Millimeter-Wave Wireless: The "Other" Type of Spectrum Sharing

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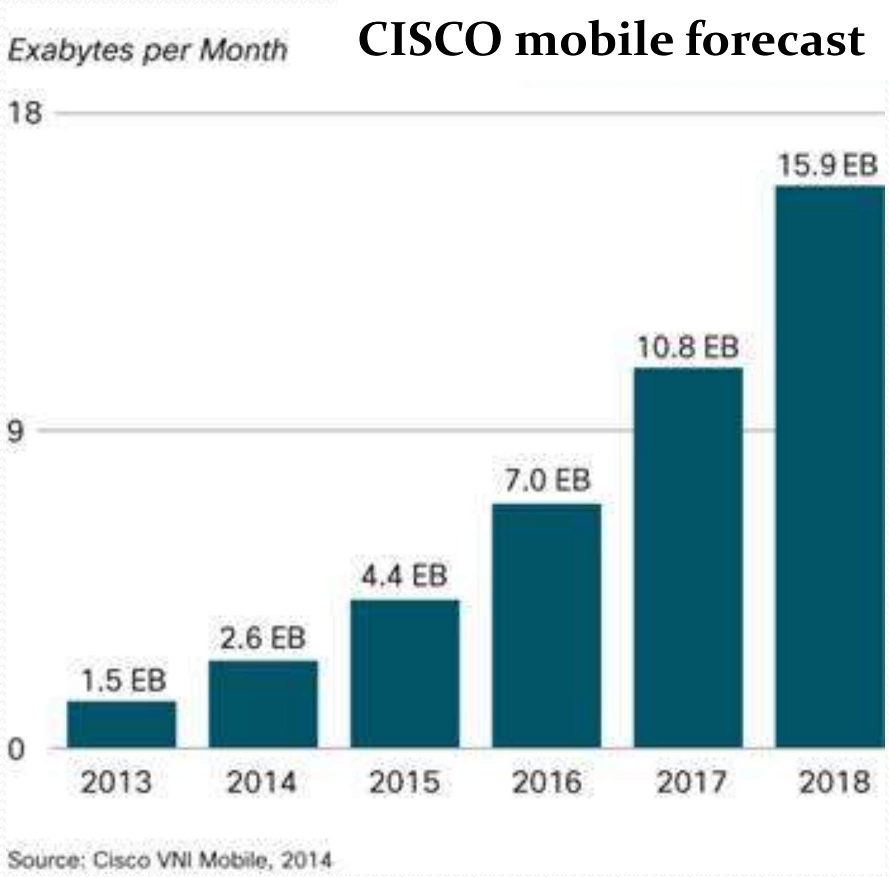
The spectrum crunch and mobile wireless



- Mobile devices and connections in 2013 grew to 7 billion with smartphones representing 95% of total global handset traffic.
- By the end of 2014, there will be more mobile-connected devices on earth than there are people.
- Globally, 45 percent of total mobile data traffic was offloaded onto the fixed network through Wi-Fi or femtocell in 2013.

Source: Cisco 2013-2018 Global Mobile Data Traffic Forecast, Feb. 2014

What could we do with unlimited spectrum?

Situational awareness

Entertainment

Public safety

Machine to machine

Robust infrastructure

Telemedicine

Media and Social Media

Things we never imagined.

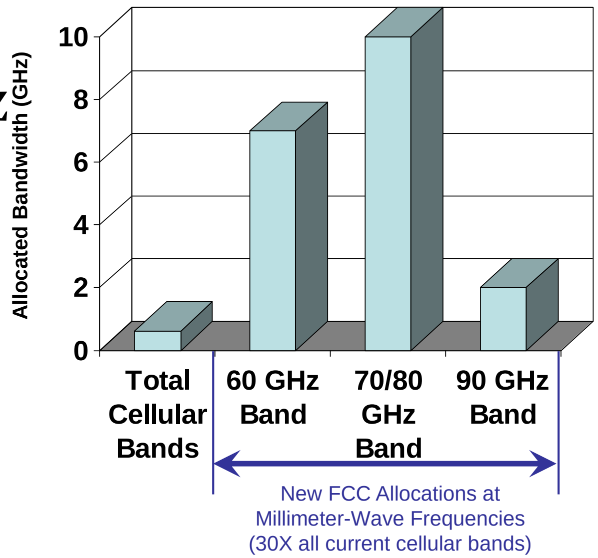
Why mmWave? Alignment of critical factors

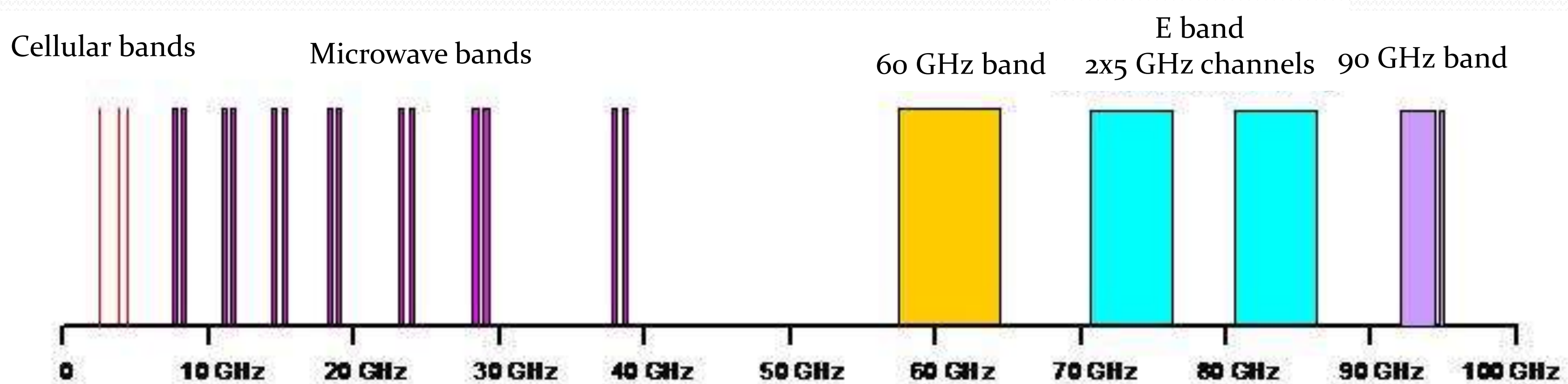
- Regulatory
  - E-Band millimeter-wave spectrum relatively open, may become available
- Technology
  - Silicon devices now have adequate speed for integrated antennas, transmitters and receivers
- National need
  - Mobile broadband network
  - Top administration priority
  - Telecommunications: Economic driver

