ON JOINT COMMUNICATIONS AND SENSING: MEASUREMENT AND MODELING FOR NEXT "G"

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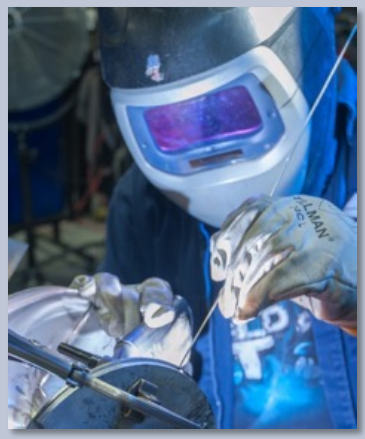
National Institute of Standards and Technology
U.S. Department of Commerce

June 2023

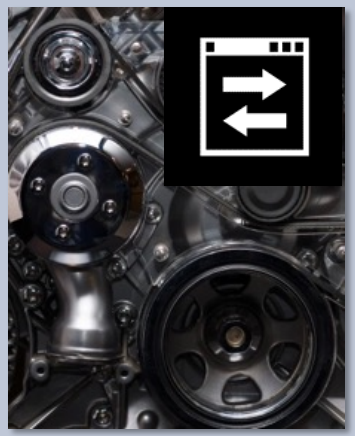
NIST Mission

To promote innovation and U.S. industrial competitiveness by advancing **measurement science**, **standards**, and **technology** in ways that enhance economic security and improve our quality of life.

World-Leading Scientific and Engineering Research



Advanced Manufacturing National Programs



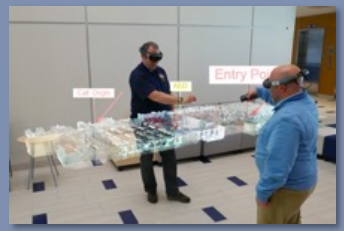
Technology Transfer and Innovation

Advanced Communications Research

NIST

Advances in Communications Metrology

- Measurement and Instrumentation
- Testing and Validation
- Partnership and Collaboration
- Standards and Dataset Dissemination



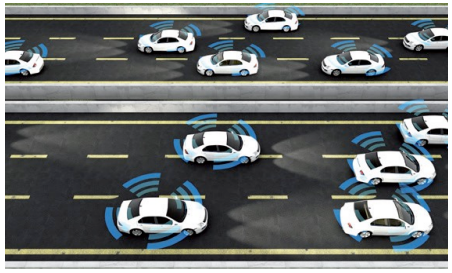
Antenna and Communications Metrology Facilities

