Development of Cost-Effective Community Testbeds for Research and Experimentation

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mmWave RCN Meeting
Jan 28 2019
Agenda

• Motivation
• State of the Art in mmWave Testbed efforts
  – Recent NSF award(s) presentation
• Group Discussion
  – Requirements, Features, Spectrum Range etc..
• Breakout
  – Spectrum
  – Universal/Modular community sourced RF+ Baseband design
  – Application Area(s) enabled
• Report Back and Readout Summary
NSF Mid-Scale Research Infrastructure Solicitations

NSF 5TH MMW RCN WORKSHOP, RALEIGH, NC
Prelim. Proposal Due: Feb. 19, 2019 (10 pages)

Full Proposal Due: May 20, 2019 (20 pages, by invitation only)

Estimated number of awards: 3 to 10, Total Funding Amount: $60M

Two project classes:

- **Implementation projects:** total projects ranging from $6M to <$20M, typical project duration is 5 years

- **Design projects:** minimum $600K, maximum <$20 million (to prepare for a future mid-scale/larger infrastructure implementation project – does not imply NSF commitment to future implementation of that project)

Does not provide operating or maintenance funds, should be sustainable

Serves to broad community, need new capabilities not available elsewhere

Examples: open-access time at a facility, access to data products/software, and/or cooperation/sharing of technology with other projects

Strong project management & robust cost estimation criteria for review

Letter of Intent: Feb. 8, 2019 (3 pages)

Prelim. Proposal Due: Mar. 11, 2019 (10 pages)

Full Proposal Due: Aug. 2, 2019 (25 pages, by invitation only)

- Needs science drivers, pre-implementation activities, implementation plan, operations/utilization plan

Estimated number of awards: 4 to 6, Total Funding Amount: $150M

Individual Projects: from $20M to $70M, project duration up to 5 years

Will consider only the implementation (typically construction or acquisition) stage of a project, including a limited degree of advanced development immediately preparatory to implementation

Will support projects in high states of readiness for implementation, i.e., those that have already matured through previous developmental investments. It does not support pre-implementation or post-implementation research, operations or maintenance.
mmWave Testbed Survey

- Rutgers, Columbia University - PAWR COSMOS
- Drexel University - MRI: Development of a mmWave Software Defined Radio Network Testbed for Hybrid Measurement and Emulation
- CMU – CRI: Mobile mm-wave MIMO Network Testbed
- University of Buffalo – A Programmable Testbed for Wideband 60 GHz WLANs with Phased Arrays
- Florida International University - mmWave-based Vehicular Communications
- Idaho National Lab -
PAWR Awardees

Round I Platforms

Salt Lake City
New York City

http://powderwireless.net
http://cosmos-lab.org
COSMOS: Cloud Enhanced Open Software Defined Mobile Wireless Testbed for City-Scale Deployment

- A multi-layered computing system with an RF thin client; flexible signal processing; network function virtualization (NFV) between a local SDR (with FPGA assist) and a remote cloud radio access network (CRAN) with massive CPU/GPU and FPGA assist
- Deployed in New York City, one of the country’s most populated urban centers
- Wideband radio signal processing (with bandwidths of ~500 MHz or more)
- Support for mmWave communication (28 and 60 GHz)
- Optical switching technology (~1 µs) provides passive WDM switch fabrics and radio over fiber interfaces for ultra-low latency connections

28GHz phased-array ICs and phased-array antenna modules (PAAM)

Deployment Area: West Manhattan/Harlem

COSMOS Radio Site Design       All-Optical Network Design
COSMOS mmWave Node Requirements

• Multilayer package with 4 transceiver ICs and 64 dual polarized antenna elements for 28GHz communication

• Massive baseband processing

• Multi-Gbps throughput (large nodes)

