

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

NADA GOLMIE

NIST FELLOW, COMMUNICATIONS TECHNOLOGY LABORATORY

NIST Mission



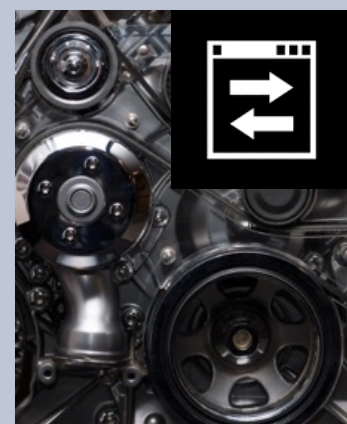
To promote innovation and U.S. industrial competitiveness by advancing **measurement science**, **standards**, and **technology** in ways that enhance economic security and improve our quality of life.



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



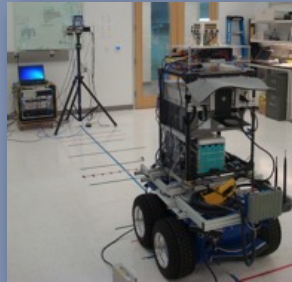
Testing and
Validation



Partnership and
Collaboration



Standards and
Dataset
Dissemination



Antenna and Communications
Metrology Facilities



Public Safety
Communications Research

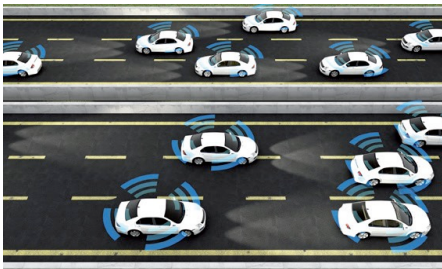


Advanced Manufacturing

Securing Next Generation Communications

THE ERA OF CHATGPT

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Enhanced Intelligence
Enhanced Control
Enhanced Automation
Enhanced Connectivity

DIGITAL TWIN

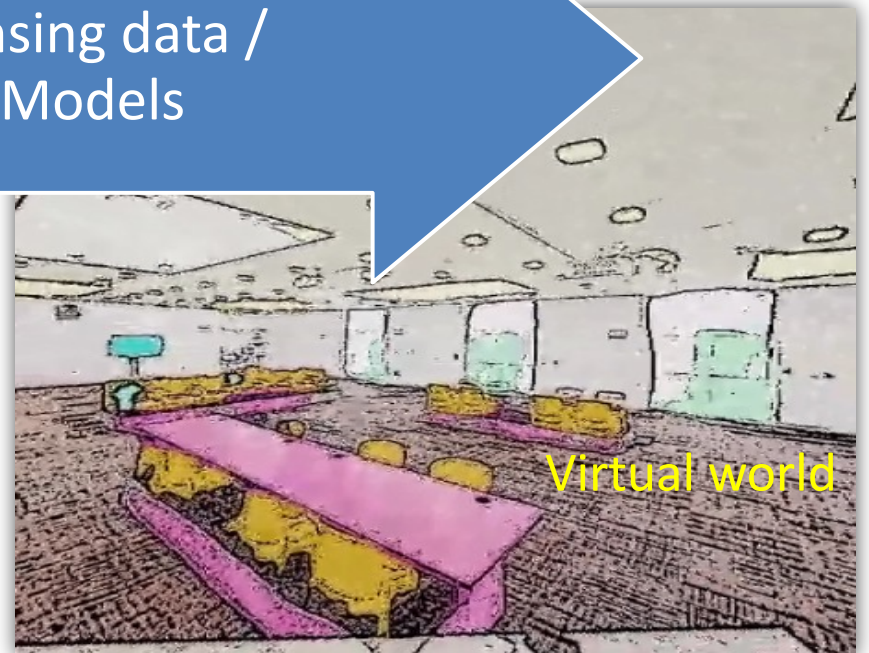
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Inference/Control

Sensing data /
Models

Physical World

Virtual world



SENSING USING COMMUNICATIONS SYSTEMS

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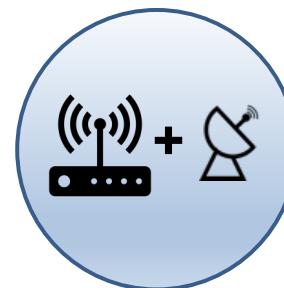
Reduce power consumption and cost.