Public Safety Communications Research

Advanced Manufacturing

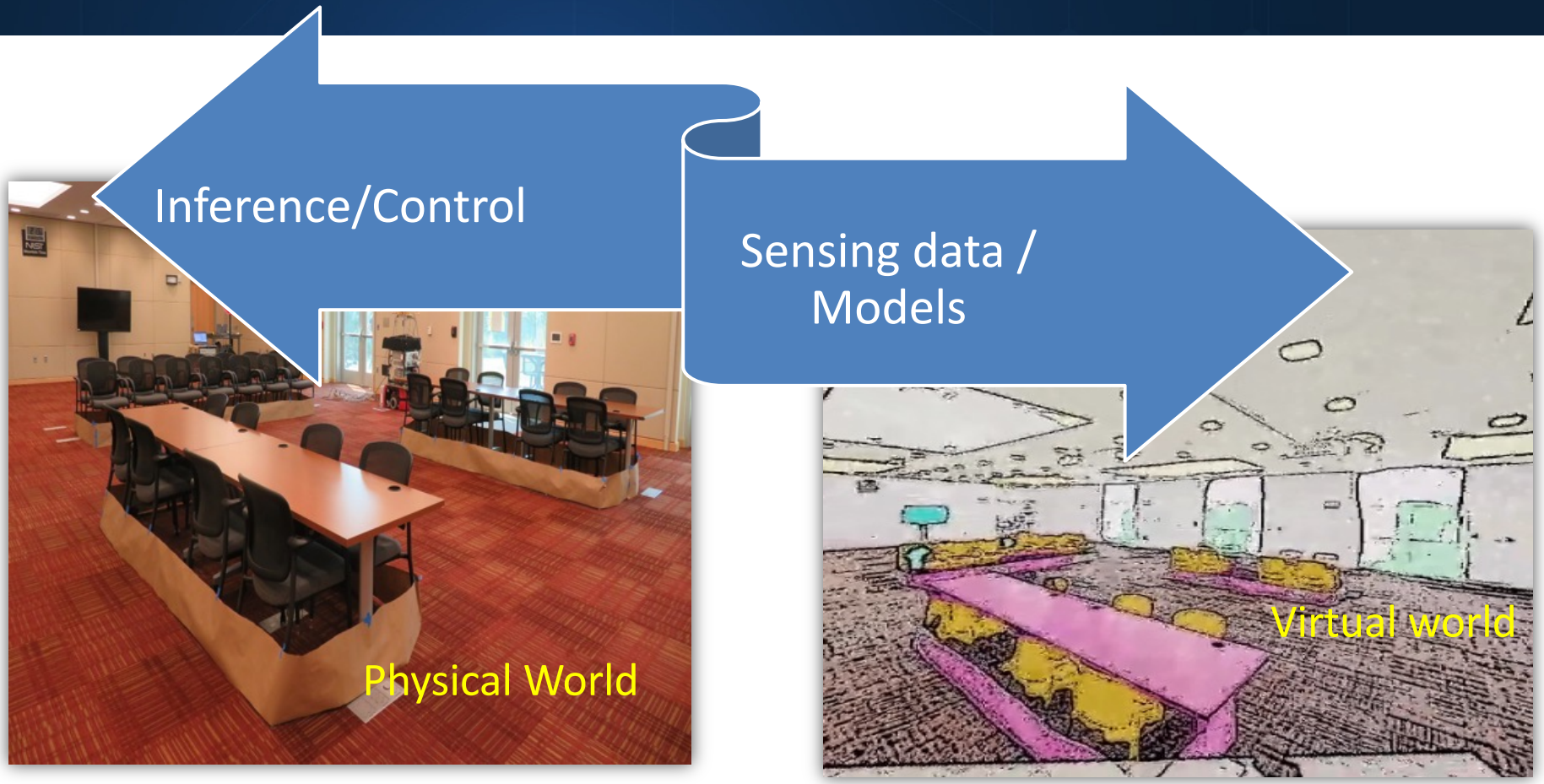
Securing Next Generation Communications

THE ERA OF CHATGPT



Enhanced Intelligence
Enhanced Control
Enhanced Automation
Enhanced Connectivity

DIGITAL TWIN

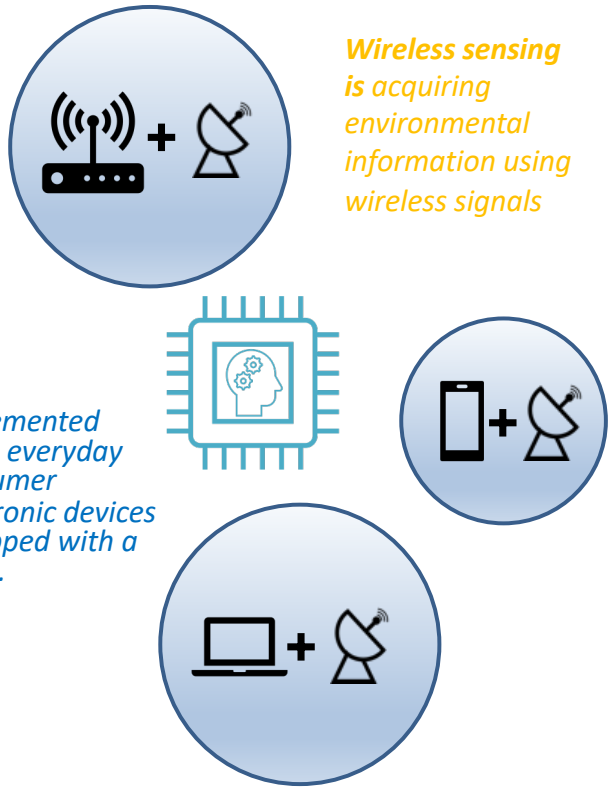


SENSING USING COMMUNICATIONS SYSTEMS

Reduce power consumption and cost.

Reuse spectrum and signals

Enable new applications



***Wireless sensing is** acquiring environmental information using wireless signals*

implemented using everyday consumer electronic devices equipped with a radio.

JOINT COMMUNICATIONS AND SENSING
KEY MEASUREMENT CHALLENGES

RF/Wireless

Propagation models
Signal processing

System Level

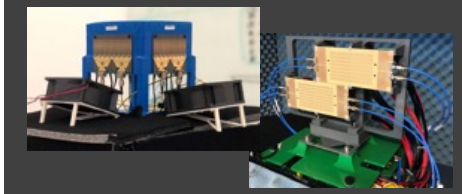
Comm. protocol
App. performance

Digital Twin

Multi-dimensional data
ML/Training

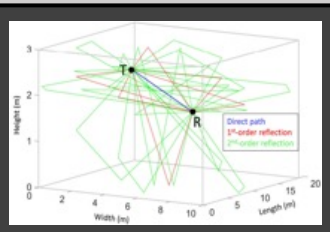
Today's Presentation

Channel Propagation Measurements



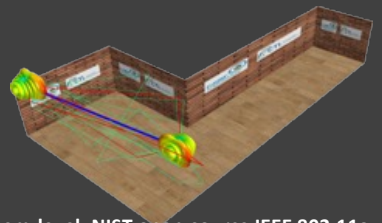
NIST Channel Sounders

Channel Modeling



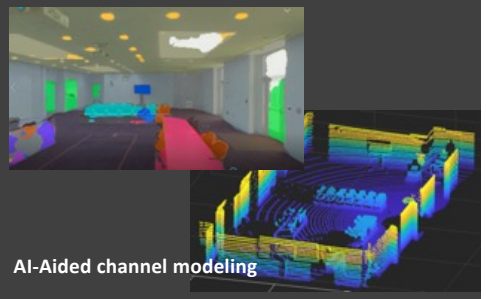
NIST Open-Source mmWave Raytracer based on channel propagation measurements

Link-Layer and System-level Simulations



System-level: NIST open-source IEEE 802.11ay implementation – Visualization of beamforming process

