5G Millimeter Wave
Channel Model Alliance

NIST
National Institute of
Standards and Technology

Communication Technology Metrology for 5G Innovation

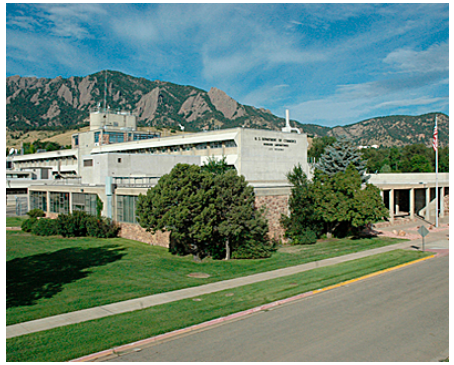
Nada Golmie
Chief, Wireless Networks Division

CTL Communications Technology Laboratory

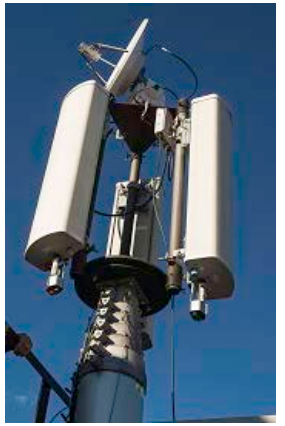
Communication Technology Laboratory
Established in 2014

NIST National Institute of Standards and Technology

Through development of appropriate measurements and standards:



- Enable robust, mission-critical, interoperable **public safety communications**
- Enable effective and efficient **spectrum use and sharing**
- Enable **advanced communications technologies**
  - Identify next generation wireless technology measurement challenges, and develop appropriate measurement science to support innovation.
  - Strengthen spectrum sharing, coexistence, and channel propagation and modeling expertise.
  - Develop measurements to support future generation wireless: massive-MIMO, millimeter wave, ultra-dense networks.
  - Support the development of future generation wireless standards and pre-standards activities.



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Advanced Communications: “5G” Program

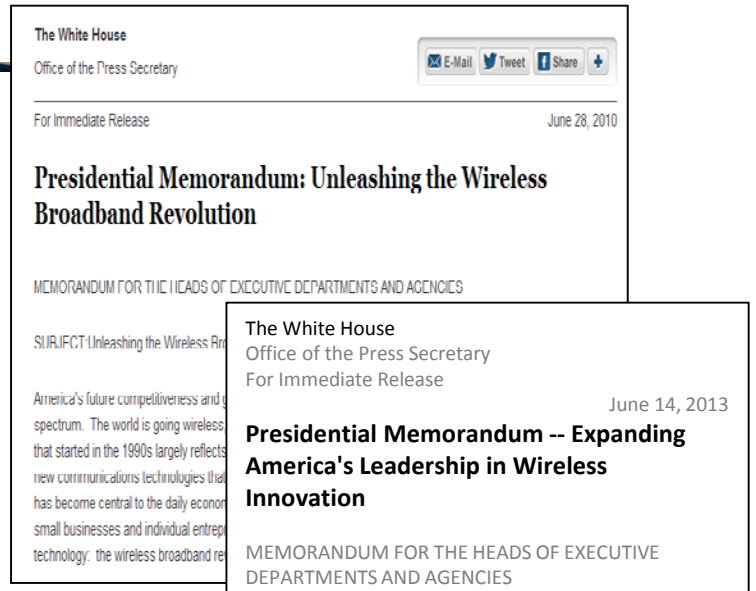
National Institute of Standards and Technology

Technical Thrusts

- **Millimeter wave metrology**
- Ultra-dense networks
- Massive MIMO

Drivers

- Exponential increase in demand for wireless data transmission – massive increases in:
  - capacity >1,000x
  - connectivity (billions of users and machines)
- Top administration priority
- Widely recognized need to develop greater resource efficiencies – including temporal, spectral, coding, and spatial
- Integrated-circuit technology provides components, antennas at millimeter wave frequencies