• Programmable, open interface

• Experimentation for beamforming, directional MAC layer, …

• Built on 5G OFDM New Radio
COSMOS mmWave Node Specifications

- 64-dual polarized antennas and 4 ICs each with 32 TRX elements
- 128 TRX elements in total
- 8 independent 16-element beamformers, each supporting 1 polarization of 16 ant.
- RF true time delay based architecture
- 28GHz RF, 5GHz ext. LO, 3GHz input/output IF
- 54dBm saturated EIRP on each polarization
COSMOS mmWave Backhaul

PAWR Industry Contribution

- Interdigital 60 GHz EdgeLink antenna
  - 38 dBi gain - 802.11ad based
- Ericsson mini-link 63XX E-band millimeter wave
  - 10 Gbps capacity and the smallest form factor
- Facebook Terragraph 60GHz radio for Channel Modeling

Tests include

- Free space path loss (FSPL)
- Reciprocity
- LOS blocking by various material (foliage, wood, glass, shelf, fence)
- NLOS reflection (wood, wall)
CRI: Mobile mm-wave MIMO Network Testbed

CNS-1823235, Started: October 2018, PI’s: J. Paramesh, S. Kumar (CMU)

**Background**

- Hardware unavailable to build testbeds.
- Low levels of integration
- Highly proprietary or non-customizable
- Focused on first phase “5G” focus or 802.11 mm-wave WLAN
- Need testbed for “beyond-5G” (advanced MIMO, integrated radar/imaging/localization etc.

**Our Approach**

- Leverage prior NSF-funded work from PI Paramesh’s group
  - Complete Hybrid Beamformers
  - Highly reconfigurable/customizable
  - Support MIMO at 28 and 39 GHz
- Leverage PI Kumar’s prior work on intuitive software interfaces for rapid beamforming (OpenRF) to apply broadly to mm-wave networking and sensing
- Meet goals identified at previous mmRCN’s:
  - Enable experimentation/optimization at all layers,
  - have a modular structure to swap components enable end-to-end experimentation in network setting
  - Control via intuitive graphical user interface.

**Status/Outlook**

- Design/integration of 1st gen sub-systems
- Deploy small network in Q4 2019
- Refine & scale up subsequently
X60: A Programmable Testbed for Wideband 60 GHz WLANs with Phased Arrays

X60: Overview

- 4 nodes
- NI mmWave Transceiver System
- 2 GHz ultra-wide channels
- Fully programmable PHY/MAC
- User-configurable phased antenna arrays
- Gigabit/s data rates
**mmWave-based Vehicular Communications**

**Motivation:** Autonomous vehicles need:

- **high-data-rate** to communicate with each other, for wider view of their surroundings
- **Secure** and **reliable** high-mobility communications
- Supporting network with **fast** decision making

**Objective:** Design and validation of secure, high-data-rate, and low-latency **vehicular communications** at the **mmWave** band

**Approach:** A **cross-layer** approach spanning:

1. **RF front-end:** Novel transceiver architecture for **high data rate**
2. **Communications:** PHY layer **security**, **RF impairments** mitigation, and **simultaneous** multi-vehicle communications
3. **Network:** Software-defined Network (SDN) paradigm and **edge-based** computing for **co-existence** among multiple air interfaces

*NSF* award CNS-1816112; Ahmed Ibrahim (aibrahim@fiu.edu), Elias Alwan, and Kemal Akkaya; Oct. 2018.
Advancing National Wireless Capability

Dr. Arupjyoti (Arup) Bhuyan

National & Homeland Security
Idaho National Laboratory

January 28, 2019
Unique National Security Capabilities

- Innovation in nuclear, control systems, power grid, wireless and physical security

- Research and Education Campus
- Controls, Energy Security Labs
- National Security Test Range
- ~20k TNT, VA Center
- Nuclear Materials R&D
- Electro-refining, SNM for Test/R&D
- Research and Education Campus
- Controls, Energy Security Labs
- Electric Grid Test Bed
- Commercial Feeds, Test Loops/Spurs
- Wireless Test Bed
- Agile Spectrum
- Water Security Test Bed
- Municipal Water System
- Radiological Ranges
- First Responder Training
- Specific Manufacturing
- 100% Quality Product

