

The 6th Workshop
NSF Research Coordination Network on Millimeter-Wave
Wireless

July 23-24, 2019

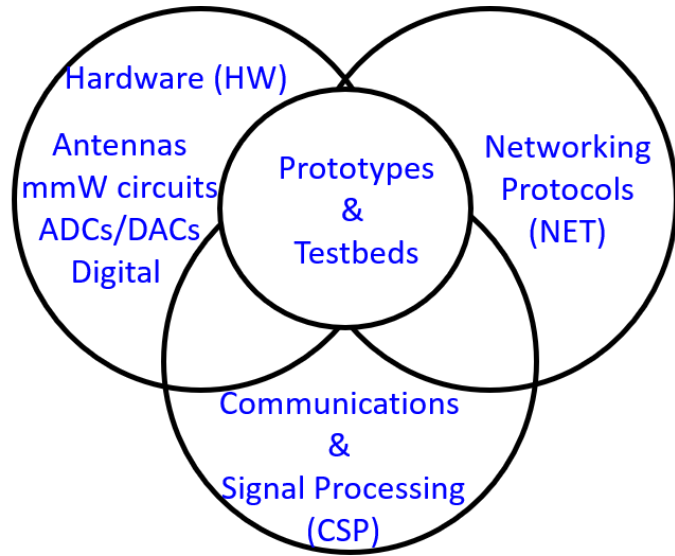
NIST

Boulder, CO

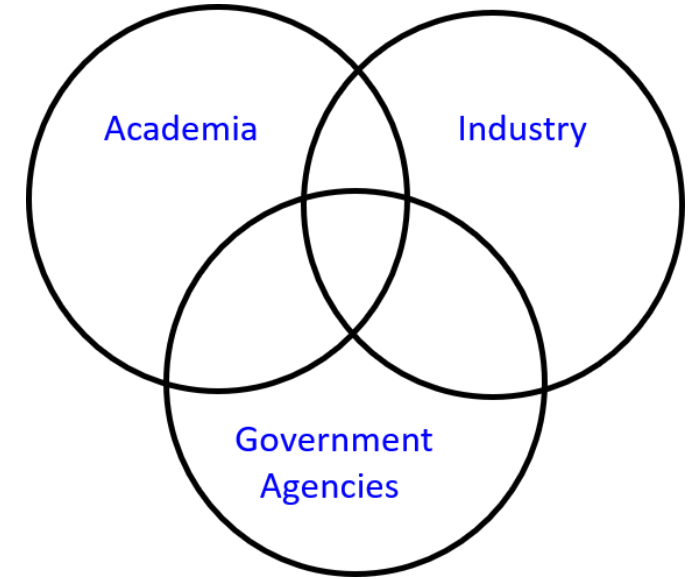
Akbar Sayeed

University of Wisconsin-Madison

mmW RCN: Rationale & Goals



Goal: Cross-fertilization of ideas to fuel the development of mmW wireless technology.



Workshops

Kick-off Workshop
Catholic U. America
Dec. 2016



2nd Workshop
UW-Madison
July 2017



3rd Workshop
U. Arizona
Jan. 2018



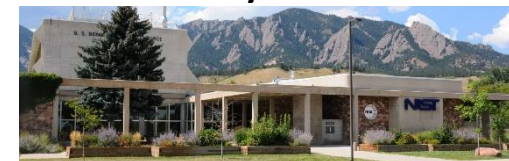
4th Workshop:
NYU Brooklyn
July 2018



5th Workshop:
NC State
Jan 2019



6th Workshop:
NIST
July 2019



Steering Committee

Academia:



Jim Buckwalter
UC-SB



Ismail Guvenc
NC State



Marwan Krunz
U. Arizona



Hang Liu
Catholic U.



Ali Niknejad
UC-Berkeley



Sundeep Rangan
NYU



Parmesh
Ramanathan
UW-Madison

Industry:



Amitava Ghosh
Nokia-Bell Labs



Ozge Koymen
Qualcomm



Carlos Cordeiro
Intel



Ashwin Sampath
MixComm



Ian Wong
National Instruments



Charlie Zhang
Samsung

Government Labs:



Kate Remley,
5G Channel Model Alliance, NIST



Nada Golmie
5G Channel Model Alliance, NIST

Canadian Representative:



David Michelson
(U. British Columbia)

European Representative:



Tommy Svensson
(Chalmers U.)

Key RCN Themes that Have Emerged

- **Interdisciplinary interface research challenges:**
 - i) **HW-CSP interface:** better system models that account for hardware characteristics
 - ii) **CSP-NET interface:** more accurate abstraction of the mmW PHY-MAC layer for network simulators.
 - iii) **mmW Standards:** 5G NR and 802.11ay/ad
 - iv) **Appropriate channel models** for both i) and ii).
- **The need for testbeds for research and experimentation in academia**
- **Need for new conferences, journals and other venues for publication**
- **Industry-Academia Collaboration:**
 - **“Moonshot” programs:** “big” research challenges for crystallizing academic-industry collaboration
 - **mmW Technology Roadmap:** i) identification of short-term (RCN 2020) and longer-term (RCN 2025) research and development goals.