The White House
Office of the Press Secretary
For Immediate Release
June 28, 2010
Presidential Memorandum: Unleashing the Wireless Broadband Revolution
MEMORANDUM FOR THE HEADS OF EXECUTIVE DEPARTMENTS AND AGENCIES
The White House
Office of the Press Secretary
For Immediate Release
June 14, 2013
Presidential Memorandum -- Expanding America's Leadership in Wireless Innovation
MEMORANDUM FOR THE HEADS OF EXECUTIVE DEPARTMENTS AND AGENCIES

> “This new era in global technology leadership will only happen if there is adequate spectrum available to support the forthcoming myriad of wireless devices, networks, and applications that can drive the new economy.”
>
> –President Barack Obama

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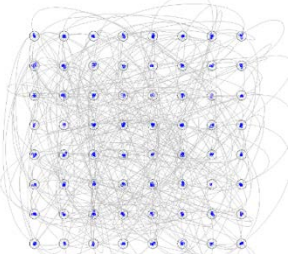
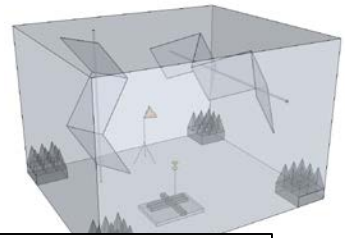
Millimeter Wave Metrology

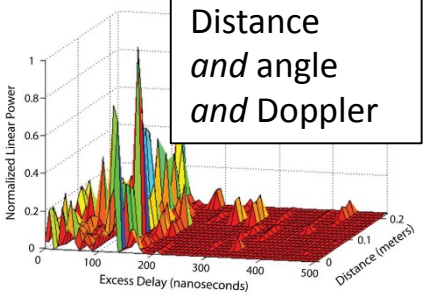
- 5th year of NIST Innovation in Measurement Science program: “Traceability to Enable Giga-bit-per-Second Mobile Wireless.”
- Channel sounders for 83.5, 28, and 60 GHz
- Development of channel propagation models
  - Contributions to SDOs (e.g. IEEE 802.11ay)
  - Calibrations, uncertainties for millimeter wave wideband vector sources and receivers: new IEEE Best Practices document.
  - Over-the-air test of highly integrated millimeter wave devices
  - Nonlinear network analysis of amplifiers, circuit components



1.6% EVM at 45 GHz



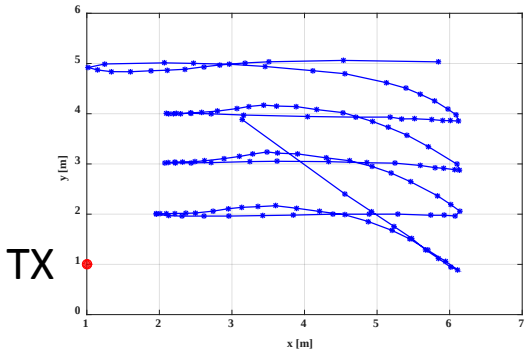
1% uncertainty?



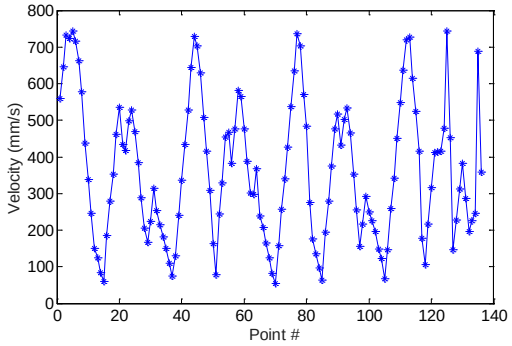
Distance *and* angle *and* Doppler

Unique Channel Sounders

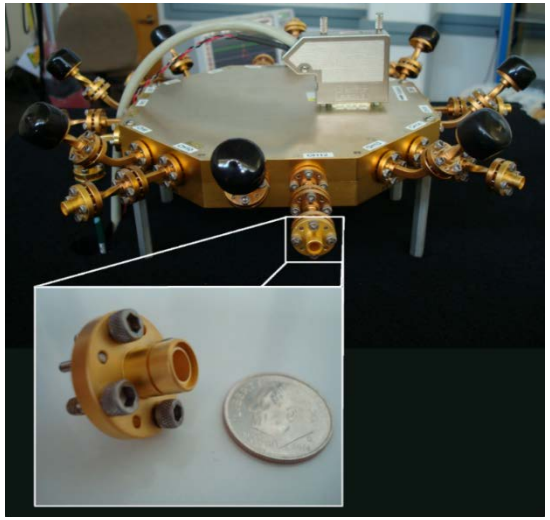
83.5 GHz channel measurements in NIST lab