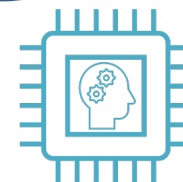
Reuse spectrum and signals



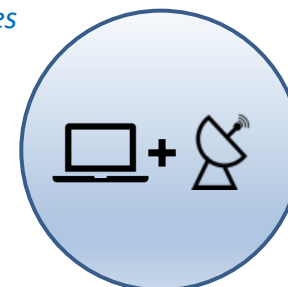
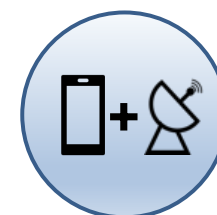
Enable new applications



Wireless sensing is acquiring environmental information using wireless signals



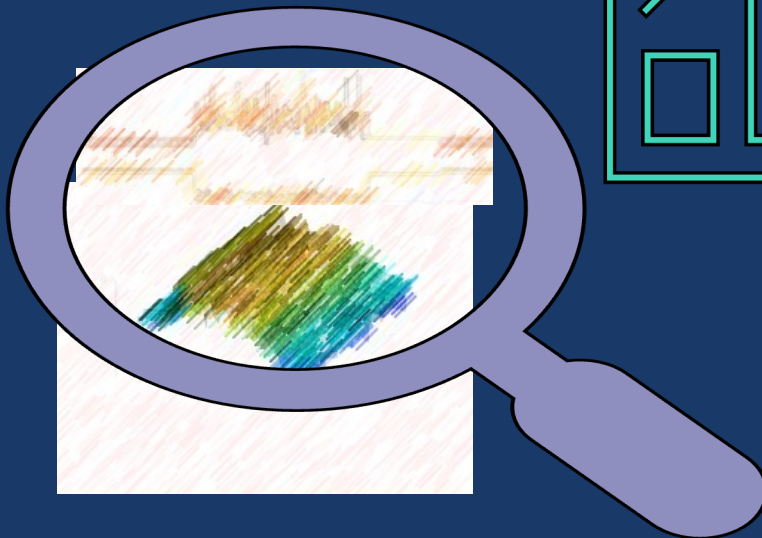
implemented using everyday consumer electronic devices equipped with a radio.



JOINT COMMUNICATIONS AND SENSING

KEY MEASUREMENT CHALLENGES

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RF/Wireless

Propagation models

Signal processing

System Level

Comm. protocol

App. performance

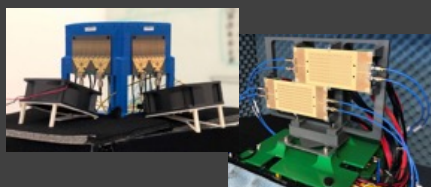
Digital Twin

Multi-dimensional data

ML/Training

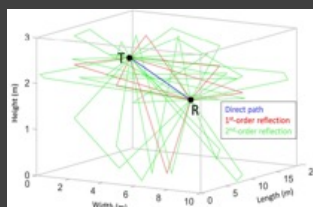
Today's Presentation

Channel Propagation Measurements



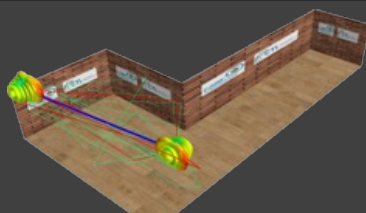
NIST Channel Sounders

Channel Modeling



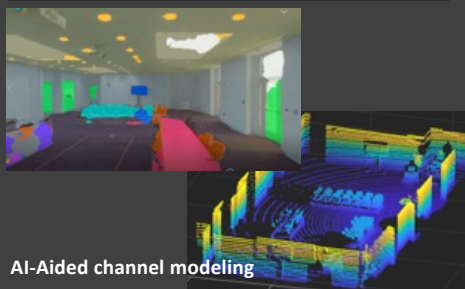
NIST Open-Source mmWave Raytracer based on channel propagation measurements