Data Dissemination Collaboration



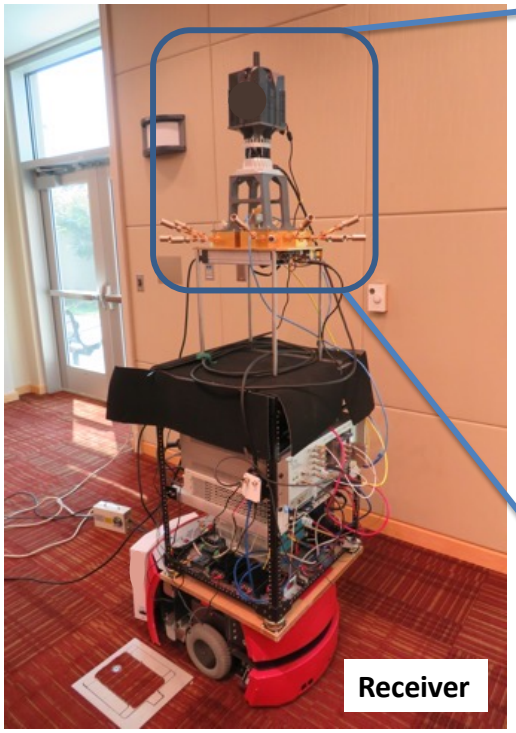
AI-Aided channel modeling

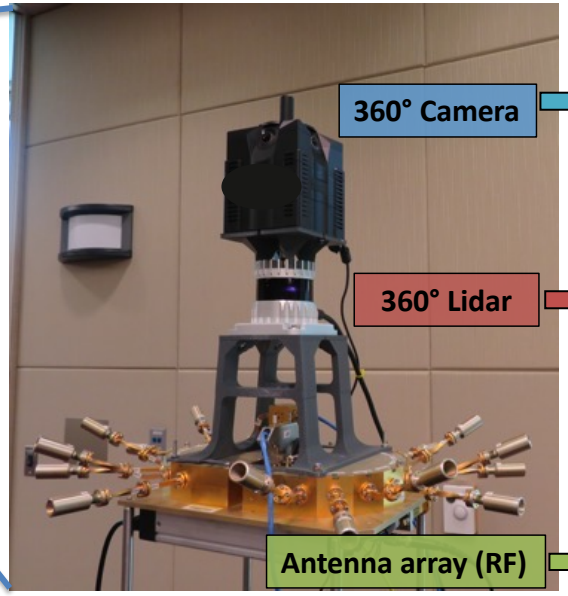
NIST

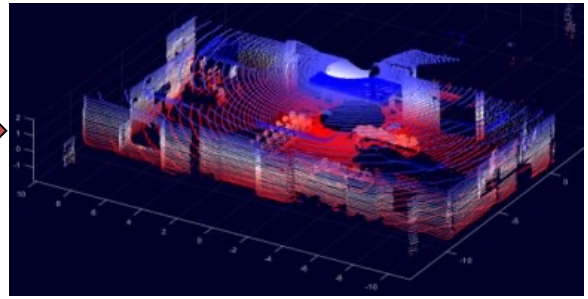
- Designing and building measurement instruments
- Developing model abstractions for performance evaluation
- Using AI/Machine learning
- Disseminating models and measurement Datasets

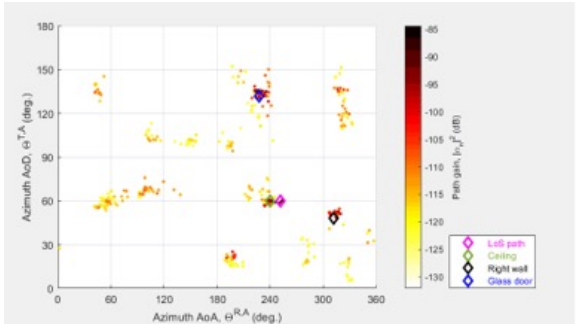
MEASUREMENT SYSTEM

MEASUREMENT SYSTEM





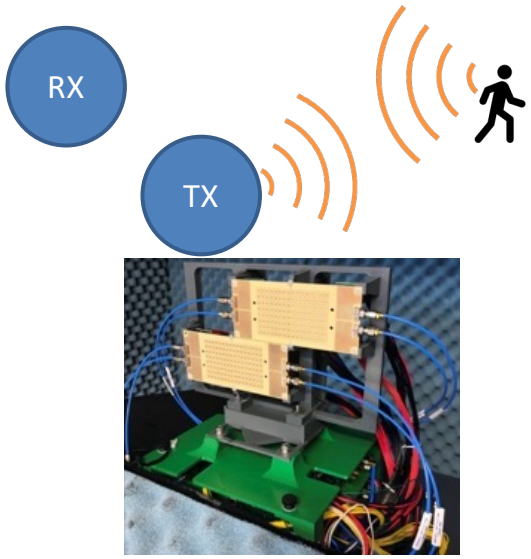


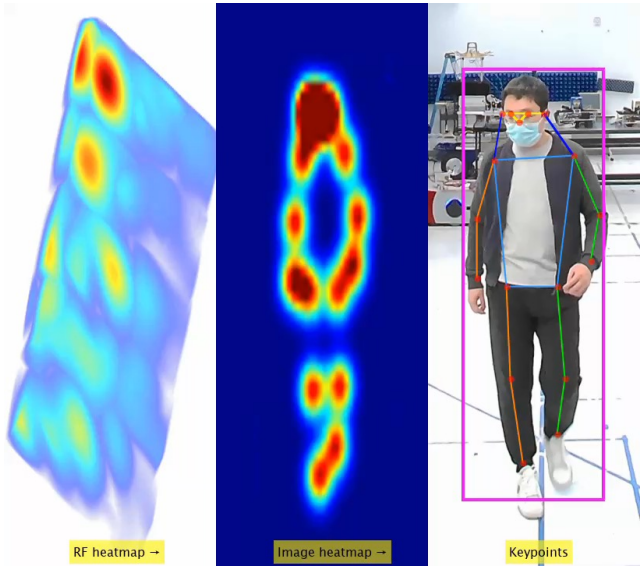


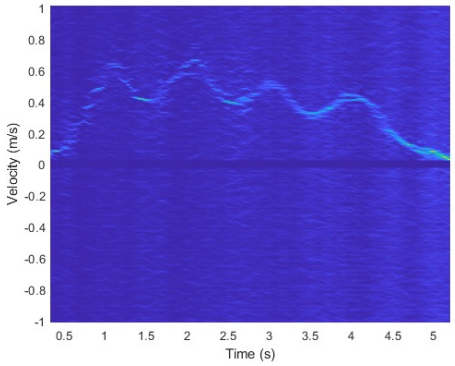
While in motion, the receiver collected:

- RF data
- 360° lidar data
- 360° photos of the environment.