Kickoff Workshop – Dec 2016, Washington DC

- Keynotes: Jon Wilkins (FCC) and Julius Knapp (FCC)
- The interfaces are where the exciting research challenges are:
 - HW-CSP Interface
 - CSP-NET Interface
- Prototypes and testbed
- New venues for publications
- 37 posters



2nd Workshop – July 2017, Madison, WI

- **Keynotes:** Ted Woodward (DARPA 100G), mmWave 5G NR: Boon Loong Ng (Samsung), Amitava Ghosh (Nokia-Bell Labs)
- Breakouts: HW-CSP; CSP-NET Breakouts; Hardware tools for testing and development of mmW
- 5G NR Standards – lots of interest
- 33 posters in 3 sessions
- 7 Demos:
 - Channel Emulator for mmWave Systems, Aditya Dhananjay and Marco Mezzavilla, NYU
 - 5G Antenna Design Software, Nick Buris
 - [WiMi mmWave platform](#), Xinyu Zhang, UW-Madison
 - [mmWave CAP-MIMO testbed](#), Chris Hall, Kevin Zhu, Dian Hu and Akbar Sayeed, UW-Madison
 - mmWave platforms, Sarah Yost and Ian Wong, National Instruments
 - video of Qualcomm’s mmWave prototype in mobile scenarios, Ashwin Sampath, Qualcomm
 - Diane Benz, Keysights



3rd Workshop – January 2018, Tucson, AZ

- Keynotes: Amitava Ghosh (Nokia Bell Labs), Carlos Cordiero (Intel)
- Breakouts: HW-CSP, CSP-NET, mmWave standards: 5G NR and 802.11ad/ay
- Posters: 36 posters
- Demos: The National Instruments team demoed a variety of mmWave platforms. NI also hosted a [hands-on workshop](#) on Jan 19, from 1-4pm. NI poster: [LTE MAC/PHY Prototyping Platform](#)



4th Workshop – July 2018, Brooklyn, NY

- Keynotes: John Cioffi (Terabit DSL), Ted Rappaport (mmW challenges)
- Breakouts: HW-CSP, CSP-NET, Community Testbed Development
- 30 posters
- Demos
 - [mmW Channel Sounder “Verification Box”](#), *Kate Remley*, NIST.
 - **FreeStar: A 360° Steerable Antenna for Fixed and Mobile mmW 5G Applications**, *Stefan O’Dougherty*, FreeFall. Proof-of-concept demonstration of a dielectric “polyrod” antenna operating at 27 GHz. The hub-and-spoke design of the full system will enable 360 degree steerable-beam coverage for connected vehicles, small base stations, and other mobile systems for 5G.
 - **140 GHz Channel Sounder, NYU Wireless**, *Yunchou Xing, Ojas Kanhere, Shihao Ju* . This live demonstration shows a 140 GHz millimeter-wave channel sounder with a time resolution of less than 2 ns and a large dynamic range. The channel sounder is capable of bi-directional angular measurements and can help with precise indoor localization.
 - **Performance assessment of COTS mmWave radios for drone communications**, *G. Bielsa, M. Zhang, W. Xia, L. Soularue, T. Clare, M. Mezzavilla, J. Widmer, S. Rangan, D. Shasha*. The goal of this project is to assess and understand the feasibility of mmWave radios for aerial (drone) links at low altitude. This preliminary work reports the performance of COTS mmWave radios connected to a DJI Matrice Pro 600 drone.



5th Workshop, January 2019, Raleigh, NC

- Keynotes: Sanyogita Shamsunder (Verizon), Tim Hancock (DARPA)
- Breakouts: HW-CSP, CSP-NET, Community Testbed Development
- 43 posters
- Demos:
 - [M3FORCE: 5G mmWave RF Module](#), Ren-Jr Chen and Wen Chiang Chen, Industrial Technology Research Institute, Taiwan.
 - [NCSU 28 GHz Channel Sounder](#), Ozgur Ozdemir and Ismail Guvenc.
 - NIST's Ray Tracing Based Channel Simulator
 - [5G Millimeter-Wave Basestation](#), John Oates, Vandita Raikar, Steve Dorn, Analog Devices.