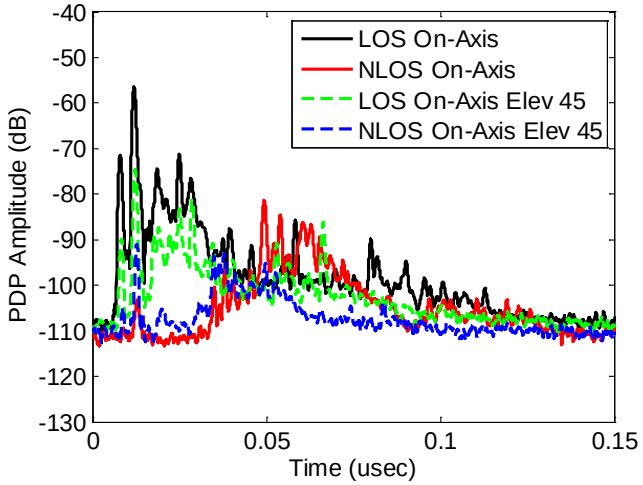


Receive array location



Receive array velocity





Power delay profile: one location

- Fast: electronic switching and direct digitization of 16 scalar feed horn receive antennas
- Mobile: Robotic, laser-guided navigation system
  - Centimeter accuracy (indoor),
  - GPS equipped (outdoor)
- Directional: 45°Angle of arrival resolution over upper hemisphere

Channel Modeling Capabilities

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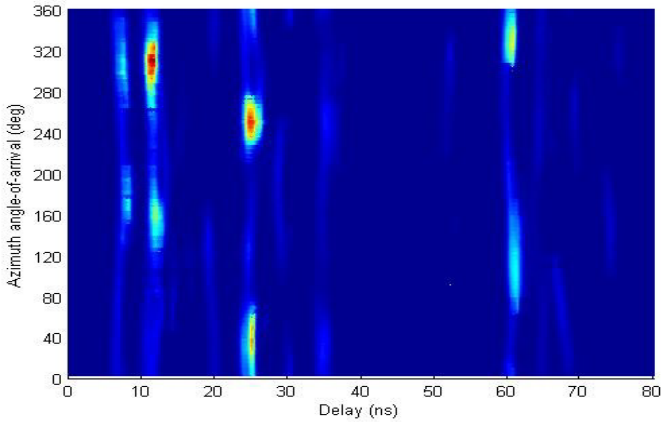
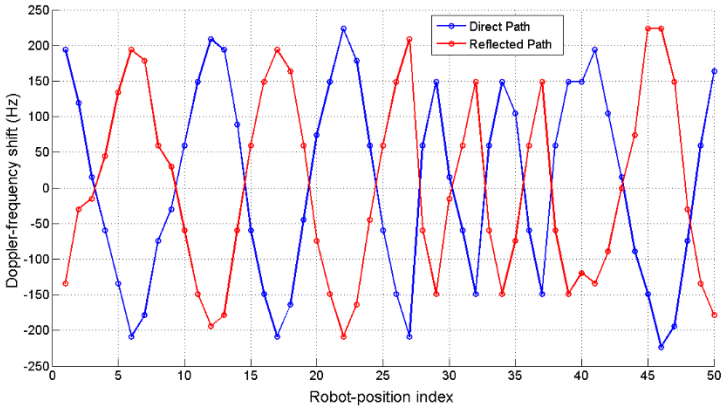
Multidimensional power profiles

- Each path indexed according to delay, azimuth, and elevation
- Enables parameterizing Saleh-Valenzuela-type models
- RMS-delay/angle spread and coherence bandwidth
- Example shown is power vs. azimuth and delay