MEASUREMENTS FOR HUMAN SENSING







S.Y. Jun, J. Chuang, D. Caudill, C. Gentile, S. Blandino, N. Golmie, “NIST mmWave Phased-Array Channel Sounder for Human Sensing,” Document IEEE 802.11-21/1675r0, Oct. 2021. https://mentor.ieee.org/802.11/dcn/21/11-21-1675-00-00bf-mmwave-phased-array-channel-sounder-for-human-sensing.pptx.

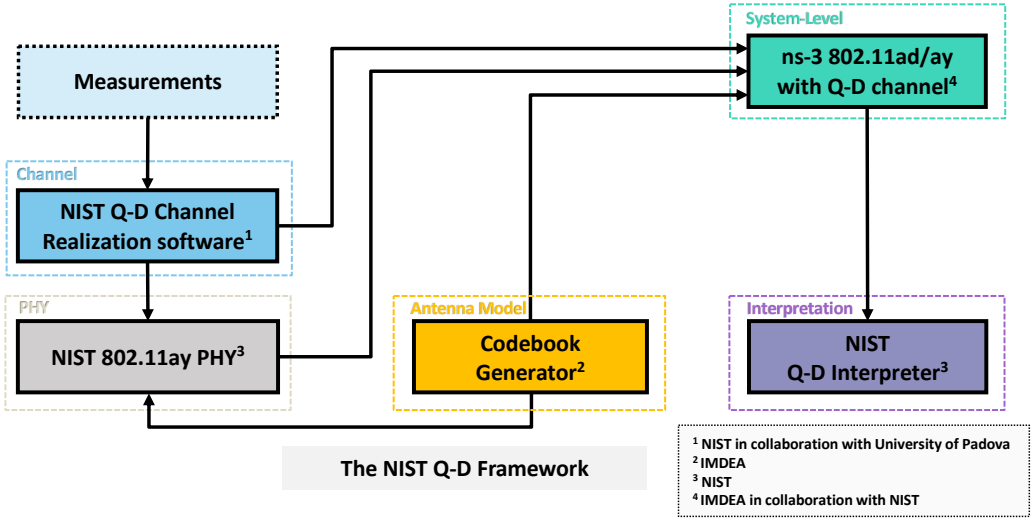
S. Blandino, T. Ropitault, C. R. C. M. da Silva, A. Sahoo and N. Golmie, "IEEE 802.11bf DMG Sensing: Enabling High-Resolution mmWave Wi-Fi Sensing," in IEEE Open Journal of Vehicular Technology, 2023.

PROPAGATION AND SYSTEM LEVEL MODELING

MEASUREMENT-BASED MODELING & TOOLS SUITE

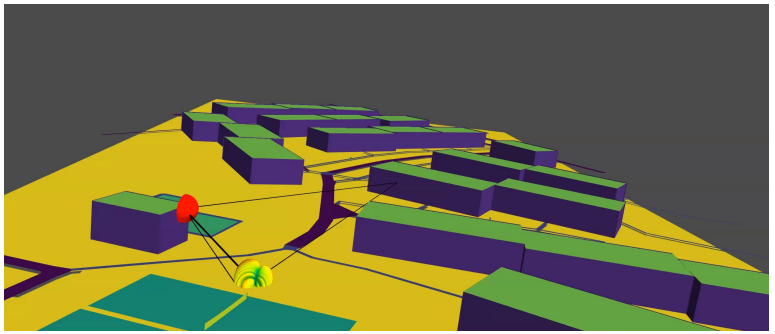
MMWAVE WIFI: IEEE 802.11AD/AY/BF

- **The NIST Q-D Framework**
  - 5 software packages to evaluate IEEE 802.11ad/ay
  - Available at: https://github.com/wigig-tools
- **Various system-level evaluations performed**
  - End-to-End performance [1,2]
  - Beamforming/Scheduling [3,4]
  - Virtual reality/MIMO [5,6]
- **Many Collaborators**
  - University of Padova, IMDEA, NYU, University of Washington
  - Intel/Mathworks
  - Large number of forks (>60)