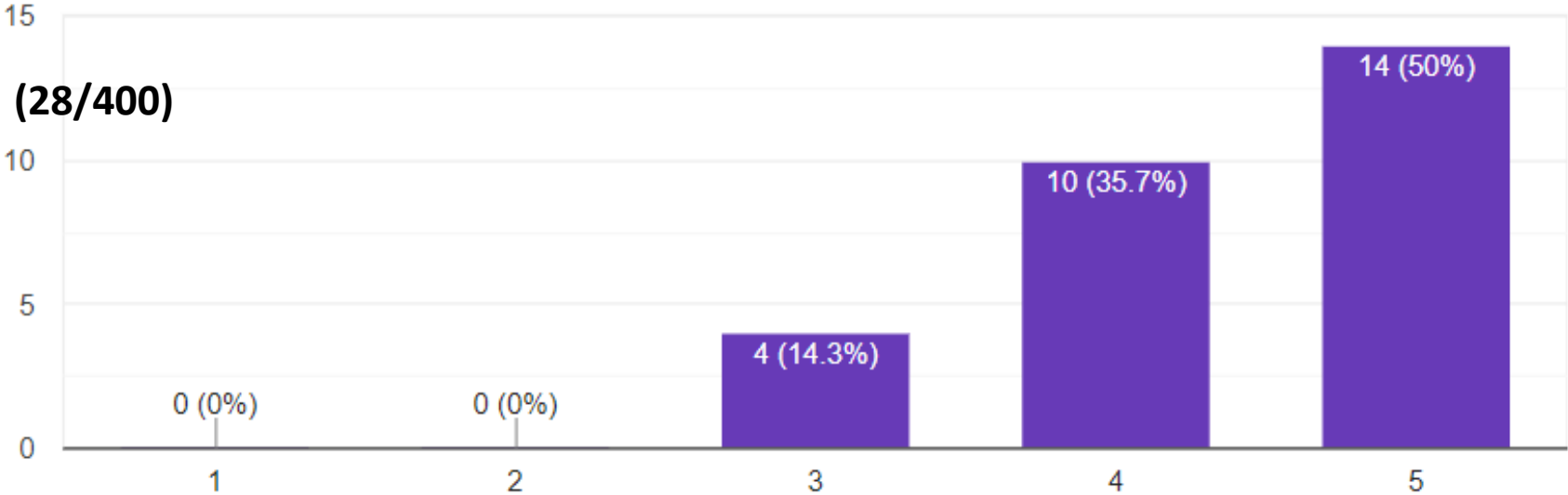
mmW RCN Community Survey

1. On a scale of 1-5, how well did the RCN facilitate research interaction and collaboration across the different technical areas (HW, CSP, NET) for you and your team?
2. On a scale of 1-5, how well did the RCN facilitate interaction and collaboration between academia and industry?
3. On a scale of 1-5, how much the RCN workshops and activities have contributed to the basic research and development of mmW wireless technology?
4. Would you like the RCN to continue in the future (perhaps in some modified form)?
5. What aspects of wireless research and technology development should a future RCN focus on?

On a scale of 1-5, how well did the RCN facilitate research interaction and collaboration across the different technical areas (HW, CSP, NET) for you and your team?

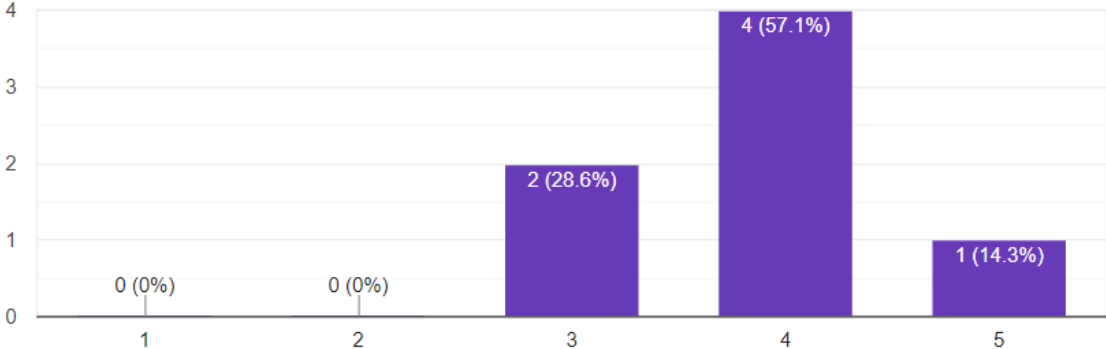
28 responses

mmW RCN community (28/400)



7 responses

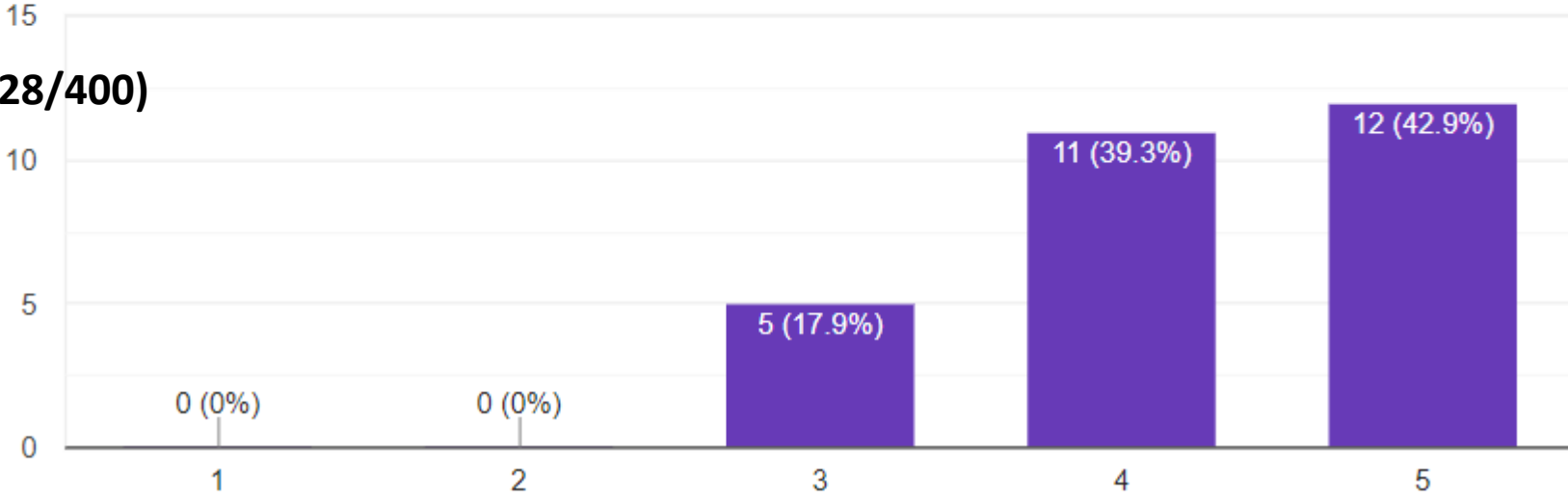
Steering Committee (7/16)