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



Designing and building measurement instruments



Developing model abstractions for performance evaluation



Using AI/Machine learning

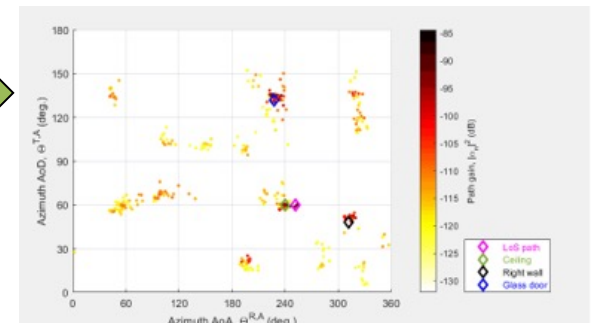
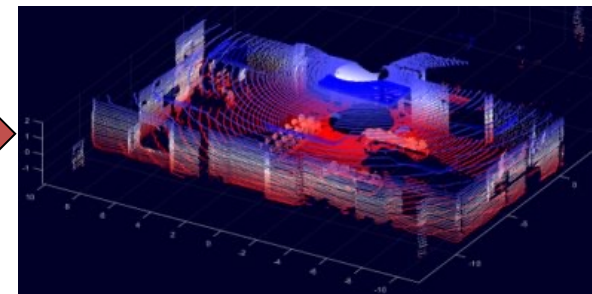
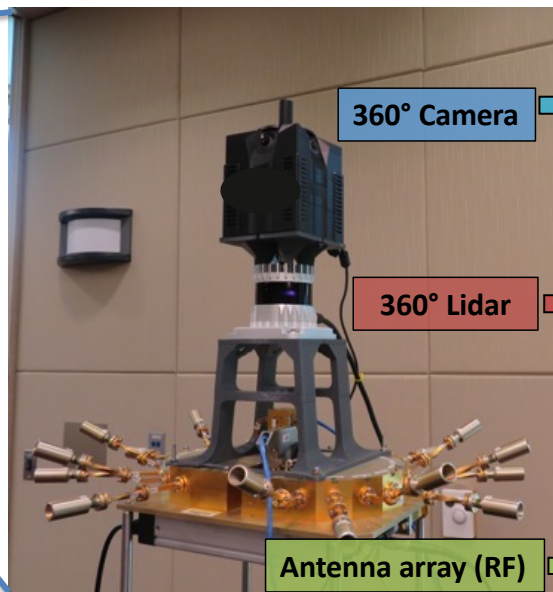
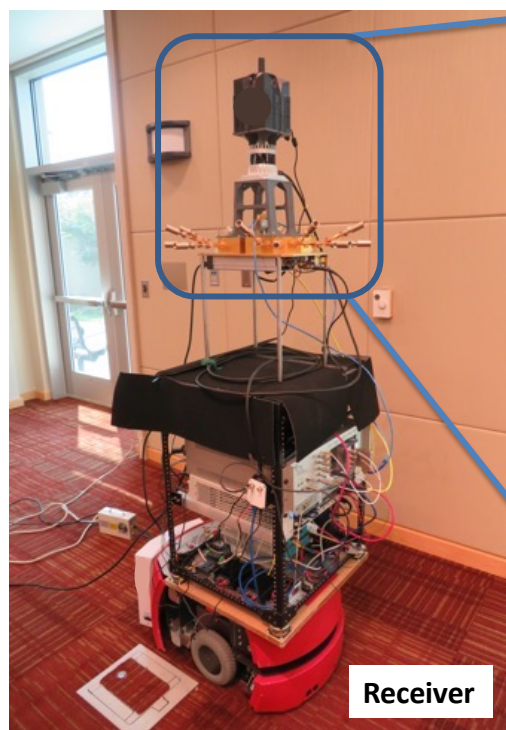