The NIST Q-D Framework

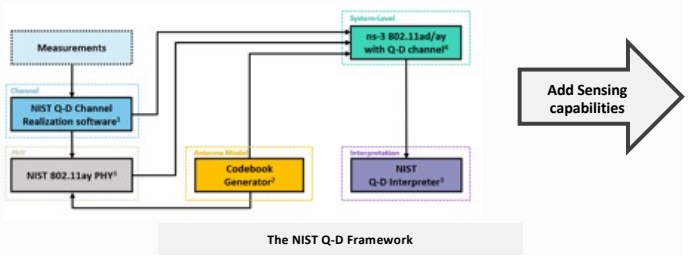
[1] H. Assasa, J. Widmer, T. Ropitault, A. Bodi, N. Golmie, "High Fidelity Simulation of IEEE 802.11ad in ns-3 Using a Quasi-deterministic Channel Model". Published at WNS3 19.
[2] H. Assasa, N. Grosheva, T. Ropitault, S. Blandino, N Golmie, J. Widmer, "Implementation and Evaluation of a WLAN IEEE 802.11ay Model in Network Simulator ns-3". Published at WNS3 21.
[3] N. Grosheva, H. Assasa, T. Ropitault, P. Mateo, J. Widmer, N. Golmie "A Comprehensive Analysis and Performance Enhancements for the IEEE 802.11ay Group Beamforming Protocol". Published at WOWMOM 22.
[4] A. Sahoo, W. Gao, T. Ropitault, N. Golmie "Admission Control and Scheduling of Isochronous Traffic in IEEE 802.11ad MAC". Published at MSWiM 2021
[5] J. Chakareski, M. Khan, T. Ropitault, N. Golmie, S. Blandino "6DOF virtual reality dataset and performance evaluation of millimeter wave vs. free-space-optical indoor communications systems for lifelike mobile vr streaming". Published at 54th Asilomar Conference on Signals, Systems, and Computers
[6] M. Kim, T. Ropitault, S. Lee, N. Golmie, Hanny Assassa, Jorg Widmer, "A Link Quality Estimation-based Beamforming Training Protocol for IEEE 802.11ay MU-MIMO Communications" Published in in IEEE Transactions on Communications



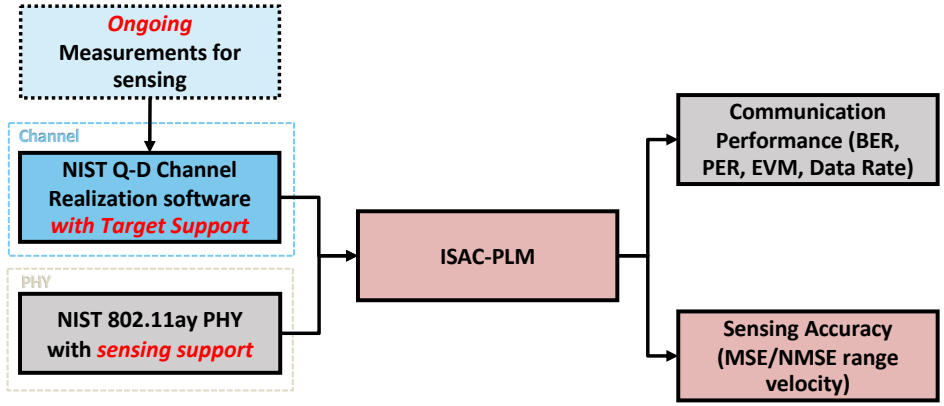
MEASUREMENT-BASED MODELING & TOOLS SUITE

WIFI SENSING: IEEE 802.11BF

- **The NIST Integrated Sensing And Communication (ISAC) Framework**
  - Extend the Q-D framework to evaluate WiFi sensing
  - A modified PHY for sensing, ISAC Physical Layer Model (PLM), is available at: https://github.com/wigig-tools/isac-plm



The NIST Q-D Framework

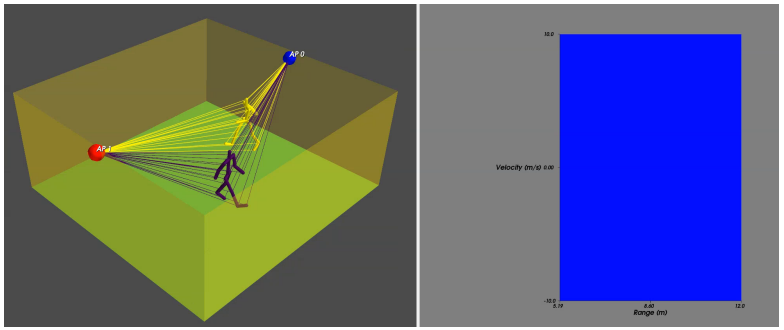


The NIST ISAC Framework

S. Blandino, T. Ropitault, A. Sahoo, N. Golmie, "Tools, Models and Dataset for IEEE 802.11ay CSI-based Sensing". Presented at WCNC22.

T. Ropitault., S.Blandino, N. Varshney, N. Golmie," Q-D simulation & Modeling framework for sensing" Document IEEE 802.11-21, May 2021. https://mentor.ieee.org/802.11/dcn/21/11-21-0746-01-00bf-q-d-simulation-modeling-framework-for-sensing.pptx

S. Blandino, T. Ropitault, N. Varshney, N. Golmie, "A preliminary channel model using raytracing to detect human presence", May 2021. https://mentor.ieee.org/802.11/dcn/21/11-21-0747-01-00bf-a-preliminary-channel-model-using-raytracing-to-detect-human-presence.pptx