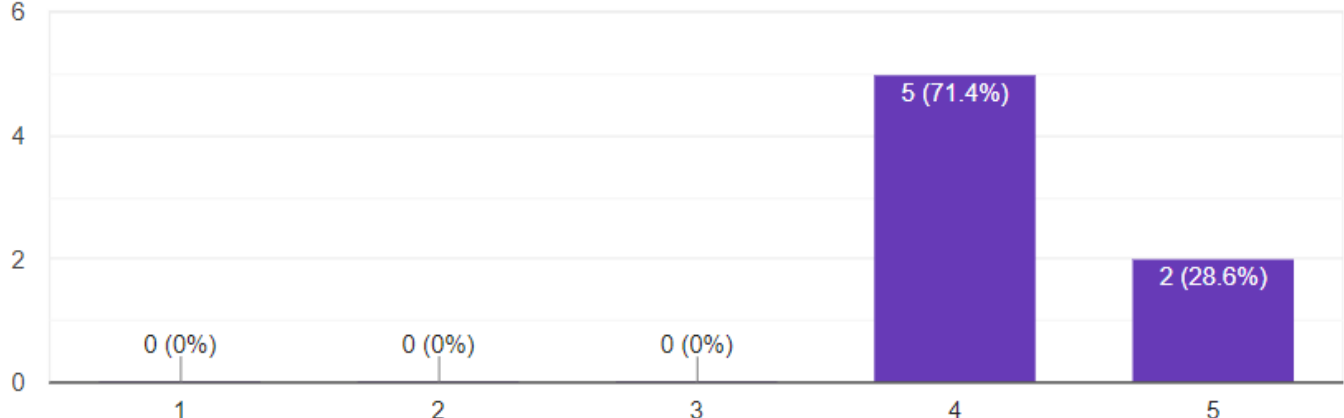
On a scale of 1-5, how much the RCN workshops and activities have contributed to the basic research and development of mmW wireless technology?

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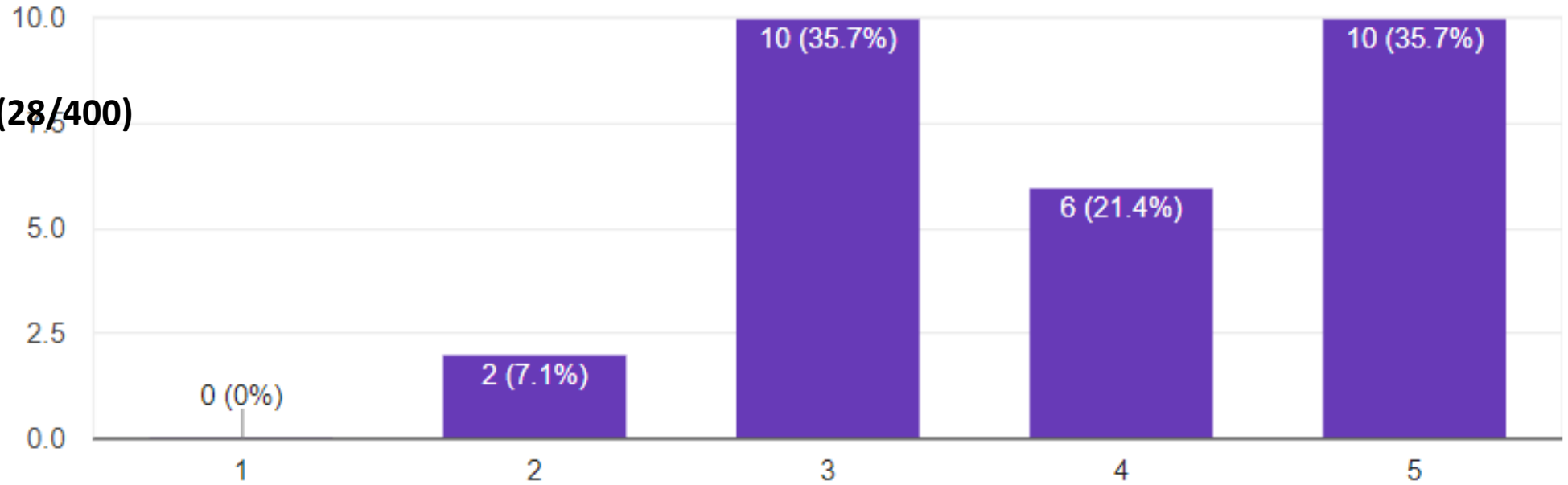
Steering Committee (7/16)