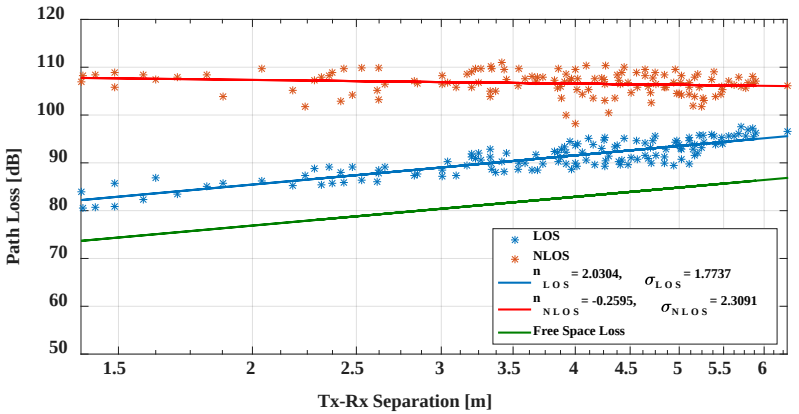


Small-scale fading and Doppler-frequency shift

- Fading distribution (Rayleigh, Rician, etc.) and Doppler-frequency shift computed for each path
- Coherence time computed from Doppler-frequency spread over all paths
- Example confirms that the direct path and the wall-reflected path have opposite Doppler shift

Large-scale path loss and shadowing

- The path loss for each path can be computed separately
- Example shows path loss exponent of direct LOS path is ~2.0



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Response to Industry Need

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Key Causes for Action:

- Industry needs accurate millimeter wave channel models ASAP for standardization and to optimize hardware design for a variety of different usage scenarios and environments.
- Individual research organizations do not have the scale, visibility or resources to characterize millimeter wave propagation across a sufficiently broad spectrum.
- Need for increased partnership and communication between Industry and Academia.
- Lack of understanding of current millimeter wave research efforts and need for improved coordination.

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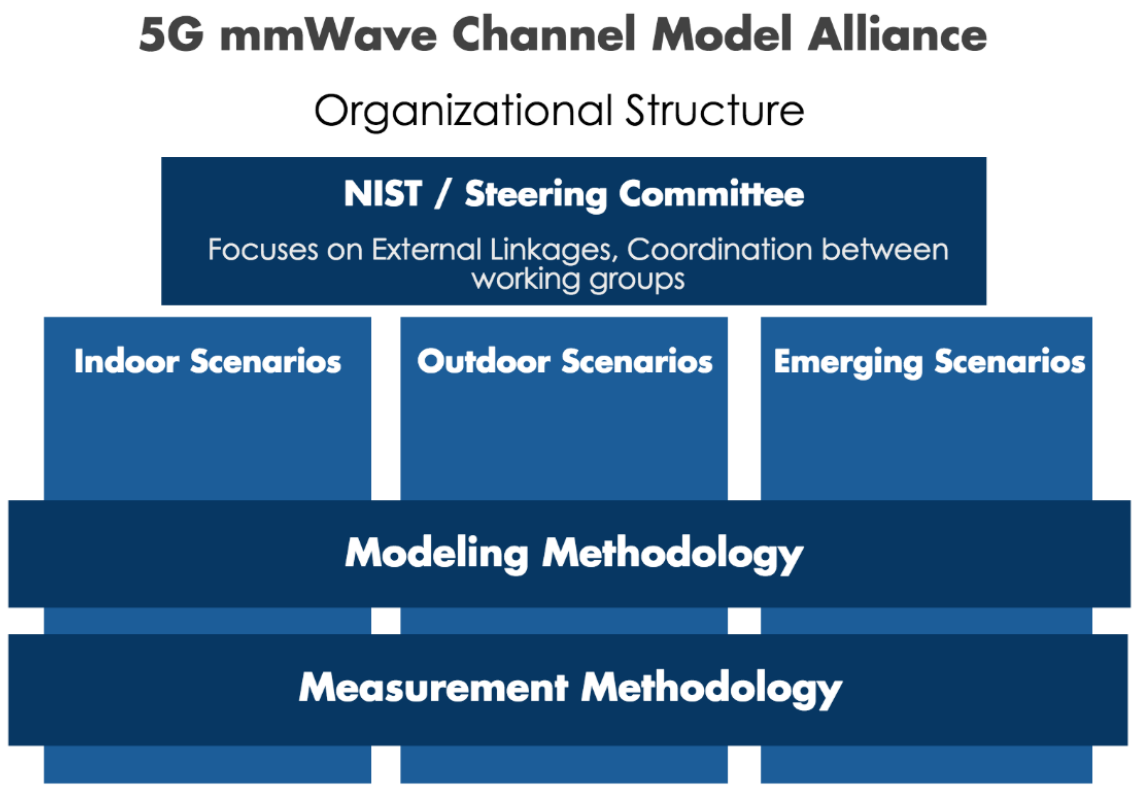
NIST/CTL Establishes 5G Millimeter Wave Channel Model Alliance