> "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

Lots of spectrum is potentially available

- Fixed Microwave Service bands at 26-29 GHz (LMDS) and 38-40 GHz
- The V-band at 57-64 GHz (802.11ad, high oxygen absorption)
- The E- and W-Bands represent thirty times our current cell-phone bandwidth at millimeter waves





A new day for millimeter waves

World-wide interest in “5G” communications at mm-wave frequencies

5G PPP

5G Forum
Korean 5G will lead the globe

National Science Foundation
WHERE DISCOVERIES BEGIN

METIS

IMT-2020
(5G) Promotion Group

NYU WIRELESS

Oct. 17, 2014: The FCC voted to issue a Notice of Inquiry to “explore innovative developments in the use of spectrum above 24 GHz for mobile wireless services, and how the Commission can facilitate the development and deployment of those technologies.”

Can millimeter-waves be used for mobile communications?

- Many in the global community think so. Doubters need proof.

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Millimeter Wave Mobile Communications for 5G Cellular: It Will Work!

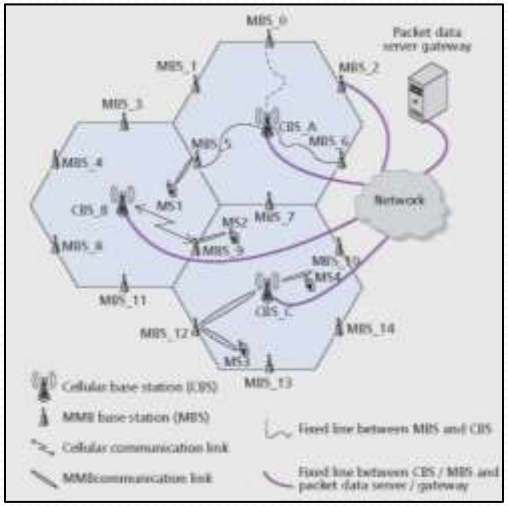
THEODORE S. RAPPAPORT[1], SHU SUN[1], RIMMA MAYZUS[1], HANG ZHAO[1], YANIV AZAR[1], KEVIN WANG[1], GEORGE N. WONG[1], JOCELYN K. SCHULZ[1], MATHEW SAMIMI[1], AND FELIX GUTIERREZ[1]
[1]NYU WIRELESS, Polytechnic Institute of New York University, New York, NY 11201, USA

Topics in Radio Communications

An Introduction to Millimeter-Wave Mobile Broadband Systems

Zhouyue Pi and Farooq Khan, Samsung Electronics

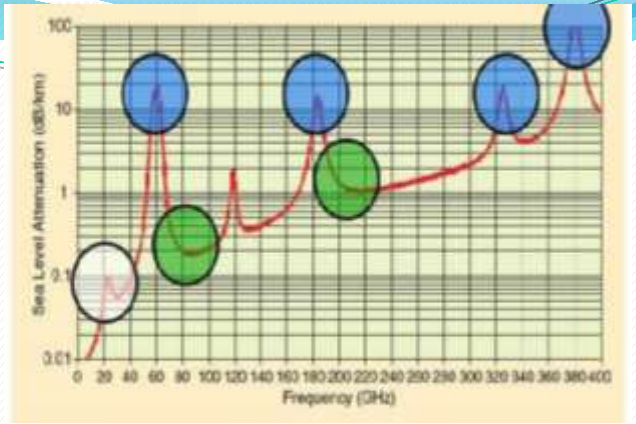
IEEE Communications Magazine • June 2011



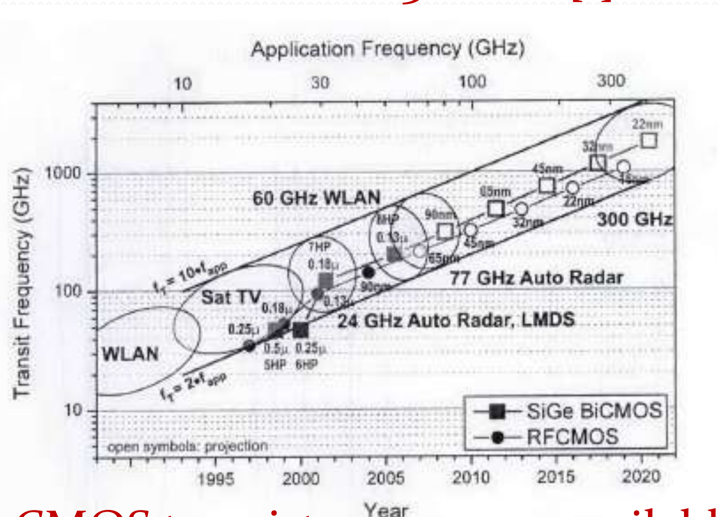
Samsung's vision of a 30 GHz "cell phone" system

Technical enablers

- Free-space path loss is not critical for <1 km
  - Well-suited for cellular and mesh-networked architectures
- Transistor speed
  - US microwave industry still the world leader; this helps the US exploit its cutting edge
- Short wavelengths enable active agile antennas



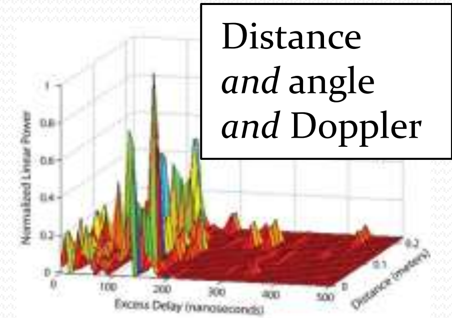
The attenuation caused by atmospheric absorption is less than 0.02 dB over 200 m at 28 GHz and 38 GHz [1].



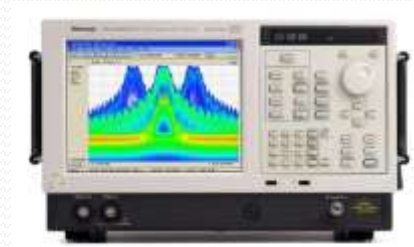
CMOS transistors are now available at frequencies over 77 GHz

[1] T. S. Rappaport, J. N. Murdock, and F. Gutierrez, ``State of the art in 60 GHz integrated circuits & systems for wireless communications,'' *Proc. IEEE*, vol. 99, no. 8, pp. 13901436, Aug. 2011.