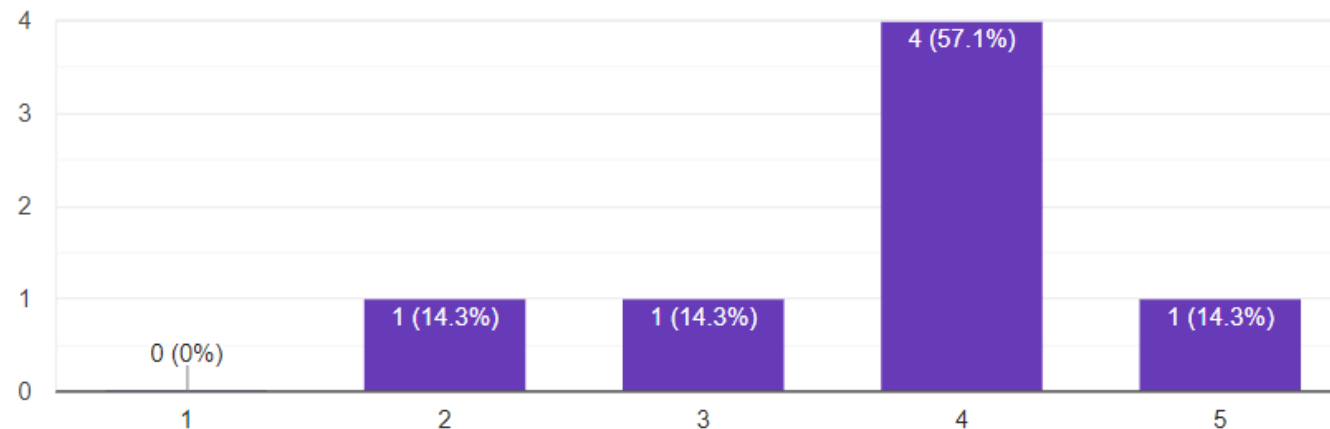
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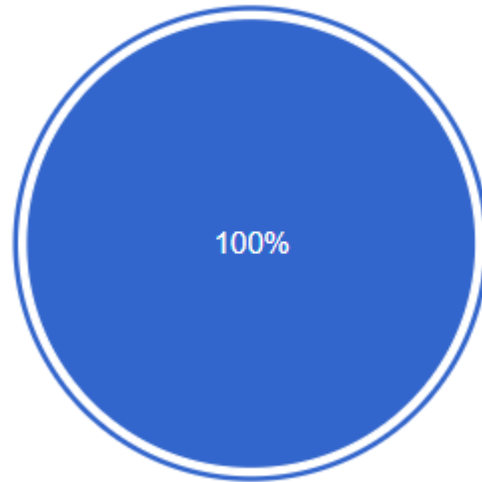
mmW RCN community (28/400)



Steering Committee (7/16)



Would you like the RCN to continue in the future (perhaps in some modified form)?



Potential Directions for future RCN?

- **CSP-NET: interaction between the PHY (CSP-HW) and higher layers**
 - develop channel models, simulators, and emulators to attain a predictive framework for increased accuracy and efficiency of infrastructure deployment
- **Community Testbed Development**
 - A roadmap for testbed development that incrementally chips at the challenges to attain the goals of the roadmap – engaging the community
 - Specific goal-oriented testbed development projects that move the needle in:
 - science & engineering innovation
 - academic-industry collaboration, and
 - industry bottom line
- **HW-CSP-NET: Spectrum sensing for spectrum sharing and monitoring**
- **Health impacts of exposure to mmW and higher frequencies:**
 - What's the state of the art?
 - Any holes in basic S&E?
 - Recommendations for balancing public *health concerns* versus the *need for new infrastructure*
 - Identification of industry sponsored project(s) that help formulate recommendations
 - Project(s) run by an independent entity (e.g. NIST?)
 - Leveraging technology (e.g. directional transmission) to minimize health impacts

What aspect(s) of the mmW RCN experience did you find most useful?

- Learning about the challenges and opportunities in the mmWave space. The cross-layer connect was especially helpful.
- Great opportunity for keeping up to date with recent advancements in the mmWave community and great opportunity for top-level networking
- Priceless networking and one-on-one discussions among mmW community members.

What aspect(s) of the mmW RCN experience did you find least useful?

- Six month spacing between workshop isn't suitable for academic groups. We typically don't receive the level of funding whereby we will have new results to share every six months. Yearly frequency would be better.
- It wasn't clear that there was much actionable from the meeting. Unclear connection between meeting outcomes and funding priorities. Additionally, the meetings were too full so that hardware researchers could not attend system talks which prevented cross-disciplinary discussion.

