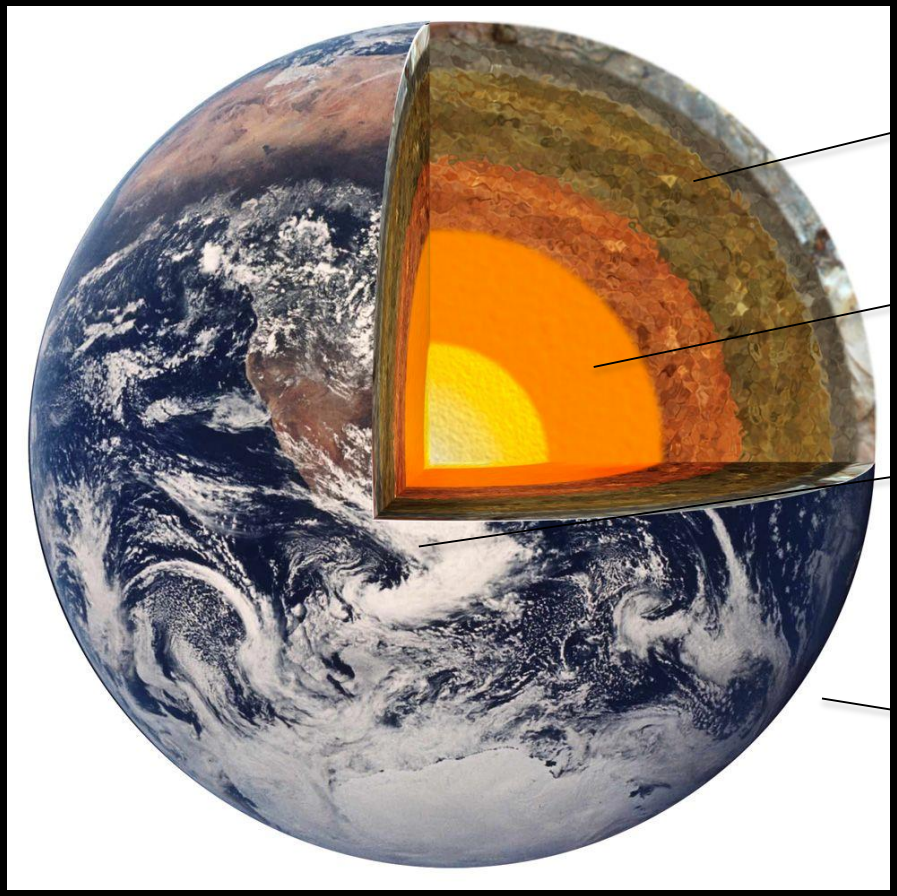
Wireless Research @ NSF - 5G and beyond

Thyaga Nandagopal

Program Director, National Science Foundation &

Co-Chair, Wireless Spectrum R&D Interagency Working Group, NITRD

NSF vision of future networks:
Everything is the Cloud, Wireless is the Cloud's Skin



Edge datacenters

Regional datacenters

Core datacenters

Ubiquitous high-capacity wireless "skin"

Slide Credit: Chip Elliott (BBN)

NSF goals with “5G and beyond”

- Enable cutting-edge research
  - Educate next-generation workforce
  - Seed disruptive innovation
- Encourage industry-university cooperation
- Participate in ‘visioning’ activities to identify emerging themes/topics
- Empower academic researchers to contribute to standards creation/verification
- Creation of national-scale test infrastructure

