IEEE 5G and Beyond Testbed Workshop

ORB1T Pilot

September 24th, 2017

Ivan Seskar
WINLAB
Department of ECE
Rutgers, The State University of New Jersey
seskar (at) winlab (dot) Rutgers (dot) edu
IEEE 5G Testbeds Working Group

Main Workgroup Objectives

- Leverage IEEE community’s strong simulation, measurement and calibration capabilities for testbeds by developing testing standards and calibration methods.

- Inventory types of testbeds that are available, serve as facilitator for setting up a testbed federations and make them available to IEEE community.

- Collaborate with the vendor and research community to expand existing testbeds with next generation of technologies (as they become available).

- Organize workshops related to 5G experimental aspects (including use case scenarios).

- Propose and drive development of (future) testbed requirements.

- Coordination with other development efforts (PAWR, ONF, 5G-PPP, etc).
5G: Technical Challenges

- Faster Cellular Radios Access
  - ~1-10 Gbps
  - ~1000x capacity
  - Wideband PHY
  - Cloud RAN arch
  - Massive MIMO
  - mmWave (60 Ghz)
  - Multi-Radio access
  - HetNet (+WiFi, etc.)

- Low-Latency/ Low-Power Access Network
  - For Real-Time IoT
  - Custom PHY for IoT
  - New MAC protocols
  - RAN redesign
  - Light-weight control
  - Control/data separation
  - Network protocol redesign

- New Spectrum & Dynamic Spectrum Access
  - 60 Ghz & other new bands
  - New unlicensed/shared spectrum
  - Dynamic spectrum access
  - Spectrum sharing techniques
  - Non-contiguous spectrum
  - Network/DB coordination methods

- Next-Gen Mobile Network
  - Mobile network redesign
  - Convergence with Internet
  - Clean-slate Mobile Internet
  - Software Defined Networks
  - Open wireless network APIs
  - Cloud services & computing
  - Edge cloud/fog computing
  - Virtualization, NFV
5G: Capacity, Capacity, Capacity

**Research Viewpoint**

\[
1000 = 10 \times 10 \times 10
\]

\[
\frac{\text{bits/sec}}{\text{km}^2} = \frac{\text{bits/sec/Hz}}{\text{cell}} \times \frac{\text{cell}}{\text{km}^2} \times \text{Hz}
\]

- Spectral efficiency
- Bandwidth
- Cell density

**Industry Viewpoint**

- Air Interface
- Spectrum
- Networking

Giuseppe Caire: "Massive MIMO: implementation issues and impact on network optimization" 2016 Tyrrhenian International Workshop on Digital Communications (TIW16)

Qian (Clara) Li, Huaning Niu, Apostolos (Tolis) Papathanassiou, and Geng Wu: "5G Network Capacity" IEEE vehicular technology magazine, March 2014
### 5G: Capacity, Capacity, Capacity (cont’d)

<table>
<thead>
<tr>
<th></th>
<th><strong>Academia</strong></th>
<th><strong>Industry</strong></th>
</tr>
</thead>
</table>
| Spectral Efficiency/Air Interface | Massive MIMO: Serve 10-20 users per sector with 100-200 antennas per BS  | • Coordinated Multipoint Tx/Rx  
• 3-D/Full-Dimensional MIMO  
• New Modulation and/or Coding Schemes |
| Cell Density/Networking         | Small Cells & Heterogeneous SoNs: From 300m to 90m cell radius on average  | • Cell Densification  
• WLAN Offloading  
• Integrated MultiRAT Operation  
• Device-to-Device  
• Joint Scheduling, Nonorthogonal Multiple Access  
• Information and Communication Technology Coupling |
| Bandwidth/Spectrum              | mmWaves: From 2-6 GHz to 20-60 GHz                                         | • More Licensed and Unlicensed Spectrum, mmWaves  
• Licensed Shared Access  
• Unlicensed Spectrum Sharing |
Softwarization in Wireless Networks

In radio access networks - Agility in spatial, temporal and frequency dimensions enabling:

- Fine-grained physical layer/network programmability
- Flexibility in spectrum management
- Dynamic provisioning
- Heterogeneous deployments.