Disseminating models and measurement Datasets

MEASUREMENT SYSTEM

MEASUREMENT SYSTEM

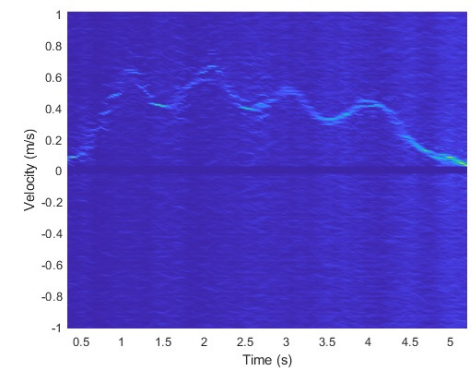
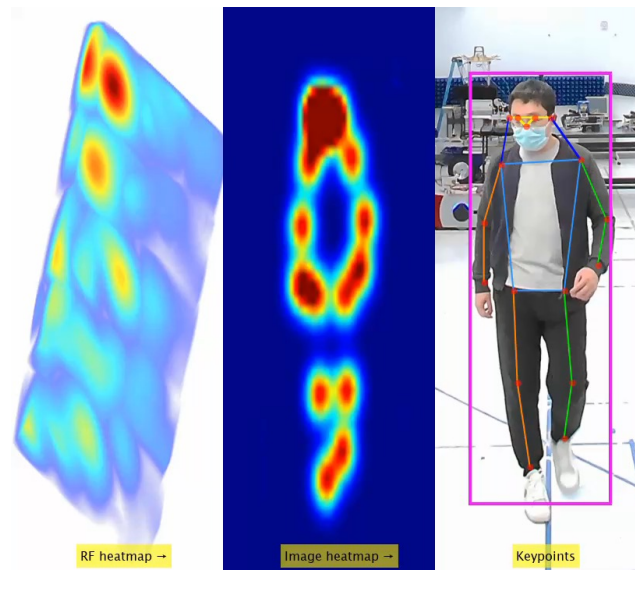
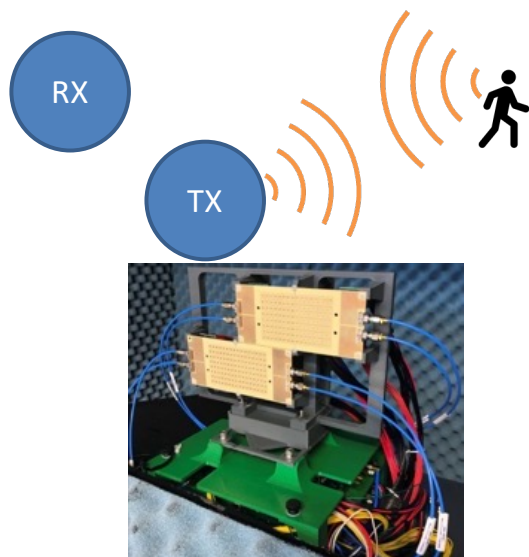
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While in motion, the receiver collected:

- 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

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- **The NIST Q-D Framework**

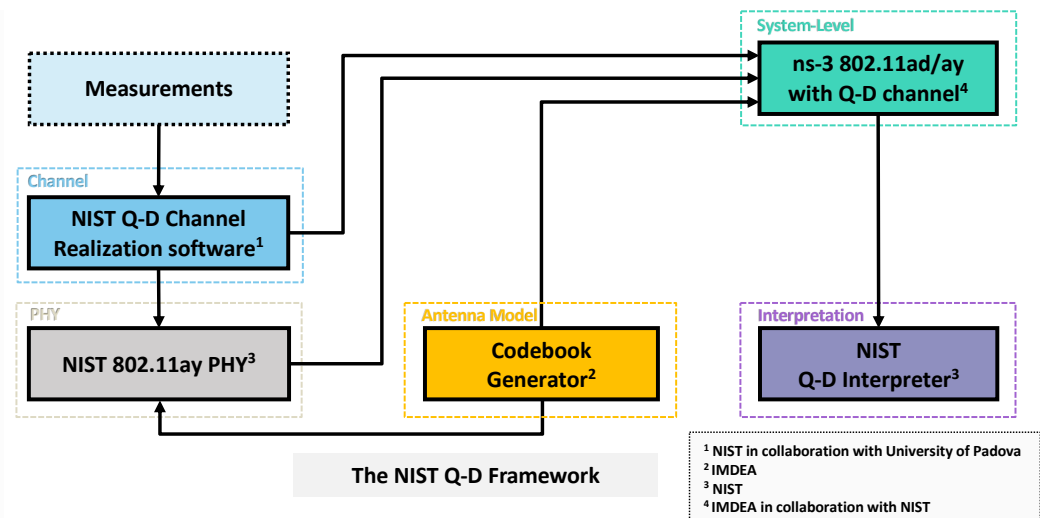
- 5 software packages to evaluate IEEE 802.11ad/ay
- Available at: <https://github.com/wigiq-tools>