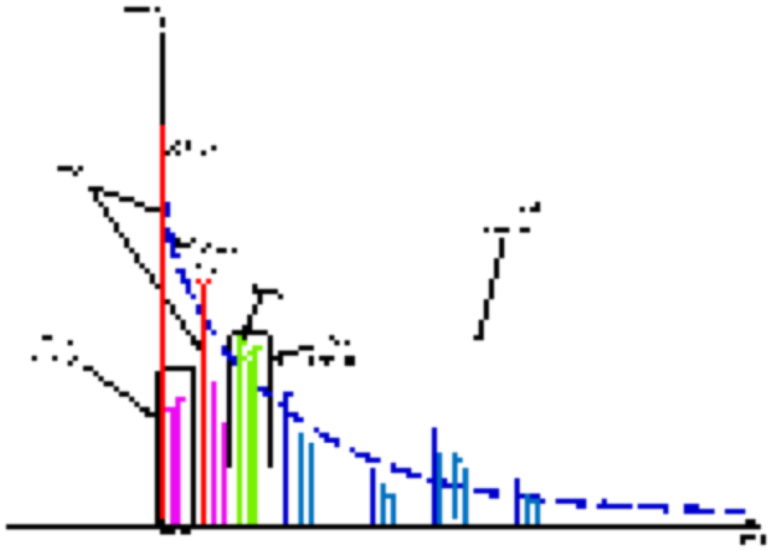
EXTENDING QUASI-DETERMINISTIC CHANNEL MODEL FOR SENSING

Quasi-Deterministic Model

- D-rays
  - Deterministic strong rays from macro-objects reflections.
- R-rays
  - Relatively weak random rays from static surfaces reflections.
- F-rays
  - Relatively weak random rays from dynamic surfaces reflections.

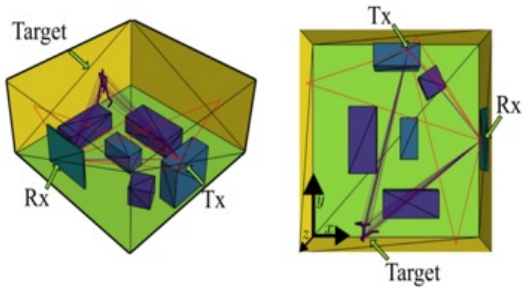
Extended Q-D methodology for Sensing:

- **Target rays (T-rays)**
  - **Relatively weak deterministic rays from dynamic targets scattering centers.**

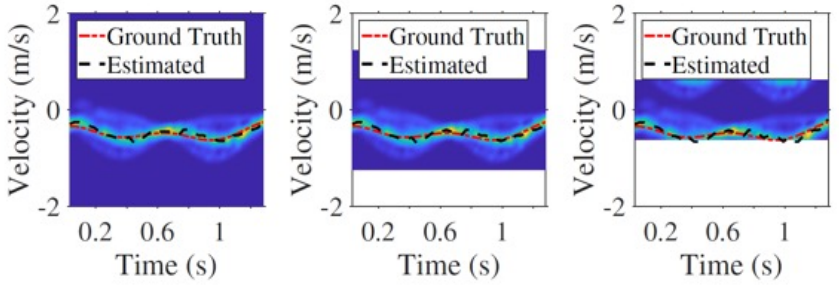


[*S. Blandino, T. Ropitault, N. Varshney, N. Golmie, "A preliminary channel model using raytracing to detect human presence", May 2021. https://mentor.ieee.org/802.11/dcn/21/11-21-0747-01-00bf-a-preliminary-channel-model-using-raytracing-to-detect-human-presence.pptx*

EVALUATION OF IEEE 802.11BF EDMG PHY

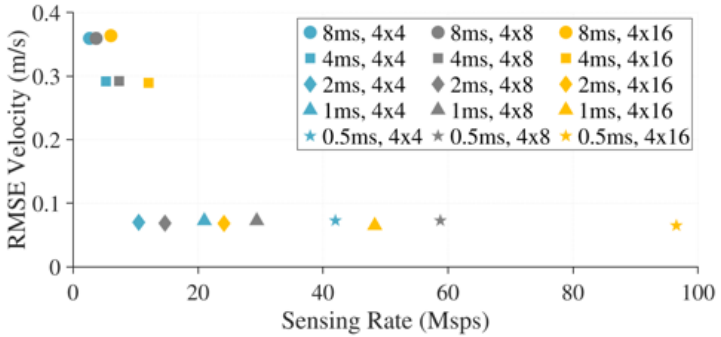


Impact of Pulse Repetition Interval on microdoppler and velocity estimation



PRI 0.5ms **PRI 1ms** **PRI 2ms**

Trade-off velocity accuracy-sensing rate



The overhead introduced by sensing is kept below 5.5% of the system symbol rate.

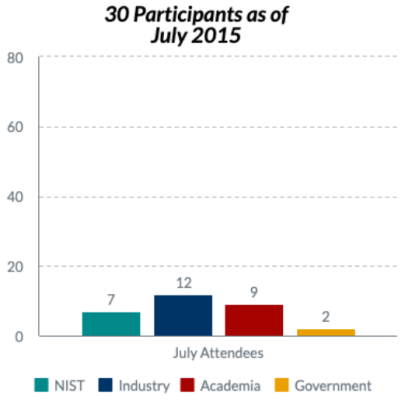
S. Blandino, T. Ropitault, C. da Silva, A. Sahoo, N. Golmie, "IEEE 802.11bf DMG Sensing: Enabling High-Resolution mmWave Wi-Fi Sensing," in IEEE Open Journal of Vehicular Technology, January 2023.