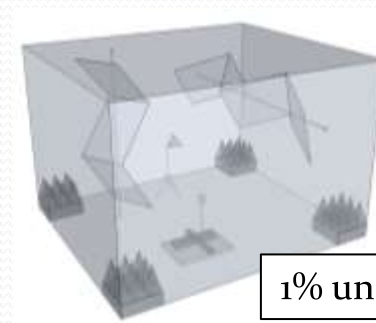
NIST Role: Metrology for an industry that does not yet exist…



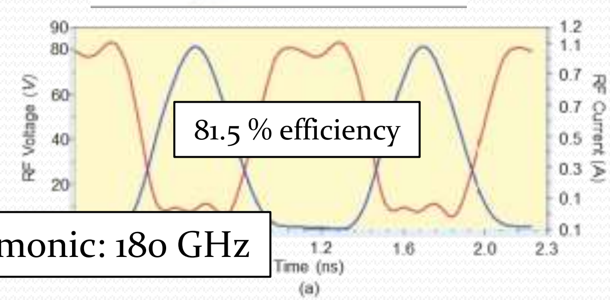
Today's issues will likely arise in the future – but solutions will be harder



- Hardware calibrations and traceability:
  Complex modulated signals
- Propagation channel models:
  Hardware and standards development

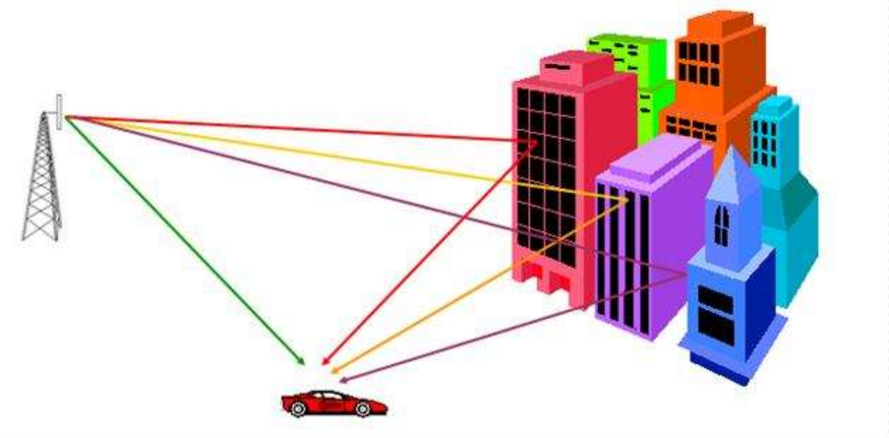


- Free-field test methods:
  Devices with integrated antennas
- Large-signal network analysis:
  Nonlinear transistor operation for increased efficiency



Technical Challenge: RF Channel Characteristics

- Mm-wave: unknown propagation conditions
- Industry needs to decide on system requirements
- What kind of services can be provided?



Measurement Solution:

- Channel measurements with fast, accurate channel sounder
- New channel models to support standards development
- Communication Protocols: what is best for mm-wave?

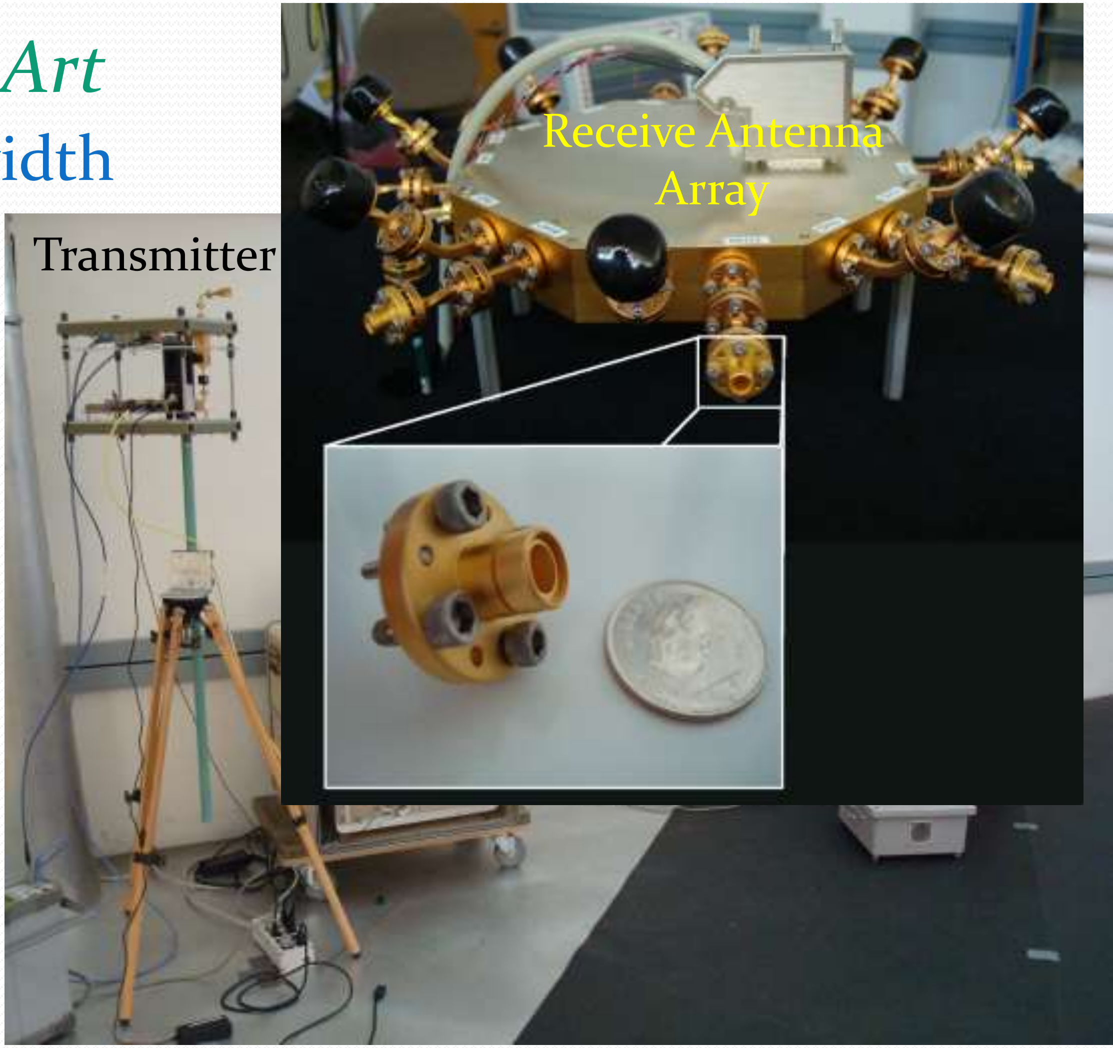
Impairments anticipated:

- Loss: little penetration
- Reflections: angle of arrival for active antennas
- Doppler: even at pedestrian speeds

83.5 GHz Channel Sounder for Mobile Wireless

Extends the State of the Art

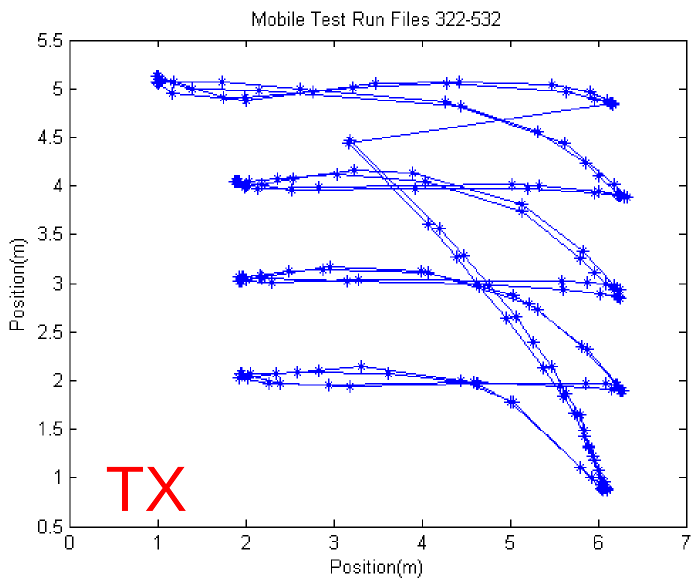
- 1 GHz modulation bandwidth
- Mobile positioning (automated, repeatable)
- Fast: electronic switching direct digitization
- 16 receive antennas



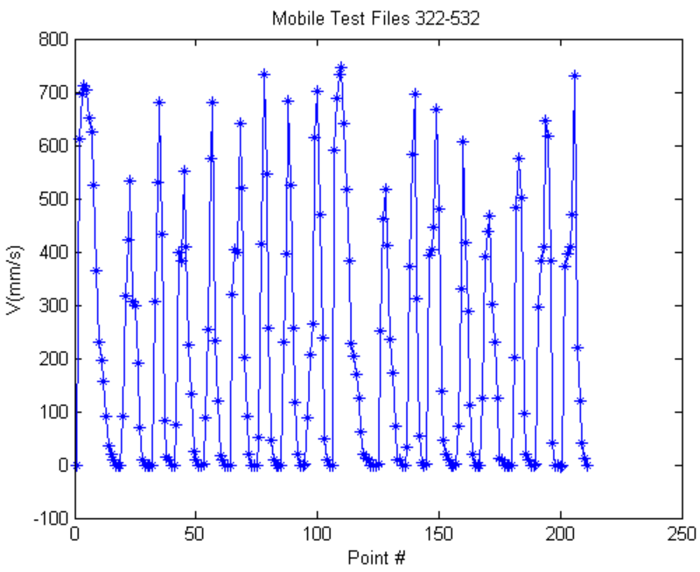
- 28 GHz and 60 GHz systems in progress

Wireless Industry Requirements (1)

- Mobile and untethered for channel statistics and Doppler



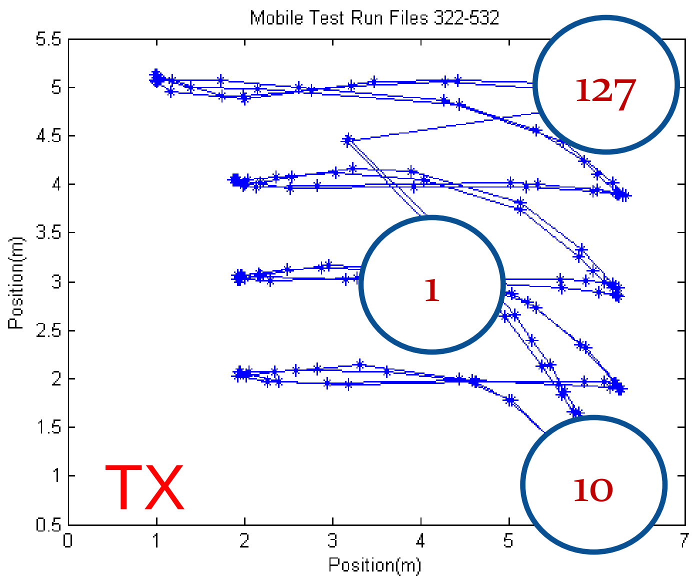
Robot zig-zag pattern in open lab space: repeatable.