- **Various system-level evaluations performed**

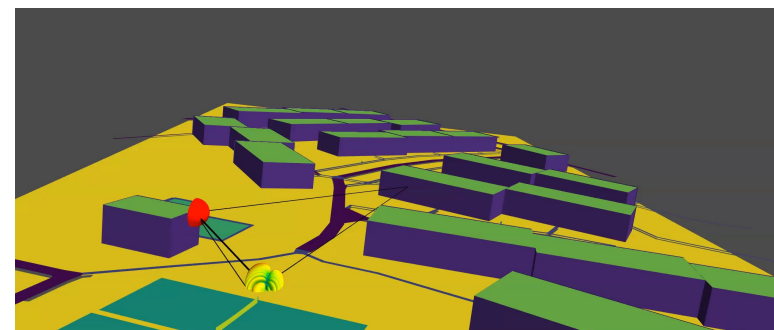
- End-to-End performance [1,2]
- Beamforming/Scheduling [3,4]
- Virtual reality/MIMO [5,6]

- **Many Collaborators**

- University of Padova, IMDEA, NYU, University of Washington
- Intel/Mathworks
- Large number of forks (>60)



- [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 Assasa, Jorg Widmer, "A Link Quality Estimation-based Beamforming Training Protocol for IEEE 802.11ay MU-MIMO Communications" Published in IEEE Transactions on Communications



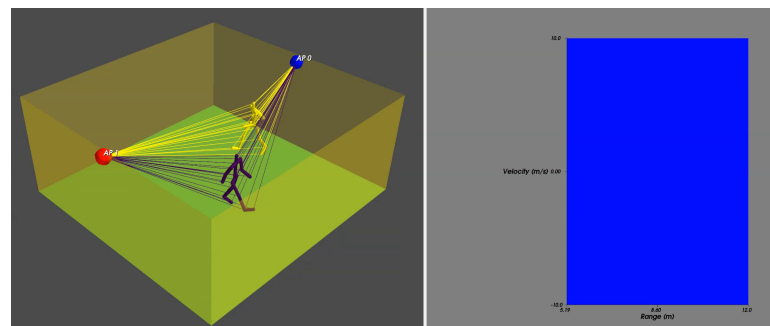
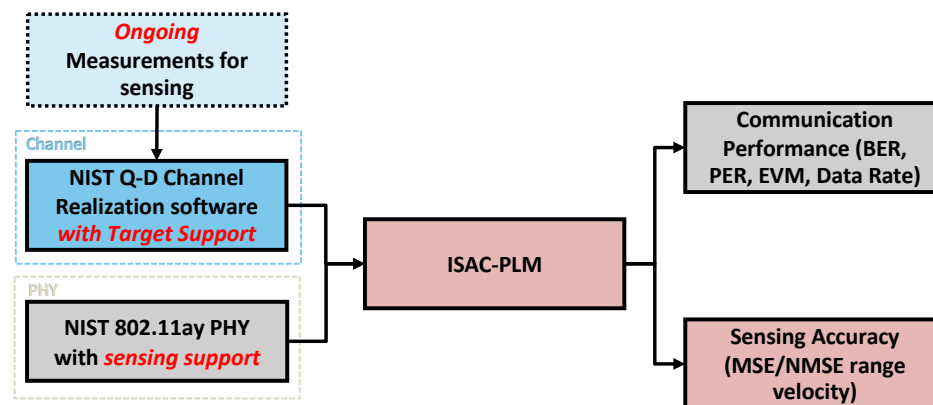
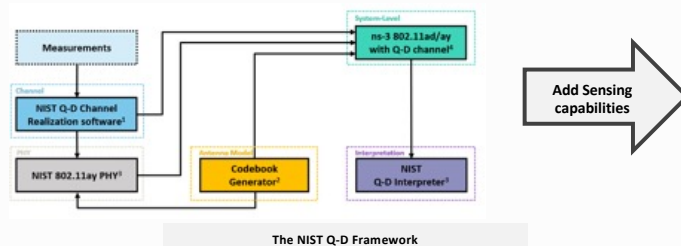
MEASUREMENT-BASED MODELING & TOOLS SUITE

