MIMO with newer boards

Coming soon: ACM MobiSys 2021



Off-the-Shelf Devices as Research Platform

- Highly important for standard compliant, large scale IEEE 802.11ad at 60GHz deployments
- Support for TP-Link Talon and Mikrotik wAP 60G
- Ported OpenWRT to the routers
  - Custom embedded Linux OS (open source)
  - Extended 802.11ad Linux drivers
- nexmon framework for binary driver firmware patching
  - Custom extensions to the firmware
  - Modify beam training, beam forming, …
  - Small cells, 5G offloading



Joint work with TU Darmstadt
https://github.com/seemoo-lab/talon-tools

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IEEE 802.11ad/ay for the ns-3 Simulator

- Comprehensive simulation model of IEEE 802.11ad for the ns-3 network simulator
  - The code for our model is publicly available on GitHub: https://github.com/hanyassasa87/ns3-802.11ad.git
  - Being merged into main line ns-3
- Currently implementing IEEE 802.11ay
  - Efficient simulation of SU/MU-MIMO
  - High fidelity simulation of a large-scale, heterogeneous 802.11ay networks
- Research work:
  - In-depth study of 802.11ad protocol performance at scale
  - Analysis of 802.11ay beam training and impact of interference

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