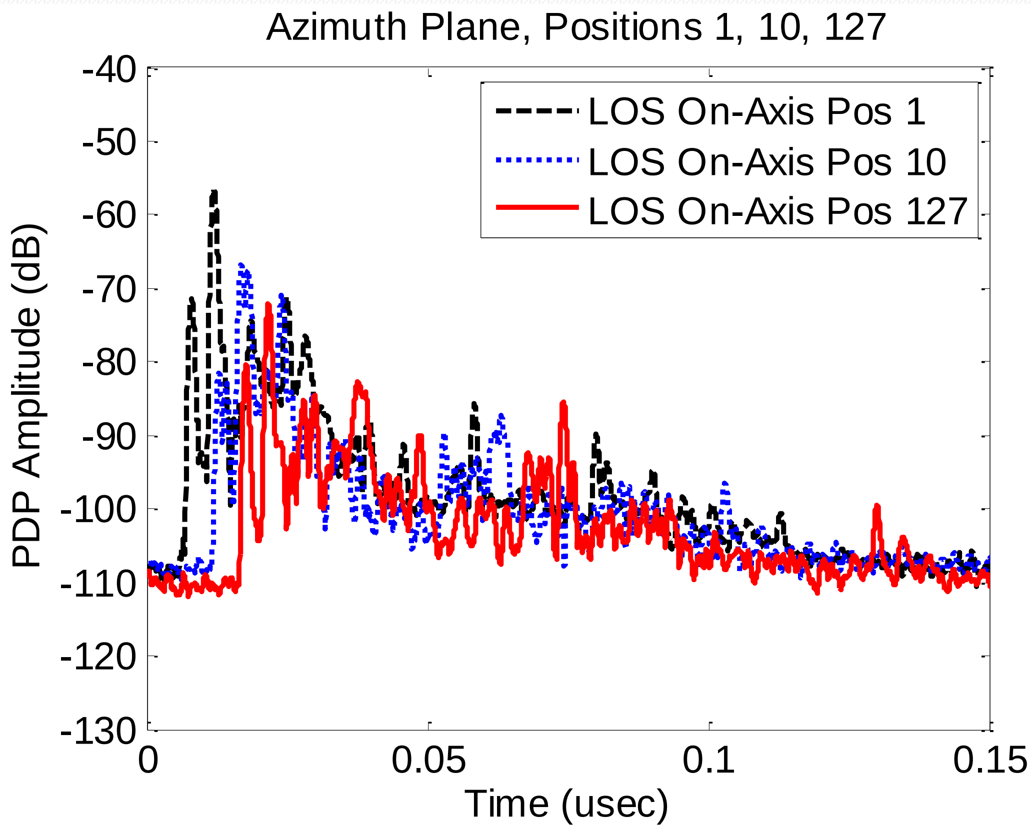
Velocity measured for Doppler

Wireless Industry Requirements (2)

- Calibrated power and time-delay data for channel statistics



Measurements at three robot locations

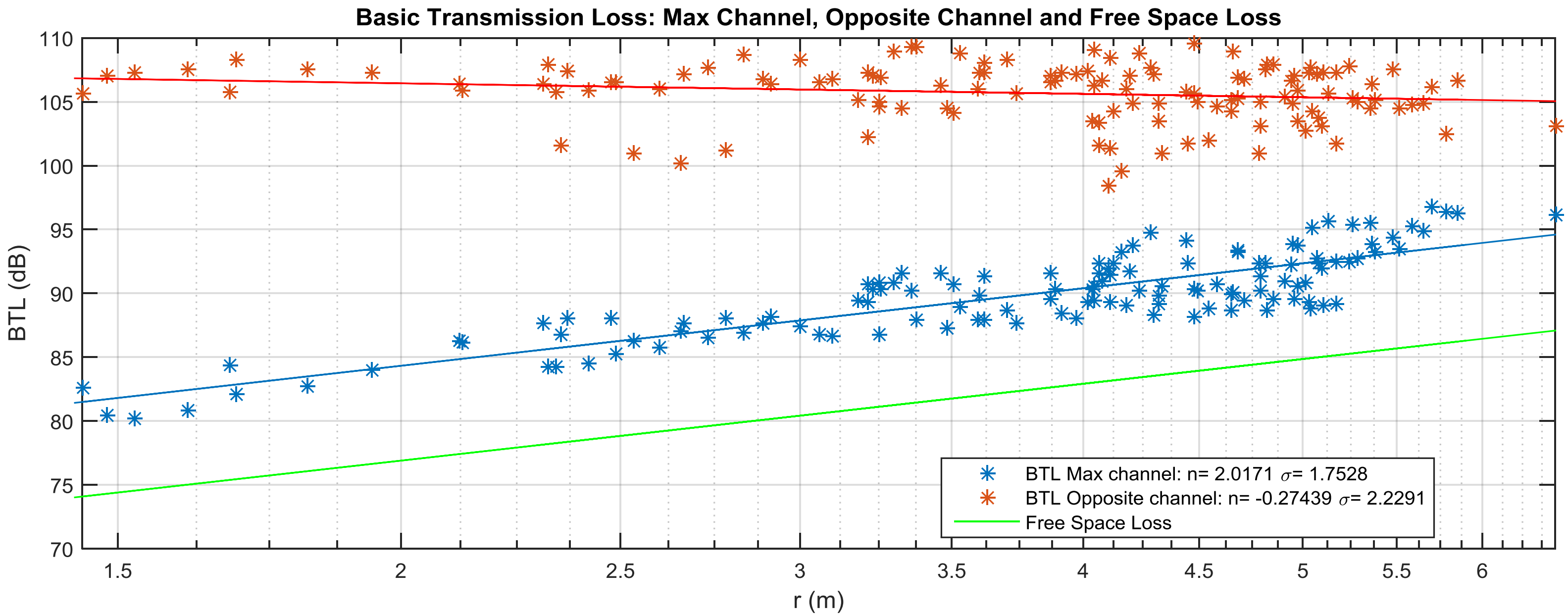


As distance between TX and RX increases:

- Time delay gets longer
- Power gets lower

Wireless Industry Requirement (3)