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>



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>

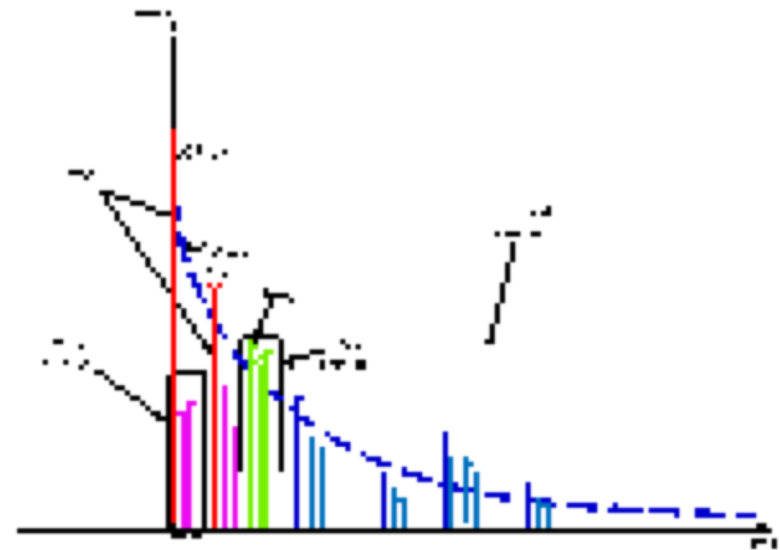
EXTENDING QUASI-DETERMINISTIC CHANNEL MODEL FOR SENSING

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.

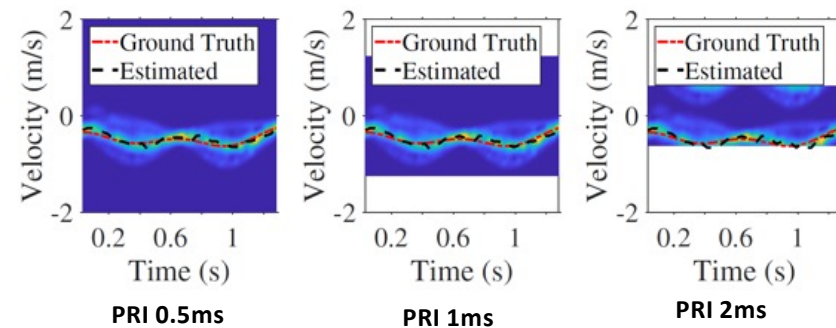
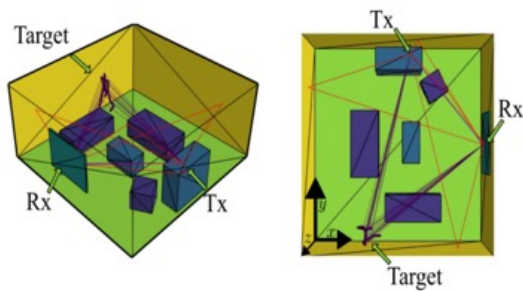
Extended Q-D methodology for Sensing:

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

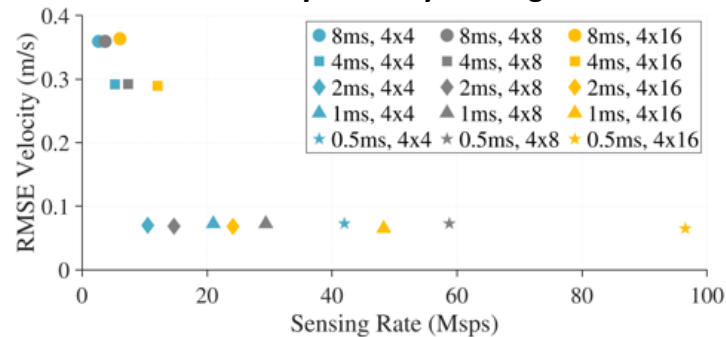


EVALUATION OF IEEE 802.11BF EDMG PHY

Impact of Pulse Repetition Interval on microdoppler and velocity estimation



Trade-off velocity accuracy-sensing rate



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

DATA DISSEMINATION AND COLLABORATIONS

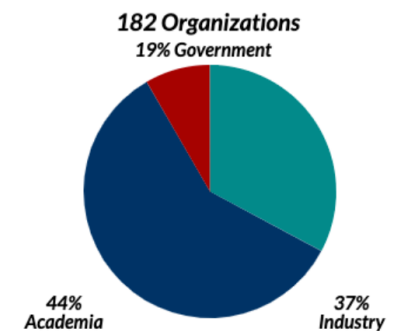
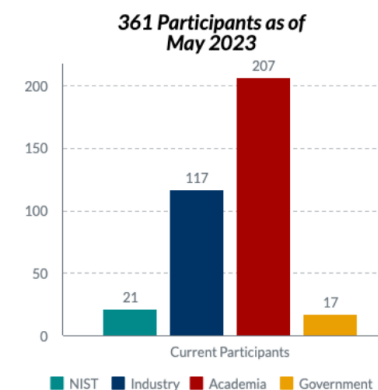
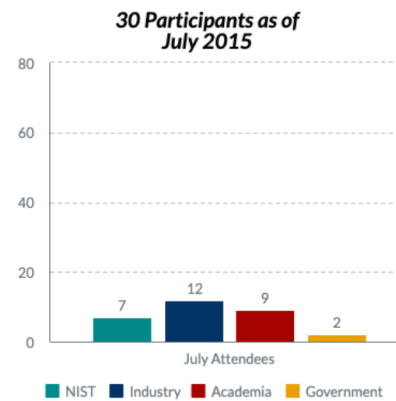
NEXTG CHANNEL MODEL ALLIANCE



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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

NIST



NextG Channel Model Alliance

The NextG Channel Model Alliance will provide a venue to promote fundamental research into measurement, analysis, identification of physical parameters, and statistical representations of mmWave propagation channels. In addition to making available methodology and best practice data, the Alliance will focus on the development of usage scenarios for Indoor, Outdoor and Emerging environments.

In addition, the following visionary goals were identified:

- Refining, improving, and troubleshooting the initial channel models developed by international standards-making bodies.
- Focusing on unaddressed usage scenarios, parameters, frequencies, and architecture.
- Providing a source of continuity for stakeholders involved in different stages in the standards development lifecycle.
- Serving as a liaison to other consortia and international groups.
- Aggregating new and improved channel measurement and modeling methodologies and best practices.

Participation is open to all and no membership fee is required to ensure the broadest participation in the Alliance. Working group meetings are conducted via conference call and Web Experience. Notes and outcomes from working group meetings may be found on the Wiki (link below).

If you are interested in participating in this group or attending future working group meetings, please contact:

- Marc Leh (mleh@corneralliance.com),
- Dr. Nada Golmie (nada.golmie@nist.gov), or
- Dr. Kate Remley (kate.remley@nist.gov).

50 datasets/
6 datasets + models.

Upload/Download

Search

Sharing permission

File Organization

NextG Channel Model Alliance -- 2021 Kickoff Survey

The NextG Channel Model Alliance wants to solicit input from participants to better understand the goals, priorities, and research activities that would provide value to your research. Please complete the survey below to inform the development of work products and discussion topics for upcoming meetings.

Contact Marc Leh (mleh@corneralliance.com) with a

nada.golmie@nist.gov (not shared) [Switch acc](#)

* Required

Name *

Your answer

Organization *

Your answer

Email *

Your answer

Research Targets

How could the NextG Channel Model Alliance provide value modeling activities should this group prioritize in 2021-2022?

Research Targets

How could the NextG Channel Model Alliance provide value to your research? What measurement and modeling activities should this group prioritize in 2021-2022?

Your answer

Current or Planned Research Activities

What topics are you interested in to increase awareness, exchange ideas, and/or collaborate with other participants on your work? What measurement and/or modeling activities do you plan to complete in 2021-2022 (specific frequency bands, environments, use cases that you intend to research)?

Your answer

Datasets to Contribute

What existing measurement, modeling, or other datasets would you be willing to share on the data repository? (link: <https://nextg.nist.gov>)

Your answer

New Data Types, Models, Features

What new scenarios, models, and/or software functionality should we consider implementing in the data repository? (link: <https://nextg.nist.gov>)

Your answer

New Participants

Who could benefit from participating in this working group, mailing list, and data sharing platform? You are welcome to provide contact information for your colleagues if appropriate.