Broad array of programs

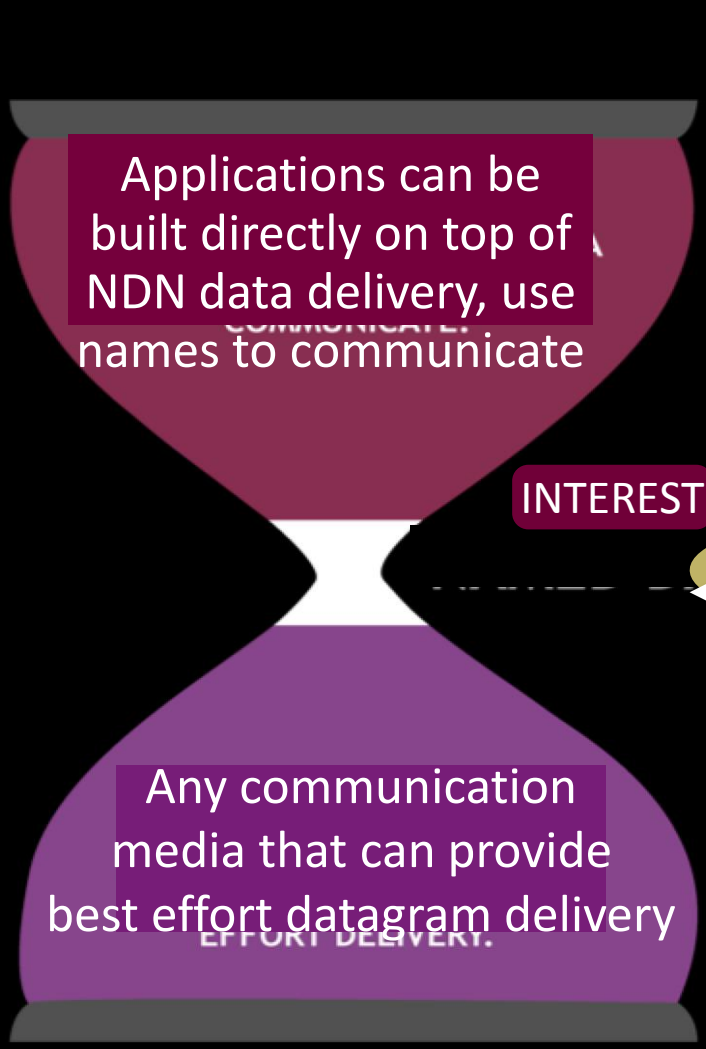
- Networking Technologies and Systems (NeTS)
- Communications Circuits and Sensing Systems (CCSS)
- Communication and Information Fundamentals (CIF)
- Others
  - Enhanced Access to Radio Spectrum (EARS)
  - Wireless Innovation between Finland and US (WiFiUS)
  - Future Internet Architectures (FIA)
  - Global Environment for Networking Innovation (GENI)
- Cumulative funding exceeding $100 M/year
  - Researchers in all major US institutions
  - Training ground for next gen scientists/engineers