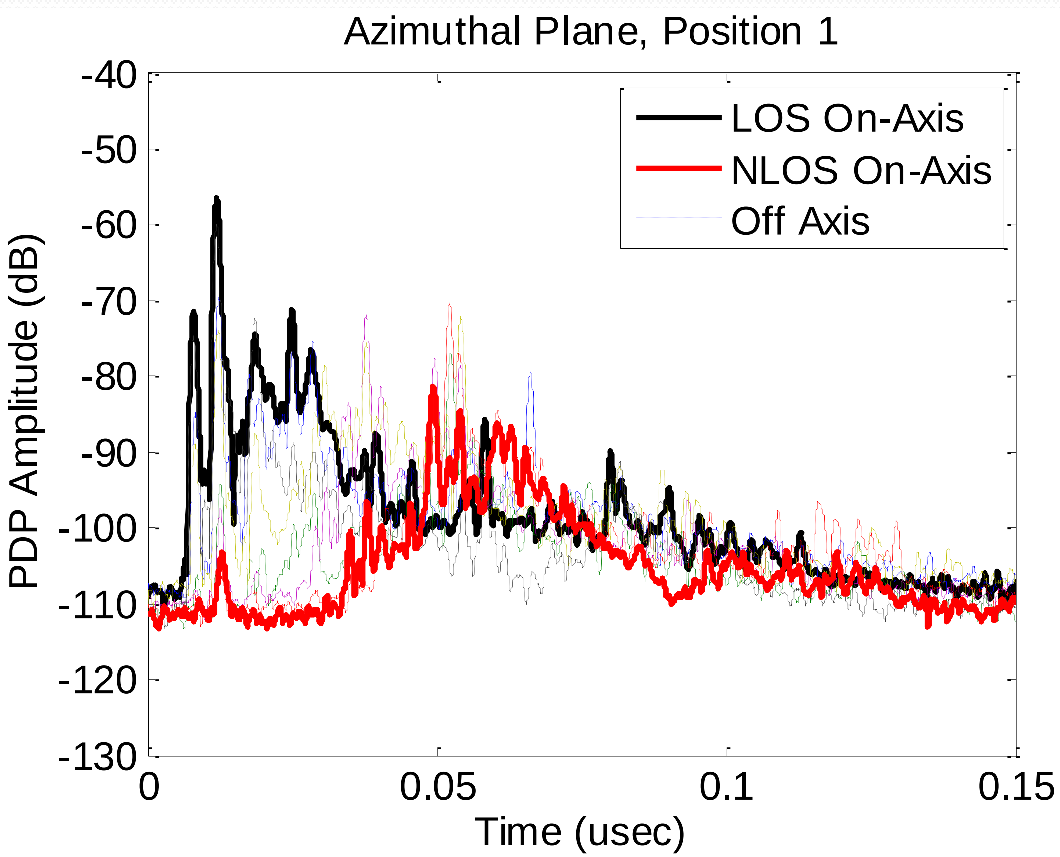
- Fast acquisition for statistics of direct and reflected signals
- No. of independent channels for MIMO

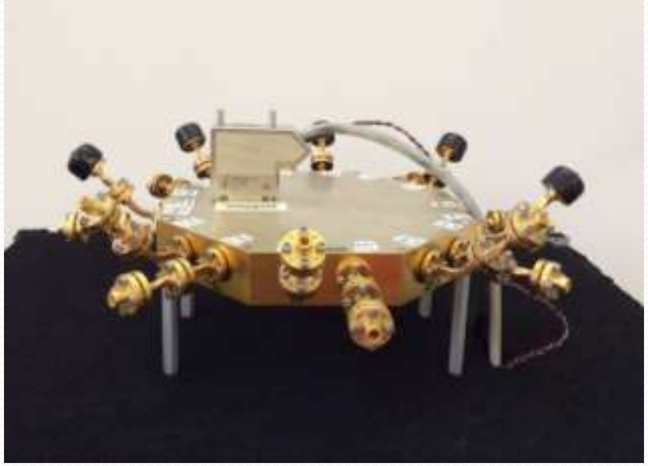


- LOS signals approximately free space (n=2.02)
- NLOS signals approximately constant across space

Wireless Industry Requirement (4)

- Angle of arrival: needed for directional antenna arrays

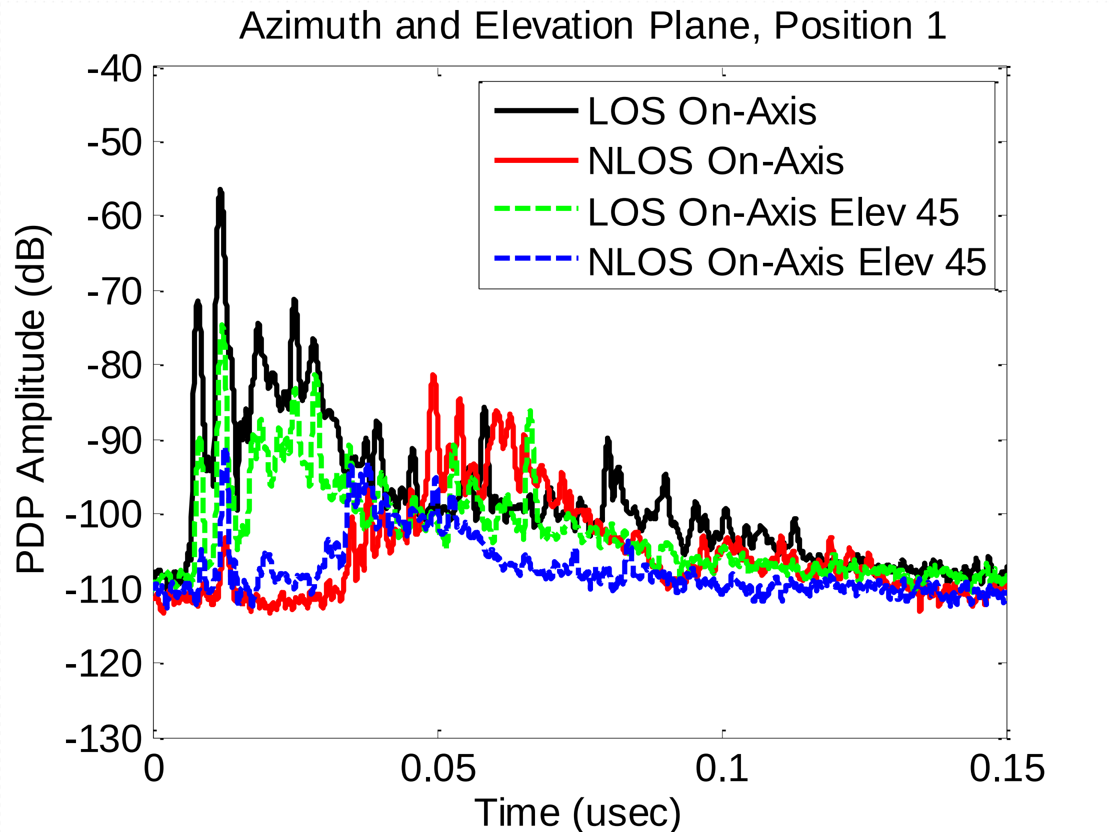




- LOS direct : first arrival, strongest
- NLOS on-axis: last arrival
- Off Axis: variable arrival times

Wireless Industry Requirement (5)