✓ Full-scale real-world testing and demonstrations for deployment (designed, built and operated by INL)
✓ Integrated testing across multidisciplinary areas (radiological, physical security, explosive, power, controls, cyber)
✓ Rapid development through model, test, validate, and refine (high fidelity, effects-based modeling, rapid testing and measurement)
✓ Access to the full range of support services (lineman, engineers, rad techs, fire fighters and security forces)
✓ Ability to develop prototypes, manufacturing process and resolve uncertainty
Wireless security is essential to protecting the nation’s critical infrastructure

INL Capabilities Secure Wireless Solutions from Concept through Validation and Deployment

Wireless Research:
Develop solutions to national spectrum and wireless communications security challenges (WSComm\textsuperscript{1}, WiFIRE\textsuperscript{2}, mmWave physical layer security, 5G Cellular UAS\textsuperscript{3})

Wireless Modeling & Simulation:
Advanced software engineering, validation and testing of wireless security solution technology design (IMOM\textsuperscript{4})

Wireless Test Bed:
Test and validate full-scale deployment of wireless communications security technology solutions (JamX 17\textsuperscript{5})

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\textsuperscript{1} Wireless Spectrum Communications, \textsuperscript{2} Wireless RF signal Identification and protocol Reverse Engineering, \textsuperscript{3} Unmanned Aircraft System, \textsuperscript{4} Improved Many on Many, \textsuperscript{5} 2017 First Responder Jamming Exercise
Isolated, Reconfigurable, Multidisciplinary, High-Fidelity Environment

- INL Range
  - Monitoring Equipment
  - Call Generator
  - PTSN Simulator
- Idaho Falls
  - Power Grid Labs
- Cellular Network Operations Centers
- Fixed Cell Sites
- Cell Switch Center
- Multiple Test Sites
  - Mobile Platforms
  - Cellular NOC
  - Cyber & SCADA Labs
IDaho Falls IS RANKED 
5th 
MOST AFFORDABLE CITY IN 
AMERICA.

ENJOY MORE THAN A 
DOZEN OF THE WORLD'S BEST 
FISH FISHING STREAMS.

TOP 100 
BEST ADVENTURE TOWNS (NATIONAL GEOGRAPHIC).

FOUR 
NATIONAL PARKS AND WORLD 
RENONUED LANDMARKS WITHIN 
HOURS OF IDAHO FALLS 
(LYONSTON NATIONAL 
PARK, GRAND TETON NATIONAL 
PARK, CRIPERS OF THE MOON 
NATIONAL MONUMENT, LAVA 
HEAT SPRINGS).

32 
THE MEDIAN AGE IN 
BOISE COUNTY, MORE 
THAN HALF THE POPULATION IS 
UNDER 44 YEARS OLD.

THREE 
WORLD-CLASS SKI RESORTS RIGHT IN YOUR BACKYARD 
(GRAND TARGHEE, SUN VALLEY, AND 
JACKSON HOLE), PLUS CLOSE PROXIMITY TO NEROCIOUS ALPINE AND 
NORDIC SECON OPPORTUNITIES.
Cognitive Radio Network (CORNET)
- 48 USRP2 nodes, FCC license, remote access
- 25 X310 USRPs + 9 powerful workstations
- 10 Gbps connectivity and switching

Outdoor CORNET (O-CORNET)
- 11 SDR nodes on campus rooftops
- 5 deployable nodes
- Drone cage with ground and aerial SDRs

LTE testbed
- SDRs, eNodeBs and UEs
- RF channel emulators (0-3 GHz)
- LTE test instruments

https://cornet.wireless.vt.edu/
Cognitive Radio Test System (CRTS)

- Open source framework (research on T&E methodologies)
- Enables research & education on cognitive radios/networks
- Allows testing experimental SDRs, prototypes and COTS products (future)