Your answer

28GHz Downtown Boulder Urban Canyon Measurements

NIST 28GHz switched-array Channel Outdoor Measurements taken during the summer time. Measurement MPCs and model objects for Raytracing are included.

Parameter files:

[Environment_Scenario_ParametersList \(28GHz\).docx](#)
[Sounder_ParametersList \(28GHz\).docx](#)

Measurement files:

[NIST 28GHz UrbanCanyon Data.zip](#)

28.0 GHz outdoor

Published: 20 May 2021

Organization: NIST

[Download Zip](#)

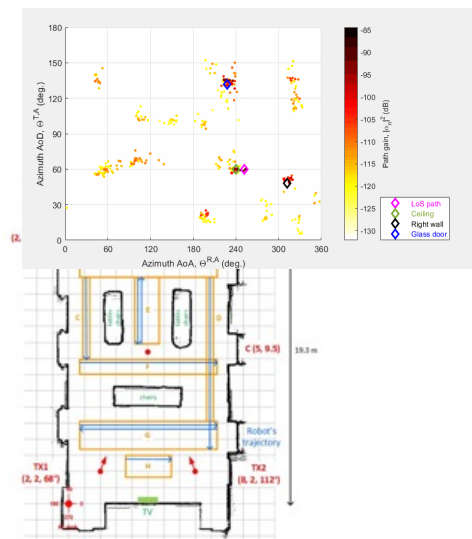
[Hide files](#)

Zip Size: 17.2 MB

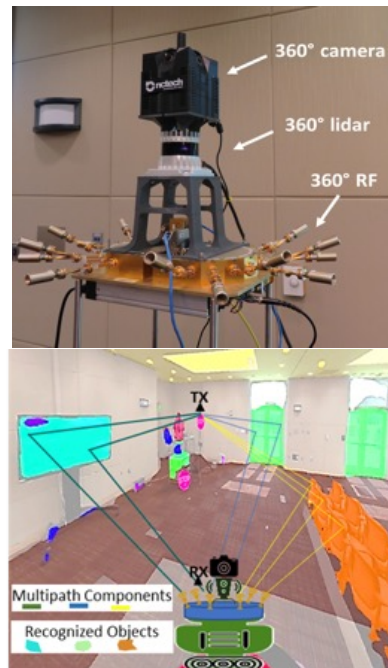
AI-BASED CHANNEL MODELING

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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 *th* 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

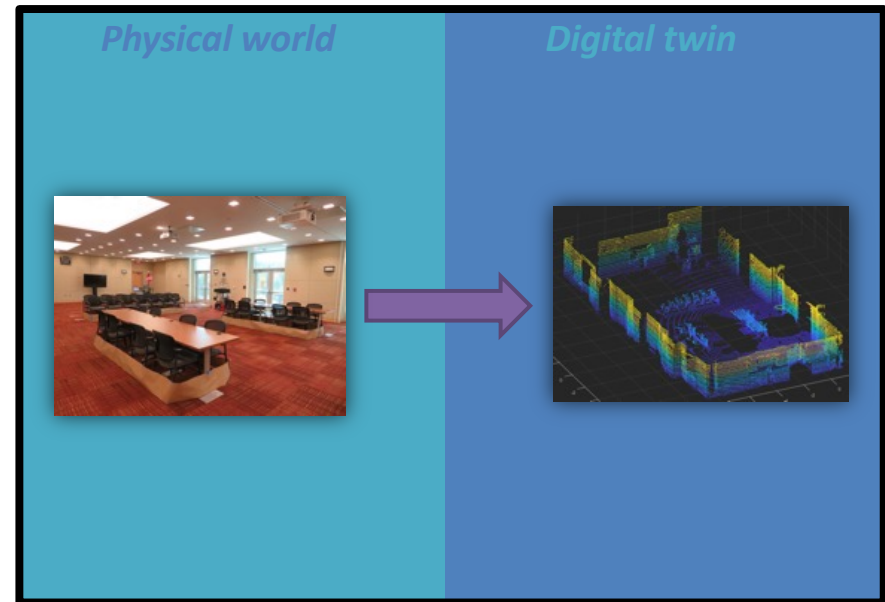
- One fixed transmitter
- One moving (position and orientation) receiver

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.

<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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