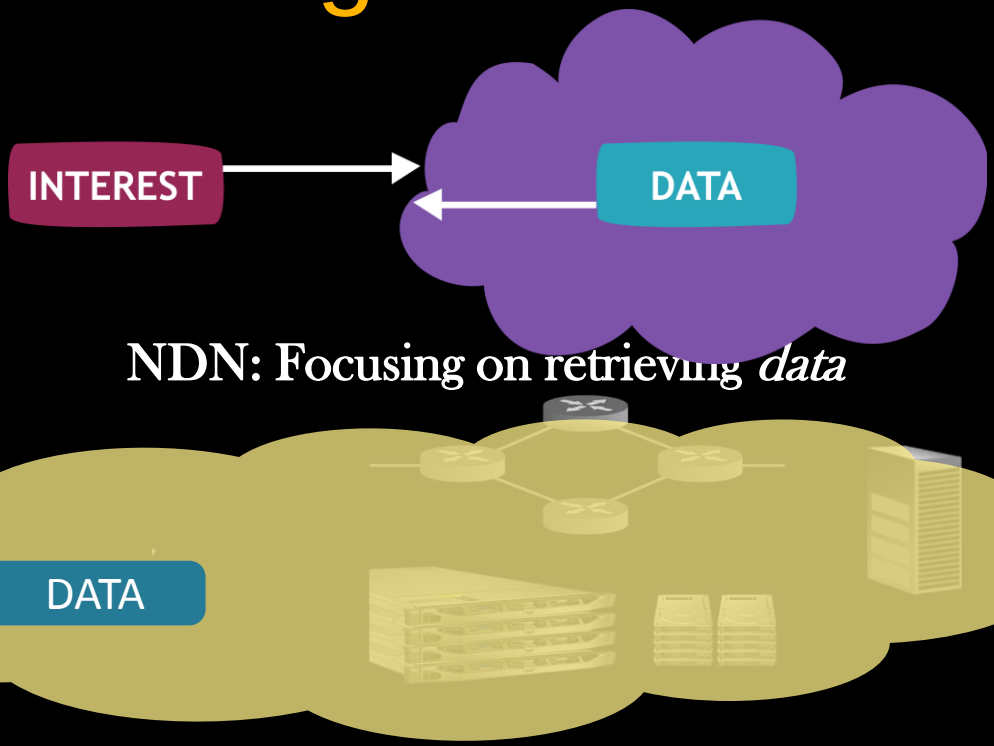
Sample projects

- Named Data Networking
- WiMi - mmWave SDR
- E2E mmWave Phased Array
- Argos – Practial Massive MIMO
- Follow at:

  http://www.nsf.gov/cise/5G/

Named Data Networking Architecture





Collaborators: UCLA, UCSD, UIUC, Univ of Michigan, Colorado State Univ, Univ of Arizona, Univ of Memphis, Washington Univ at St.Louis

Developed over 6 years – now available for commercial testing

NDN's role in 5G architecture

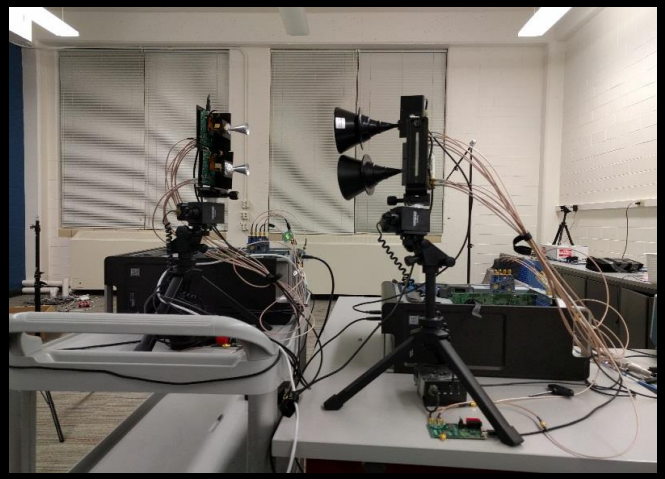
Named Data Networking focuses on data itself instead of the connections or locations of data, making 5G networks secure, efficient, scalable, and robust in data dissemination.

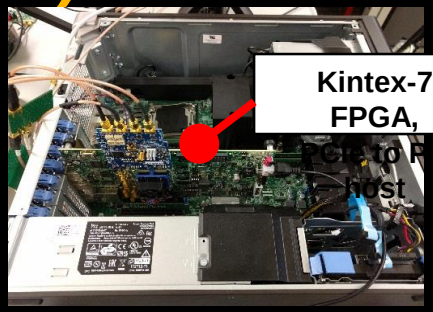
- Securing data directly, which enables ultimate data protection and trustworthiness in mobile environments where connectivity can be rich yet intermittent and data retrieved from middleboxes
  - NDN team has developed solutions toward automating trust management and data verification
- Facilitating mobility: Identifying and retrieving desired data, instead of maintaining connection with a moving target.
- Utilizing multiple interfaces and multiple paths to achieve efficiency and robustness in data delivery.
- Scalable content distribution via native in-network caching and multicast

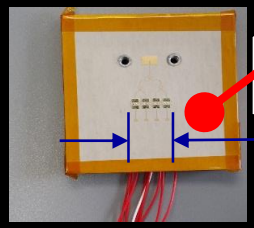
WiMi (Wisconsin Millimeter-wave Software Defined Radio) – 2.0