CORNET-3D

- Web-based visualization of RF spectrum
- Web-based control of radios
- Game-like interactive tutorials for education

Software-Defined Radio (SDR) Software

- Open source: GNU Radio, Liquid-DSP*, REDHAWK*, srsLTE**
- Commercial eNodeB and UE software (Amarisoft)
- Open-source Radio Environment Map-enabled Spectrum Access System

*originated as / based on Virginia Tech projects     **originated as project led by Marojevic
CORNET Evolution
RFnest: analog RF channel emulator
CORNET HARDWARE

- 9 Dell R7910 work stations with 4 10Gb Ethernet interfaces, 128 GB Ram, Dual 12 cores, Hyper-threaded 3 GHz processors
- Nvidia Quadro M6000 GPU available
- VMware esxi and XCP-ng Hypervisor
- At least one Virtual Machine installed per X310
- 96 port Juniper QFX5100 10 Gb switch
- 10 Gb fiber optic data interfaces for X310 nodes
- 21 X310’s operational in 11 nodes
  - X310's have dual UBX daughter-boards (except for Twin-RX in 3 units)
- One mobile node with X310
- 3 additional X310’s to be installed (first floor)
- 7 N210’s in the sandbox 4 dual USRP2 MIMO nodes (2nd floor)
- 12 USRP2 nodes (2nd and 3rd floors)
RF Schematic for integrated testbed

SDRs

Shielded Enclosure

CMW500

Switch Matrix 1

Switch Matrix 2

Switch Matrix 3

Switch Matrix 4

Filters

RFnest-2

RFnest-1

RF Nest

Ethernet Switch

CMW500

RF Switches

RF Switches

RF Switches

RF Switches

Filters

OctoClock

SDR (TD-LTE)

CMW500 (DL)
Arjuna Madanayake

Testbed Capabilities at FIU
Simulated polar patterns of the 32-beams for a ULA with $\lambda/2$ element spacing. (a) DFT, (b) ADFT, (c) the magnitude error.

Multi-beams using (a) 8x8 (64-beams); (b) 16x16 (256 beams); (b) 32x32 (1024 beams) ADFTs.
Radio Astronomy Research Driven by CASPER


- CASPER promotes **open-source hardware, software and programming tools**, which can be collectively developed by the community and re-used in multiple experiments.

- Development of hardware platforms along with high speed input output interfaces.

- A suite of open-source parameterized libraries and an FPGA-programming tool flow enabling portability of designs between generations of hardware.

- Collaboration is led by the UC Berkeley radio astronomy research group.

- CASPER Hardware platforms:
  - generations of open-source Xilinx FPGA based hardware platforms
  - compatible with an array of analog-to-digital converters (ADCs)
  - digital-to-analog converter (DAC) modules.

- CASPER tools: A set of DSP libraries and tools maintained by the folks running CASPER.

- Own mailing thread: **CASPER Mailing List**.

Images from: https://casper.ssl.berkeley.edu/
Results and Measurements

• ROACH-2 hardware platform is used with CASPER ADCs for parallel digitization of 32 IF outputs to form 32 simultaneous RF beams

• Validation of FIR and IIR trapezoidal digital beam filters.

Demo of 32-beam 5.8 GHz array receiver at 5G Brooklyn Summit 2018.

Measured beams from 32-pt. spatial ADFT

100 MHz/beam I-Q support for 32 beams = 3.2 GHz fully digital on ROACH-2
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Discussion Questions

1. What does our community need with respect to testbeds?
2. What are the key hurdles toward meeting these needs?
3. What are the key applications and research topics which currently can’t be assessed using today’s testbeds?
4. What frequency range is most important?
5. How important is modularity, reconfigurability, upgradeability, accessibility for a testbed?
Agenda

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• Small-group Breakouts
  – Spectrum
  – Universal/Modular community sourced RF+ Baseband design
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