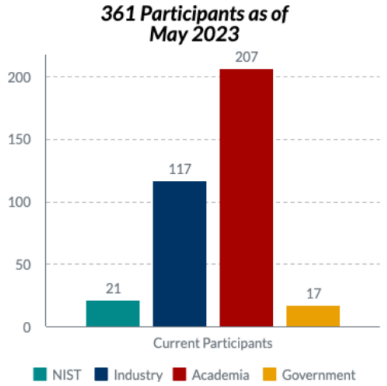
DATA DISSEMINATION AND COLLABORATIONS

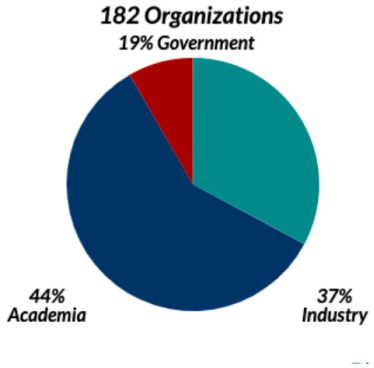
NEXTG CHANNEL MODEL ALLIANCE

An international research consortia conducting post-5G wireless experiments. Group focuses on wireless channel ***measurement*** and ***modeling***.

- Established user community for wireless signal propagation measurements and modeling : (Link)

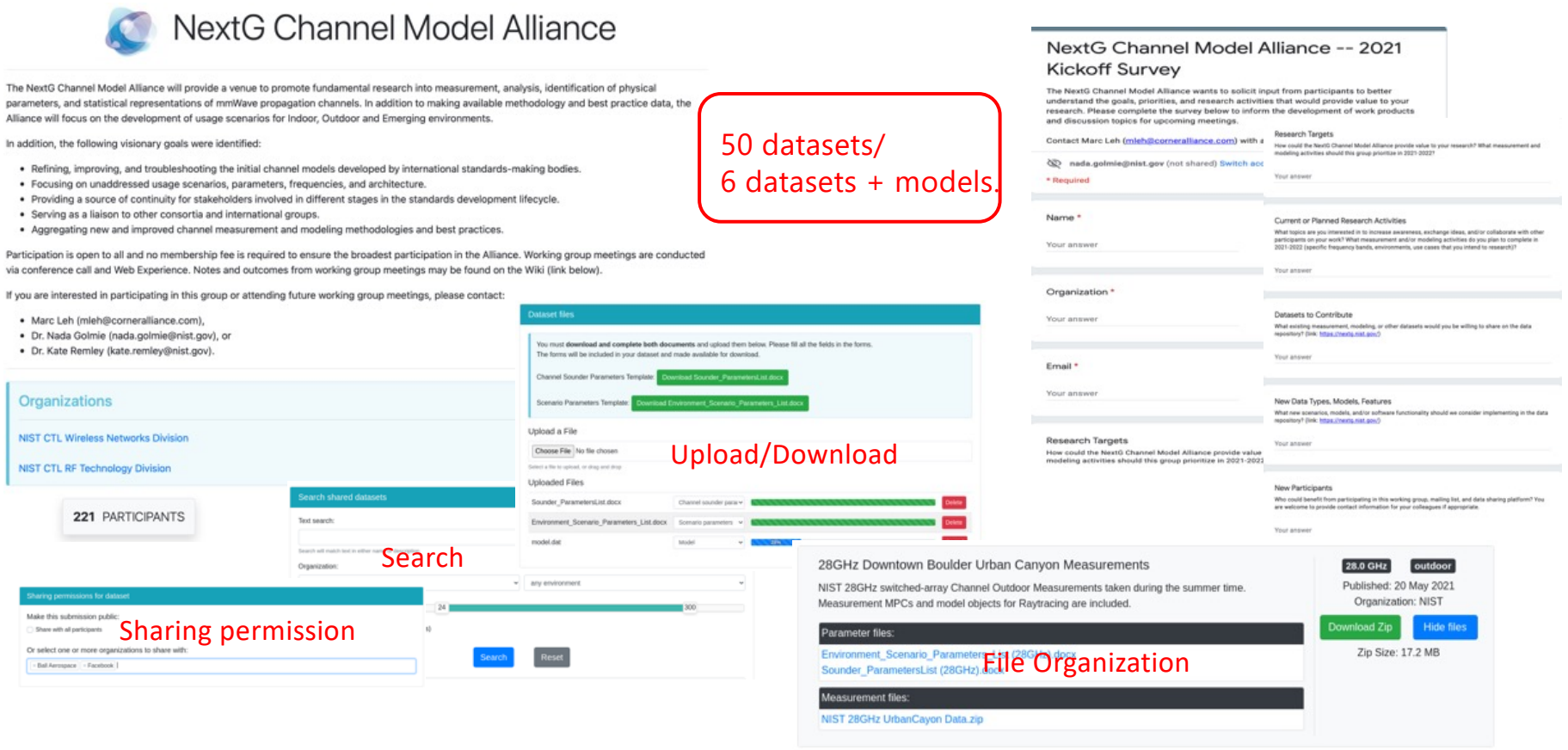






- Repository of data measurements and models available online: (Link)
- Monthly seminars and sponsored workshops and face-to-face meetings co-located with major conferences & events.