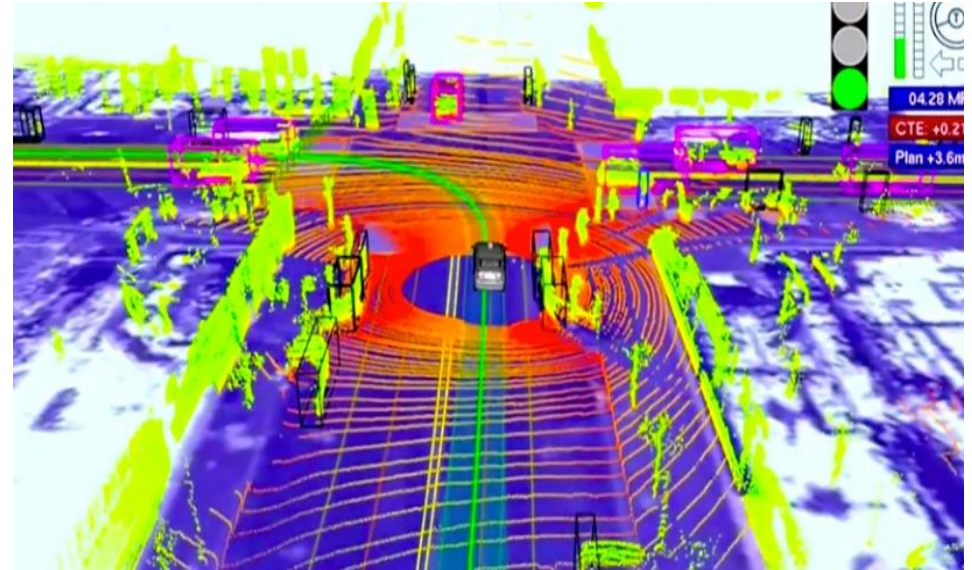
What aspects of wireless research and technology development should a future RCN focus on?

- testbed development - both hardware and basic techniques - more industrial engagement; As this topic area has evolved out of the lab, real system level implementation and experimental infrastructure to build on the research and channel studies is the need of the hour.
- AI for wireless communications, health issues related to wireless communications, and wireless networks planning with and without good infrastructures
- There are very few platforms to get a broad picture of emerging wireless technologies from networks to devices. I think RCN should continue to play this role but maybe with more "educational" aspects mixed with the research aspects. I can go anywhere to hear people in my field speak. I would like to "learn" something at the RCN about the fundamentals and new research in other fields in a more concentrated workshop approach.
- Higher frequency bands, novel applications, and some Grand Challenges (e.g., the NAE's).
- I think mm-wave MIMO is still an emerging field and should have lots of challenges left for future RCN

Measurements to Modeling to Network Simulators & Emulators (HW-CSP-NET)

- **Accurate performance prediction** prior to network deployment not possible today
- Current network models (e.g., ns-3) are limited
 - Multi-beam PHY capabilities
- Current mmW channel models limited:
 - sounders and measurements
 - models for beam dynamics & blocking
- Opportunity: **Measurement + computation**
 - Multi-beam sounders & measurements
 - Ray tracing (combined with LIDAR, e.g.)
 - → accurate channel models
- → **Accurate Network Simulators & Emulators**

Google's self-driving car use lidar to create 3D images

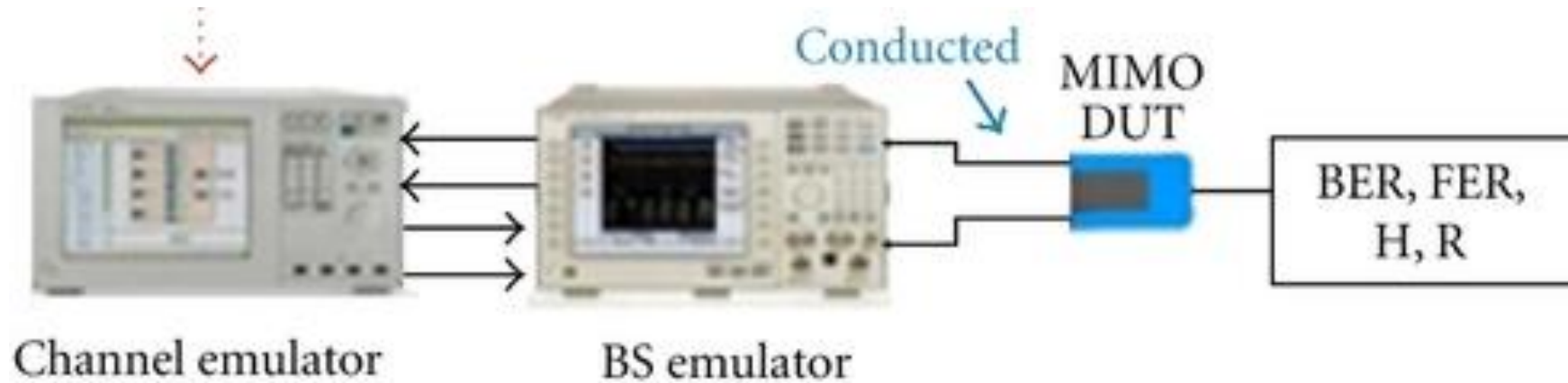


Sebastian Thrun & Chris Urmson/Google (IEEE Spectrum)