- Angle of arrival: azimuth *and* elevation

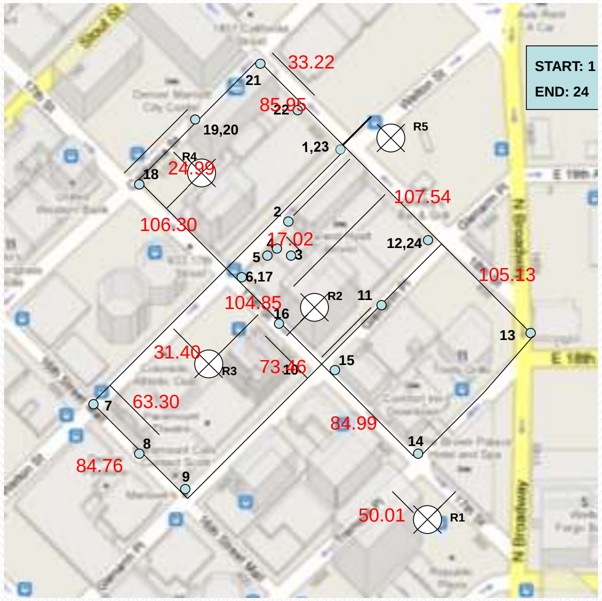


- Reflections expected to be important propagation mechanism
- Many channel sounders capture azimuth only

Channel Models for Millimeter-Wave Wireless

- Measurement campaigns:
  - Indoor environments: lab, office, corridor
  - Outdoor environments for 5G networks (mobile receiver)

- Channel model parameters:
  - Large-scale path loss and shadowing
  - Small-scale delay characteristics (power delay profile, RMS-delay spread, coherence bandwidth, fading)
  - Doppler spread and coherence time
  - Spatial channel characteristics for MIMO (angular profile, RMS-angular spread)



Downtown Denver

- Support, benchmark, and extend existing work:
  - NYU Wireless: shows outdoor link distances up to 400 m at 38 GHz
  - METIS: published a first suite of channel models for 5G networks

Evaluation of Communication Protocols

- Evaluate communication protocols for mm-wave networks
  - Develop network model of 60 GHz system to test the 83 GHz channel model
  - LTE extensions for operation in 28 GHz band
  - Simulation model for LTE in the 28 GHz band
- Characterize the effects of the channel models on the protocol performance

Transfer to standards organizations

- Contribute channel models and results to standards bodies and industry groups

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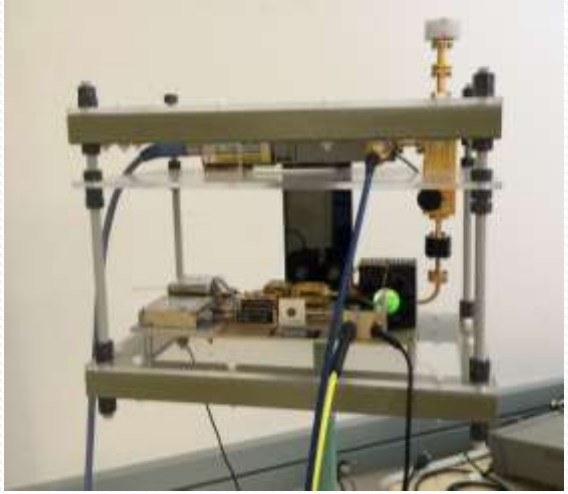
3GPP A GLOBAL INITIATIVE

Uncertainty: mmWave Channel Measurements

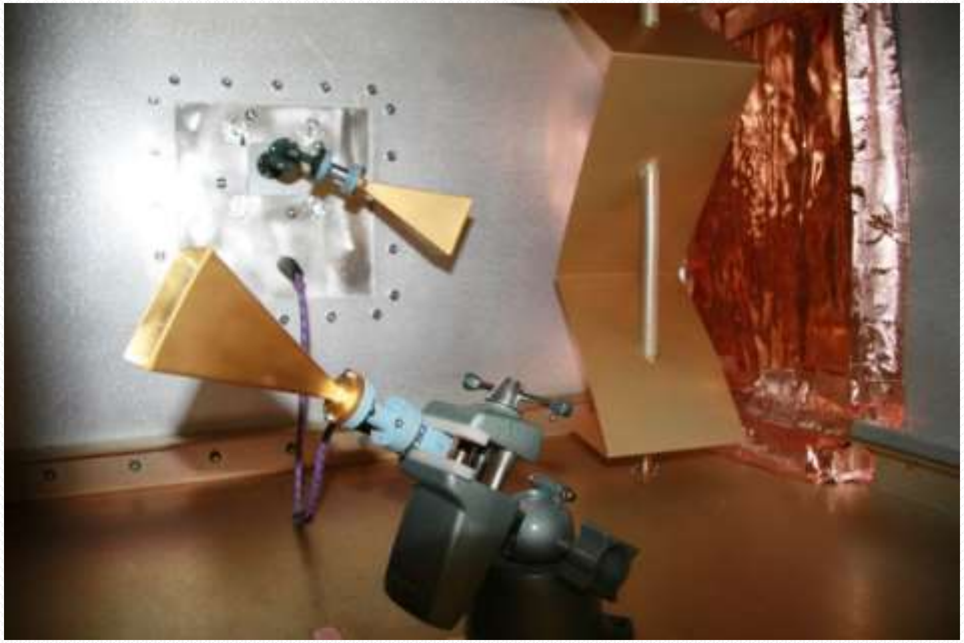
- New analysis of nonidealities of channel sounder:
  - Lack of frequency flatness over broad band
  - Timing and positioning errors
  - Nonlinearity
- Techniques for reducing measurement uncertainty
  - Predistortion of AWG signal
  - Reduce jitter and drift
- Apply NIST Microwave Uncertainty Framework

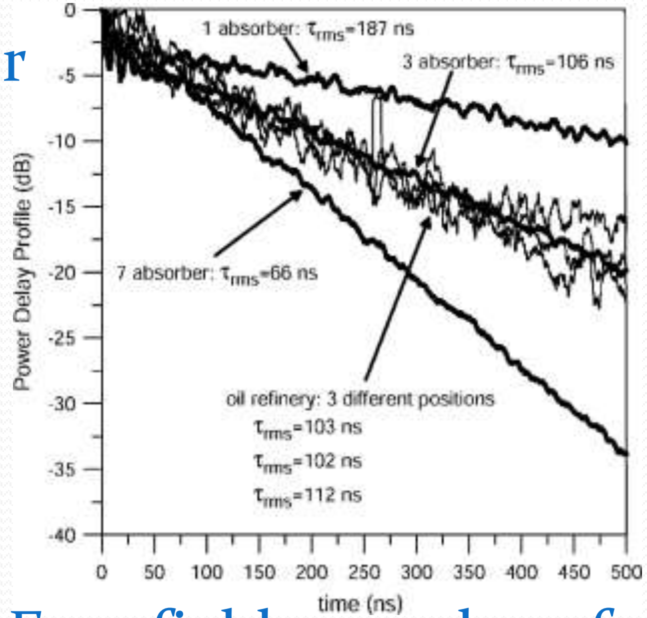


The transmitter includes frequency converters and power amplifiers: nonlinearity and distortion