In mobile edge networks - Extend softwarization from the conventional data center to the edge of wireless networks:

- Enable on demand service deployment at the most effective locations based on application requirements
- Automate service establishment/maintenance mechanisms (in a timely fashion)
Basestation Architecture Evolution

**Traditional Design**
- Core Network
- Power Amplifier
- Baseband
- Transport
- Control & Mgmt.

**Current Design**
- Core Network
- Power Amplifier Head (RRH)
- Baseband Transport Unit (BBU)
- Control & Mgmt.

**Cloud Radio Access Network (CRAN)**
- Core Network
- Power Amplifier
- Baseband
- Transport
- Control & Mgmt.

**Fronthaul**
- Common Public Radio Interface (CPRI)
- Open Base Station Architecture Initiative (OBSAI)
- Open Radio Equipment Interface (ETSI-ORI)

**Backhaul**
- S11, R4, R6
Basestation Architecture Evolution (cont’d)

- **RLC (asynch.)**
- **RLC (synch.)**
- **MAC (e.g. RRM)**
- **MAC (e.g. HARQ)**
- **FEC**
- **Scrambling**
- **Modulation, Layer mapping, Precoding**
- **Resource element mapping & IFFT**
- **D/A Conversion**
- **Antenna**

**M3**
- Coded user data

**M2**
- I/Q samples in frequency domain

**M1**
- I/Q samples in time domain (e.g. CPRI)

**M0**
- Coaxial cable

**M6-M4**
- Uncoded user data (without H-ARQ retransmissions)

- **Scaling with user data rates**
- **Scaling with bandwidth and # of antennas**
- **Relaxed latency requirements**
- **Requiring low-latency fronthaul**

*Courtesy: METIS-II Consortium*
Challenge: Efficient base band unit implementation that uses general-purpose x86 processors (GPP) for baseband processing

- front-end, channel decoding, phy procedures, L2 protocols

Key elements:

- Real-time extensions to Linux OS
  - x86-64 multicore arch

- Real-time data acquisition to PC

- SIMD optimized integer DSP
  - 64-bit MMX → 128-bit SSE2/3/4 → 256-bit AVX2
  - iFFT/FFT, Channel Estimation, Turbo Decoding

- SMP Parallelism
  - Master-worker model

Courtesy: Navid Nikaein, Eurecom/Open Air Interface
OAI Roadmap: Strategic Areas

5G Modem: new waveform, Relaying, Carrier aggregation, Full-duplex Radio, Massive MIMO, SDN/NFV, Juju/OpenStack, Ethernet Fronthaul, SDN/RAN, Juju/OpenStack, MEC API, IoT

Heterogeneous 5G Network: Ultra-dense network, Coexistence, and Aggregation, Unlicensed bands, Coexistence, and Aggregation

Large-Scale Emulation: Realistic experimentation, Channel models, Performance, System Integration, PHY abstraction

Test and measurements: Interoperability / Compliance, System Integration, Channel Sounding, Design Validation

RF Platform: Low cost BS, Soft RRH

Courtesy: Raymond Knopp, Euricom
IEEE 5G Testbed Pilot Program

- Identify testbed, tools and matching experiment types
- Define usage models
- Set the guidelines for access and use (including considering local regulations)
- Identify AAA methodology (including potential federation models)
- Start a trial with the ORBIT testbed to help with the requirements/policies development
Orbit Testbed: Hardware

- **VPN Gateway to Wide-Area Testbed**
- **Gigabit backbone**
- **80 ft (20 nodes)**
- **Control switch**
- **Data switch**
- **Application Servers** (User applications/Delay nodes/Mobility Controllers/Mobile Nodes)
- **Internet VPN Gateway/Firewall**
- **Back-end servers**
- **RF/Spectrum Measurements**
- **Interference Sources**

Diagram showing the layout of the Orbit Testbed with various nodes and servers connected by the Gigabit backbone.
ORBIT Radio Node (Version 4)

- Xeon E5-2600v3 with 18 cores
- 64 GB DDR4
- 2 x 10G Ethernet ports
- 2 x Gigabit Ethernet ports
- PCI-Express 3.0 X16
- 8 x USB 3.0
- OOB Mgmt.

- I7-4770 3.4 GHz Q87T Express chipset
- 16 GB DDR3
- 2 x Gigabit Ethernet ports
- PCI-Express 2.0 X16
- 2 x Mini-PCIExpress socket
- 8 x USB 3.0
- OOB Mgmt.
CloudLab based CPU/GPU deployment
5G Experimentation: Massive-MIMO

- 40 USRP X310s
  - Available FPGA resources:

<table>
<thead>
<tr>
<th>Resource Type</th>
<th>Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>DSP48 Blocks</td>
<td>58K</td>
</tr>
<tr>
<td>Block Rams (18 kB)</td>
<td>14K</td>
</tr>
<tr>
<td>Logic Cells</td>
<td>7.2M</td>
</tr>
<tr>
<td>Slices (LUTs)</td>
<td>1.5M</td>
</tr>
</tbody>
</table>

- RF 2 x UBX-160 (10 MHz - 6 GHz RF, 160 MHz BB BW)
- 2 x 10G Ethernet for fronthaul/interconnect
- Four corner movable mini-racks (4 x 20 x 20 -> 1 x 80 x 80)
- > 500+ GPP Cores/CloudLab Rack
- Number of GPU platforms
- 32x100G SDN aggregation switch
5G Experimentation: High Density
Goals of Federation