- NIST convened Alliance's first meeting in July 2015, in Boulder, to define charter, organizational structure, and develop plans for working group activities.



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5G Millimeter Wave Channel Model Alliance

Motivation

There is an industry and research community need for accurately characterizing the mmWave bands above 6 GHz. While there are many groups currently working on 5G channel measurements and modeling (e.g. METIS2020, COST2004, 5G Channel Model SIG, IEEE 802.11ad/802, ETSI mmWave SIG, NYU Wireless), many of these efforts are focused on developing channel models for specific wireless systems and may be short-lived or adapted once initial standards are put in place.

In response to this need, the U.S. National Institute of Standards and Technology (NIST) has offered to coordinate a 5G mmWave Channel Model Alliance of companies, academia, and government organizations to support the development of more accurate, consistent, and predictive channel models.

To facilitate the formation of this Alliance, NIST plans to convene a kick-off meeting in the late June, early July 2015 timeframe. The meeting will take place in the NIST Labs in Boulder, Colorado. The purpose of this kickoff meeting is to bring together interested parties to discuss the present state of channel sounding and modeling and to develop with the group more detailed plans for the Alliance activities, charter, and organization.

Organization Vision

The 5G mmWave Channel Model Alliance would 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 the new measurement data, it is envisioned that the alliance would focus on the development of usage scenarios, measurement techniques, and methods for reducing data to channel models.

Participation will be open to all and no membership fee would be required to ensure the broadest participation in the Alliance.

- NIST would coordinate larger face-to-face meetings held every few months (quarterly or bi-annually) to allow rapid identification and resolution of key issues related to mmWave channel modeling.
- NIST would provide a data repository where processed data would be available to all members.
- The envisioned outputs and deliverables for this effort include:
  - Raw data measurements
  - Measurement techniques
  - Channel modeling techniques
  - Improved, comprehensive, predictive channel models that can be fed to standards organizations (for example, 3GPP, IEEE 802) for the development of future mmWave wireless communication systems.

Contact Information

Dr. Nada Golmie
Chief
Wireless Networks Division, NIST,
301-975-4190
nada.golmie@nist.gov

Dr. Kate Remley
Lead
Metrology for Wireless Systems Project, NIST
303-497-3652
kate.remley@nist.gov

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Organizational Expectations

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Transparency:

- The Alliance openly publishes its mission, research activities, data, and work products
- Participation is open to the public

Flexibility:

- No formal membership, fees, binding contracts or legal agreements
- Participation is entirely voluntary

Open Data Sharing:

- Participants are encouraged to share non-sensitive information with fellow working group members
- Success of the Alliance depends on efficient, coordinated exchange of measurement and modeling data and methodologies

Member Discretion:

- Participants are not forced to share data is considered intellectual property under copyright

Connection to Other Efforts:

- Alliance research is not tied to a single wireless system, device, or organization:
  - *Broad scope provides in-depth, extensible understanding of millimeter wave propagation mechanisms*
  - *Aggregation of data from multiple sounders: more comprehensive view, more predictive models*

Developing Consensus:

- Group is not used to provide consensus advice or recommendations to NIST or SDOs

Opportunity for Partnership:

- Alliance to leverage industry conferences to publicize work, solicit additional input, and host meetings

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Less than a year later…

- Established user community

  5G Alliance Wiki Link:

  https://sites.google.com/a/corneralliance.com/5g-mmwave-channel-model-alliance-wiki/home