Lab-Based Broadband Channel Models

- Replicate 83.5 GHz channel in chamber
- Extend statistical channel modeling techniques

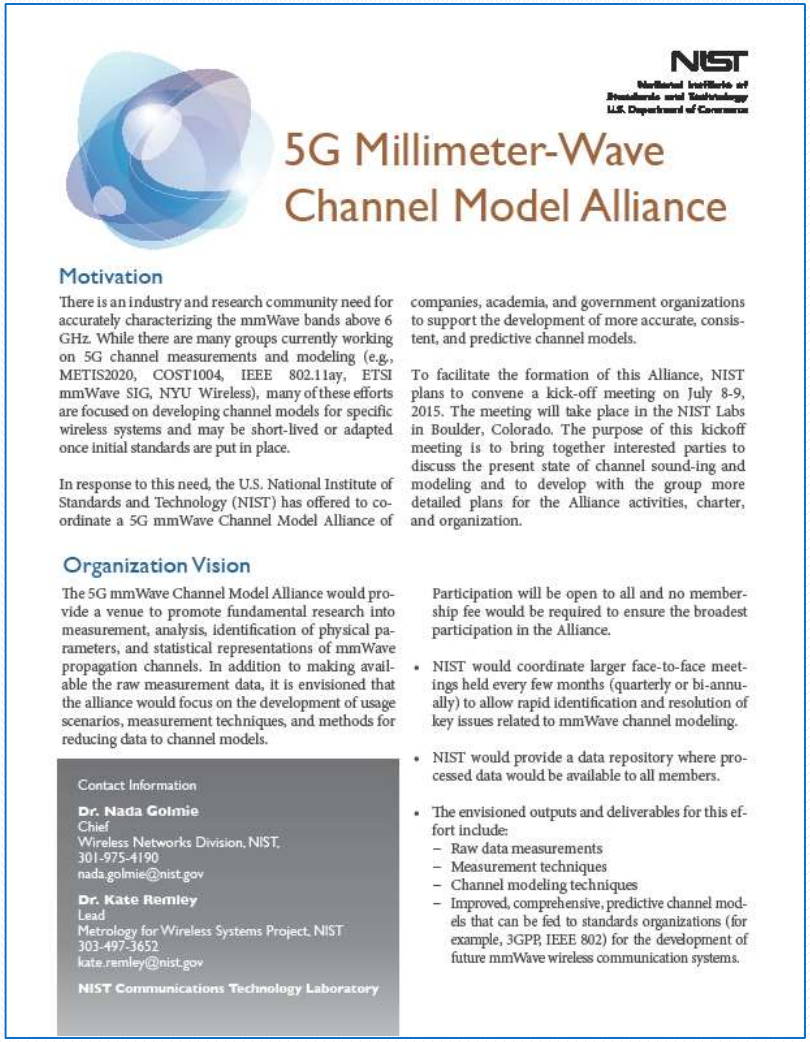




- Free-field metrology for millimeter-wave devices: low uncertainty
- Extend wireless-industry test methods based on reverberation chambers

The 5G Millimeter-Wave Channel Model Alliance

- Promote research on channel measurements, data reduction and models for millimeter-wave wireless
  - Calibration techniques
  - Models with AOD and AOA
  - Models for "massive MIMO"
  - Open database/shared models
- International participation by industry and academia



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

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, COST1004, IEEE 802.11ay, 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 on July 8-9, 2015. 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 sound-ing 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 raw 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.

Contact Information

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NIST Communications Technology Laboratory

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

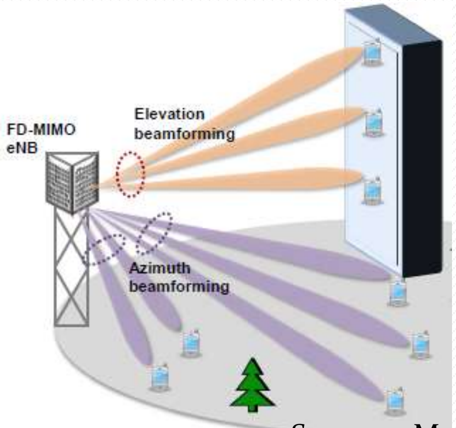
- NIST would coordinate larger face-to-face meetings held every few months (quarterly or bi-annually) to allow rapid identification and resolution of key issues related to mmWave channel modeling.
- NIST would provide a data repository where processed data would be available to all members.
- The envisioned 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.

Kick-off at NIST
Boulder July 8-9 2015

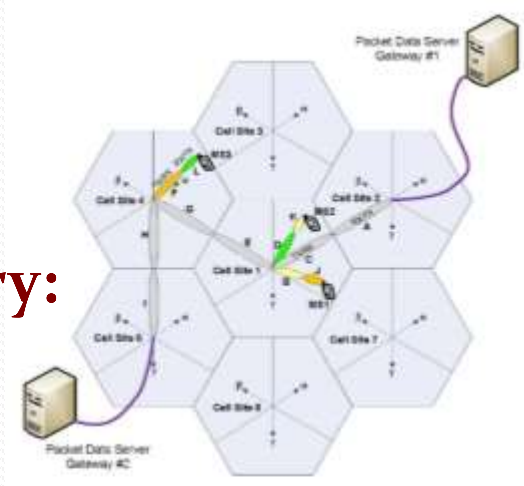
5G: in the Development and Definition Phase

5G may include:

- Massive MIMO
- Ultra-dense networks
- New modulation techniques
- Use of licensed and unlicensed spectrum
- Device-to-Device channel models and protocols
- Advanced antennas
- Multiple radio technologies



Samsung May 2014



NIST Communications Technology Laboratory:

Measurement science in support of wireless standards and technology