Collaboration with Univ of Wisconsin, National Instruments

PI: Xinyu Zhang

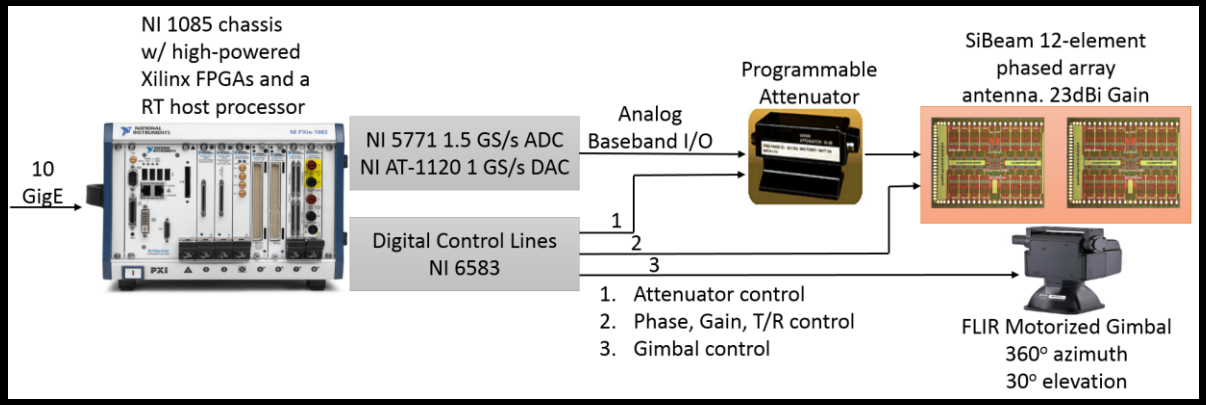






- 1 GHz Bandwidth
- Programmable phased-array antenna
- Kintex-7 FPGA baseband processor
- 4 Gbps real-time sample streaming to PC host via PCIe
- Ongoing development: mmWave MIMO, automatic modularization/parallelization, networking/sensing applications

E2E mmWave Phased Array



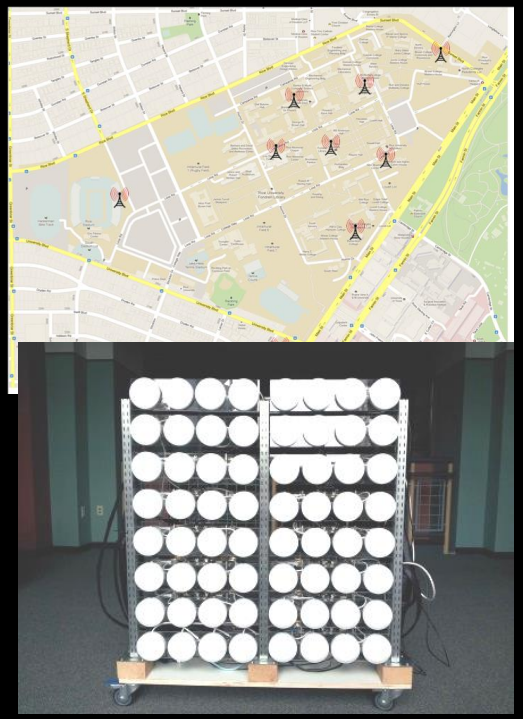
Collaboration with NYU, CUNY, National Instruments and SiBeam

PI: S. Rangan, T.S. Rappaport, A. Dhananjay,
NYU WIRELESS

- Goal: End-to-end phased array system
  - Very high rate baseband processing, 1 GHz BW, 12 steerable elements, 23 dBi gain
  - 45 degree steerable range
- Research on dynamic channel models, low latency MAC protocols, cell search / synchronization
- Status:
  - NI / SiBeam boards to ship early April 2016 for integration
  - Developed wideband channel estimator working on directional horn antennas
  - Also developed simple channel emulator until phased array arrives.
  - Working on digital design for channel synchronization algorithms

Argos: Practical Massive MIMO

- 500+ reconfigurable antennas, Argos v3
- Campus-wide (Rice Univ) deployment
- From TV Whitespace to 3.5 GHz
- $600 per radio/antenna (expected end of 2016)
- Research on
  - Scalability, control channel design, channel characterization, CSI collection overhead reduction, interference management, resource allocation