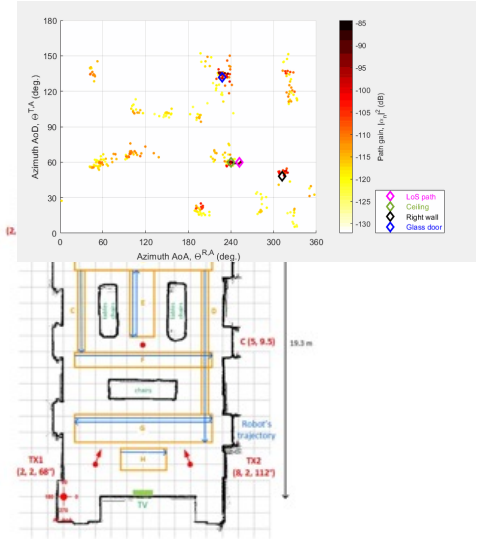
NEXTG CHANNEL MODEL ALLIANCE DATA REPOSITORY



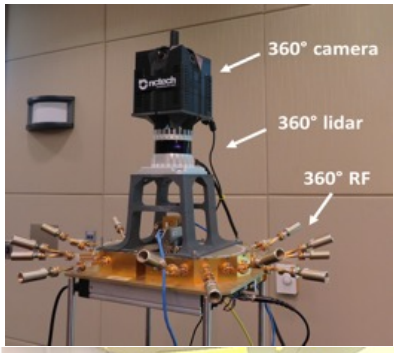
AI-BASED CHANNEL MODELING

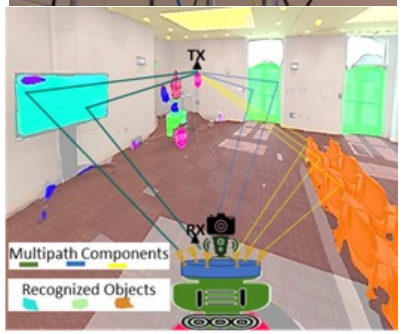
NIST

360° RF from Channel Sounder



- Measurement campaign collected with 4 TX locations and 26000+ RX locations divided into 8 areas (A-H)
- 10 cm between adjacent locations on xy grid in each area





- Camera and lidar are used to collect data in tandem with RF
- All three systems synchronized

Current Alliance Modeling Group Effort

- Off-line: Train AI structure with camera, lidar, and RF in multiple environments with NIST supplied measurements.
- On-line: Characterize new environment with camera and lidar only
- Generalize RF to new environment based on trained environments and camera/lidar of new environment

NOKIA Bell Labs

TECHNISCHE UNIVERSITÄT ILMENAU

University of Twente
The Netherlands

NIST
National Institute of Standards and Technology
U.S. Department of Commerce

360° Image from Camera

360° Range Map from Lidar

DEPTH MAP ESTIMATION IN 6G MMWAVE SYSTEMS

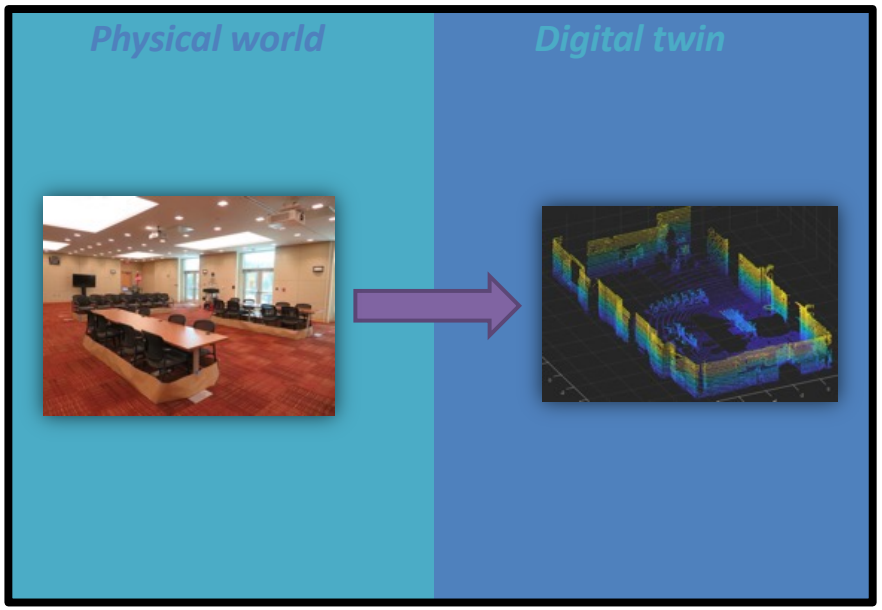
Two MIMO nodes

- One fixed transmitter
- One moving (position and orientation) receiver

Observation of environment changes over time

- Relative to position and orientation of the receiver

Challenge: estimate the depth map of the environment at each receiver position, using mm-wave signals.



ITU
AI/ML in 5G
Challenge
Applying machine learning in communication networks
ai5gchallenge@itu.int

https://challenge.aiforgood.itu.int/match/matchitem/79

PARTNERSHIPS AND COLLABORATIONS

- **NIST/CTL Facilities: https://www.nist.gov/ctl/facilities**
- **Tools for Industry: https://www.nist.gov/communications-technology-laboratory/wireless-networks-division/wireless-networks-division-tools**
- **Documentary standard development**: 3GPP, IEEE, ITU, IETF, ANSI, ATIS, Wireless Innovation Forum Spectrum Sharing Committee, CTIA, Telecom Infra Project.
- **Partnerships:** Resilient and Intelligent NextG systems (RINGS) – NSF, DOD, NIST & Industry partnership to accelerate NextG research.

MANY THANKS TO THE TEAM!

Evan Black
Anmol Bhardwaj
Samuel Berweger
Steve Blandino
Anuurag Bodi
Raied Caromi
Jack Chuang
Camillo Gentile
Damla Guven
Chieping Lai
Richard Rouil
Tanguy Ropitault
Anirudh Sahoo
Jelena Senic
William Sloan
Neeraj Varshney
Jian Wang

- *Multi-disciplinary team of RF, electrical/computer engineers, physicists, and computer scientists in Gaithersburg and Boulder.*
- *Hands-on hardware and software development*
- *Mathematical modeling and computer simulations*

THANK YOU!

QUESTIONS?

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