NYU, U. Padova, Bristol, NCSU, CRC, UW, NIST, SIRADEL

Existing RF Hardware Testing Paradigm: Channel Emulators + Conductive measurements

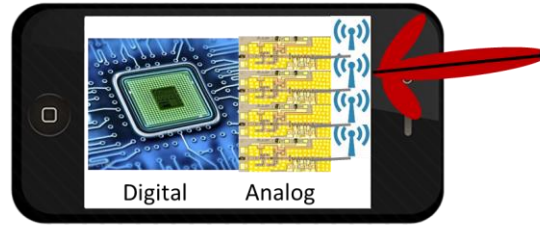


mmW technology: conductive measurements **not** possible

- Integrated modules
- Antenna arrays

Figure credit: MIMO Over-The-Air Research, Development and Testing, M. Rumney et. al.,
International Journal on Antennas and Propagation 2012.

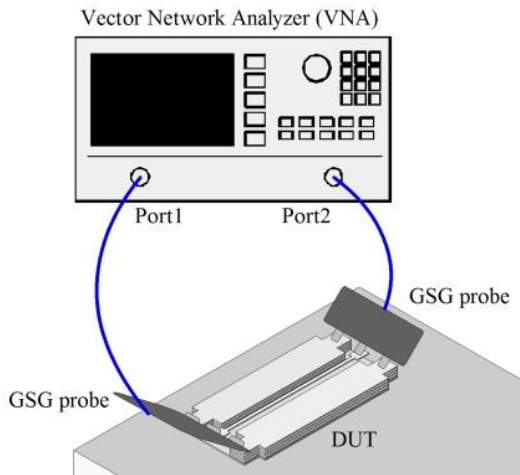
The Measurement Elephant In the Room



Courtesy:
Kate Remley

NIST

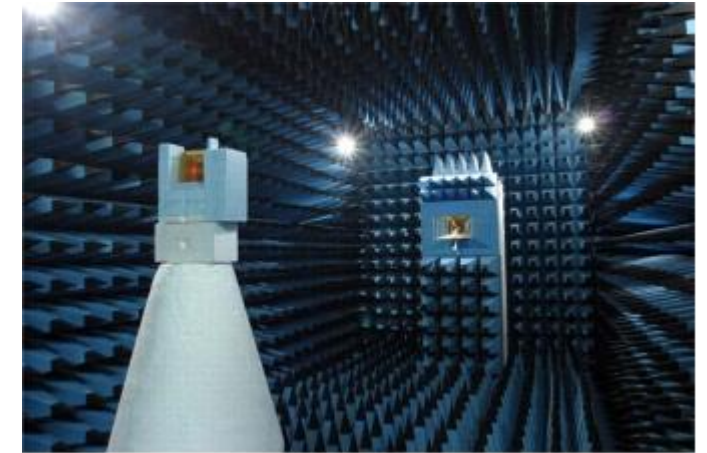
On wafer meas.