Argos v2 – 144 antennas, real-time beamforming with mobility
PI: E. Knightly, L. Zhong
Rice University

Disruptive innovation

- **Not just incremental research, but game-changers**
  - Dynamic Spectrum Sharing, Massive-MIMO, Full-Duplex, Backscatter, Architectures, Millimeter wave/FSO, Network Architectures
  - Synergy with DARPA: 100G RF (backhaul), Mobile Hotspots (mobile mm-wave), Adaptive RF (radio)

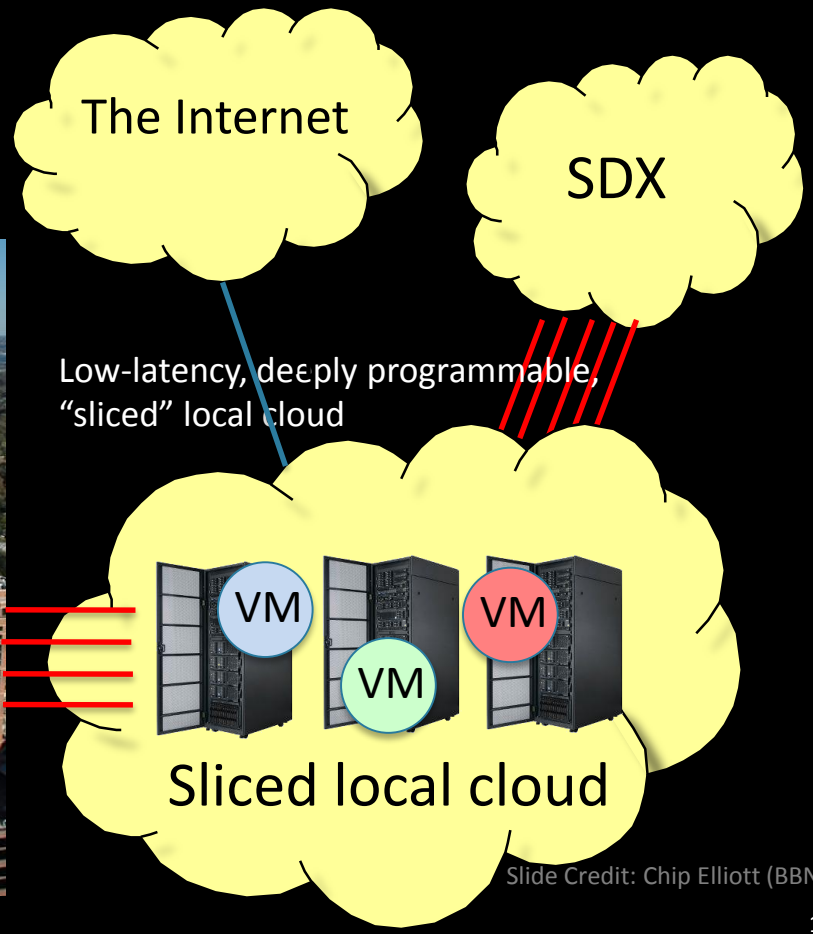
- **One measure of success – startups and tech transfers**
  - Startups: SiBeam, Kumu Networks, Dynamic Spectrum LLC, Shared Spectrum, Jeeva Wireless, Meraki Networks, BigSwitch, and many more
  - Tech transfers (NSF: AIR, IUCRC, STTR programs) – 10 or more instances per year in this domain.

Where next?

- **Research beyond 5G**
  - A world with minimal spectrum regulation – laissez faire spectrum ecosystem
  - Future Internet Architectures that can handle the revolution in content, context, security and converged systems
  - Advanced networking testbeds that can last beyond 10 years
    - Workforce development and unleashing innovation
    - Partnerships with industry and federal agencies for continued relevance and systenance

A “Deeply Programmable ” Citywide Testbed

Some slices for Researchers, others for Service Providers



Slide Credit: Chip Elliott (BBN)