- Make it easy for experimenters to use multiple testbeds
  - Single account
  - Single (or small number) of tools, choice of tools

- Multiple testbeds
  - To scale up
  - To use/combine special resources (e.g. wireless robots)
  - Redundancy (e.g. testbed in maintenance)
  - To re-use experiments (class exercises, scientifically, ...)
  - To compare environments (e.g. wireless, openflow hardware, ...)
Basics of GENI Federation

- Partitioned trust
  - All identities and assertions verified cryptographically
  - No federation member can forge credentials for other members

- Separate Authentication and Authorization
  - Authentication: “Who is this user?” (Member Authority)
  - Authorization: “Why are they allowed to use the facility?” (Slice Authority)

- Use untrusted tools as much as possible
  - Eg. multiple portals
  - “Speaks-for” for accountability

- Federation established by a trusted third party (Clearinghouse)

- Anyone can join more than one federation
  - As simple as adding and removing root certificates

Courtesy: Robert Ricci, University of Utah
Successes in GENI Federation

- 142 aggregates federated
- Moderately heterogeneous
  - Clusters
  - Wireless
  - Backbone networks
  - Existing testbeds
- Includes international resources
- Reasonably broad and consistent tool support
- Adding a new federate is easy (from a clearinghouse standpoint)
- Decentralized model / autonomous facilities
- Model is used for multiple testbeds / federations
- Multiple overlapping federations

Courtesy: Robert Ricci, University of Utah
• 32 LTE and WiMAX BS on 14 campuses
• SDN (Click and OVS based) datapath/backbone
• Sliced, virtualized and interconnected through Internet2
• 10 mini-ORBIT deployments some with SDRs
Model from Fed4FIRE

Experimenters
Fed4FIRE+
Federator
FIRE Facility providers

Open calls for funded experiments

Funding for:
- Functional innovations
- Experiment support
- Maintenance

Courtesy: Brecht Vermeulen, imec
European FIRE projects framework

Source figure: FIRE Brochure 2014 (AmpliFIRE)

Courtesy: Brecht Vermeulen, imec
Fed4FIRE – general info

- Total budget: 7.75 MEUR with 42 partners (2012-2016)

Courtesy: Brecht Vermeulen, imec
Fed4FIRE assets – facilities (doc.fed4fire.eu)

Wired
Wireless
Openflow
Cloud
Other

w-Lab.t
(MTech) Zelezaarde, Belgium

Virtual Wall
(University) Gent, Belgium

OFELIA - Bristol
(University) Bristol, Great Britain

IRIS
(UCD) Dublin, Ireland

Planetlab Europe
(UPC) Paris, France

BonFIRE
(APCI) Ile-de-France, France

Community Lab
(APCI) Spain

Smart Santander
(UCA) Santander, Spain

FIONA
(Adolfo Robles) Liebana, Spain

OFELIA - i2CAT Island
(i2CAT) Barcelona, Spain

10G TRACE TESTER
(UAM) Madrid, Spain

Perform LTE
(UAM) Málaga, Spain

NORBIT
(INCTA) Sydney, Australia

KOREN
(KAIST) Seoul, Korea

Ultra Access
(ECNM) Stanford, USA

Tengu
(INTEC) Gent, Belgium

PL-LAB
(INP) Warsaw, Poland

FuSeCo
(FOKUS) Berlin, Germany

LOG-a-TEC
(ULB) Ljubljana, Slovenia

NETMODE
(INNTU) Athens, Greece

NITOS
(INNTU) Nicosia, Greece

Courtesy: Brecht Vermeulen, imec
Fed4FIRE+ Objectives

The Fed4FIRE+ project has the objective to run and further improve Fed4FIRE’s “best-in-town” federation of experimentation facilities for the Future Internet Research and Experimentation initiative. To achieve this, the project has defined a set of sub-objectives:

- **To further exploit, enlarge and build a federated set of facilities** upon the foundations laid out by the FP7 project Fed4FIRE;
- **To aim for an open federation** to the whole FIRE community and beyond, for experimentation by industry and research organisations, through the organization of **Open Calls and Open Access mechanisms**;
- **To continuously upgrade and improve the facilities** and include technical innovations, focused towards increased user satisfaction (user-friendly tools, privacy-oriented data management, testbed SLA and reputation, experiment reproducibility, service-level experiment orchestration, federation ontologies, etc.)
- **To create an open market-place** for customers of testing services by brokering across federated testbed resources.

Courtesy: FED4Fire+ Consortium
More Info @

5g.ieee.org/testbeds
www.orbit-lab.org
www.geni.net
www.fed4fire.eu/
geniwireless.orbit-lab.org
www.winlab.rutgers.edu
www.openairinterface.org
metis-ii.5g-ppp.eu