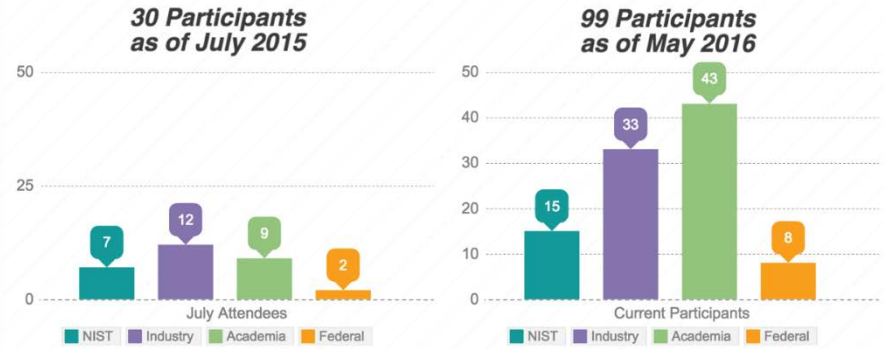
- Alliance organizing two workshops co-located with IEEE VTC, September 2016 in Montreal Canada, and IEEE Globecom, December 2016 Washington DC.

- Repository of data measurements and models coming online soon
  - *NIST to host through web services*

5G mmWave Channel Model Alliance

Below are some of the highlights of the 5G mmWave Channel Model Alliance since its kickoff meeting July 7-8, 2015 at the NIST Campus in Boulder, CO.

Increase in Participants



Organizations Represented

Industry

1. Alcatel-Lucent
2. Anite
3. AT&T
4. Cable Labs
5. Echostar
6. Huawei Technologies
7. Huawei Canada
8. Intel
9. InterDigital
10. Keysight
11. National Instruments
12. Nokia
13. octoScope
14. Qualcomm
15. Rohde & Schwarz
16. Samsung
17. Siradel
18. IEEE