On-Wafer to OTA – no connectors

- Efficiency
- Distortion
- Troubleshooting stages

Over-the-air testing

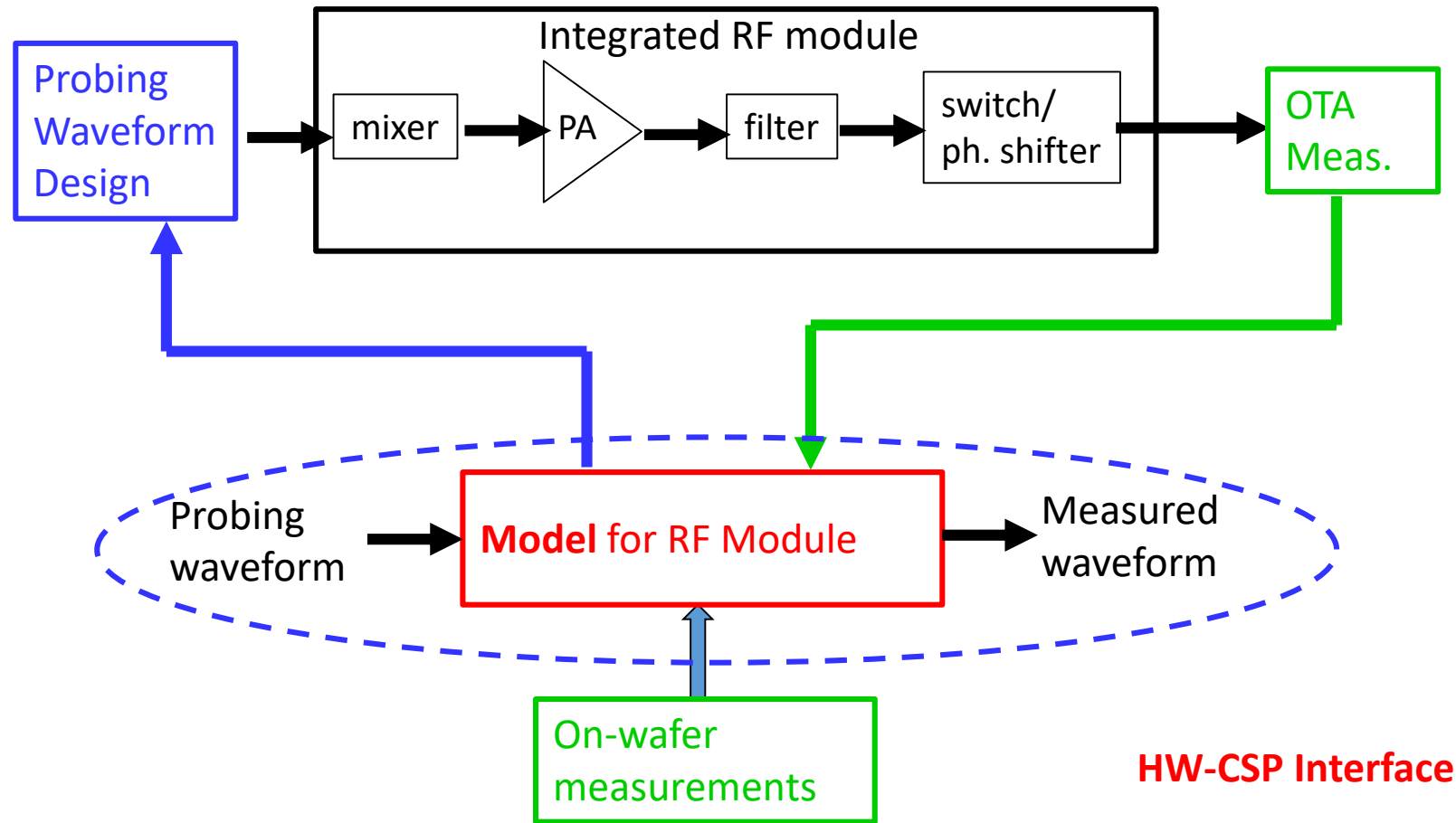


Cisco

Intech (T. Hirano, K. Okada,
J. Hirokawa and M. Ando)

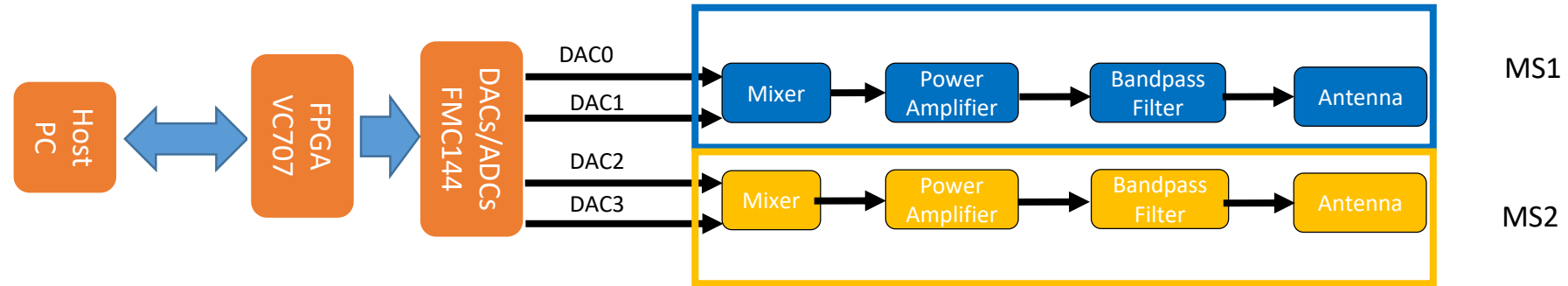
**How to merge on-wafer and OTA tests
to verify performance?**

Potential New mmW Testing Paradigm

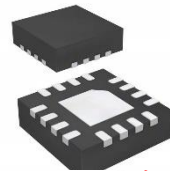


- **RF model:** what kind of on-wafer measurements?
- **OTA testing:** probing waveforms and measurements?
- Machine Learning Techniques could be leveraged

Reducing the Cost of Prototyping: A Timely Opportunity for Academic-Industrial Innovation



Surface mountable chip



\$30

PCB packaging

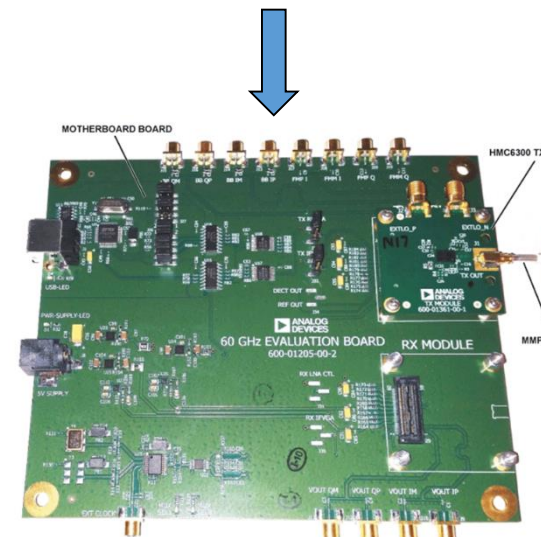


\$300

Connectorized Module



\$3000



NIST 5G mmWave Channel Model Alliance