Academia

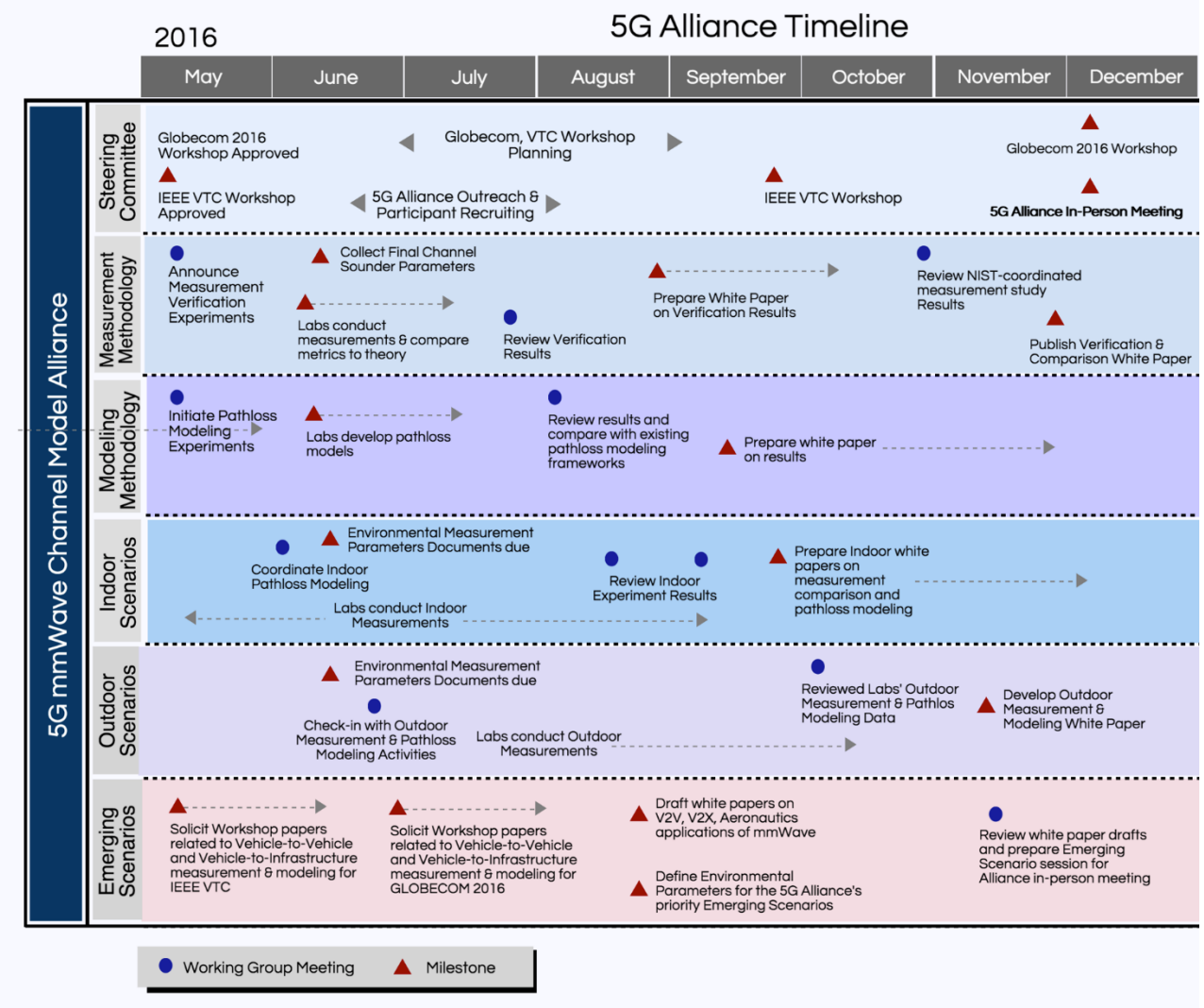
19. Beijing Jiaotong Univ
20. Boise State
21. Florida International Univ
22. Fraunhofer HHI
23. Georgia Tech
24. Michigan Tech
25. National Institute of Metrology, China
26. New Jersey Institute of Technology
27. NYU Wireless
28. Penn State
29. Polytechnic University of Leiria (Portugal)
30. Pontifical University of Rio de Janeiro
31. Portland State
32. Stanford University
33. TU Ilmenau
34. Tufts University
35. University at Buffalo
36. University of British Columbia
37. UC Berkeley
38. UC Irvine
39. UC San Diego
40. UC Santa Barbara
41. University of Chicago
42. University of Colorado
43. University of Durham (UK)
44. Univ of South Carolina
45. Univ of Southern California
46. UT Austin
47. University of Vermont
48. University of Wisconsin

Federal

49. DARPA
50. FCC
51. NSF
52. NIST
53. NTIA

Short-Term Milestones

- Select a limited number of usage scenarios:
  - *Frequencies*
  - *Environments*
  - *Parameters and metrics*
- Conduct measurements in canonical environments for hardware verification
- Develop modeling framework
- Conduct parallel measurement campaigns
- Produce initial models based on data from multiple channel sounders
  - *Submit to standards groups*
  - *Publish in the open literature*



NIST's Contributions

- Contribute measurement data and models
- Support and coordinate working groups
  - *Establish methods for joint use of data*
  - *Develop efficient data reduction techniques*
  - *Aggregate data from different channel sounders into sophisticated new models*
- Facilitate open communication
  - *Run meetings and virtual collaboration platform*
  - *Publish data, methodologies, papers and models*

Cost of NIST Support Role

- Burden on NIST technical staff
  - *Involvement in Alliance activities represents 30~40% of total labor dedicated to project*
  - *Time spent on organization and coordination is time away from lab experiments and results*
- Service contract to assist in working group facilitation/coordination
- Monthly fees and service contract to host online data repository

Going Forward – Long Term

- Establish common methods for hardware calibration and measurement with uncertainties:
  - *IEEE Guidance / Best Practice Document*
- Improved accuracy of channel models:
  - *Spatial multiplexing and/or massive MIMO*
  - *Mobility & dynamic environments*
  - *Device-to-device models*
- Methods to predict system performance
  - *Refine models selected by standards bodies, if necessary*
  - *Refine models for hardware deployment*