The Massive MIMO testbed ReRaNP, at the Norwegian University of Science and Technology, use the LabVIEW Communications MIMO Application Framework. It has 128 TX/RX radio chains, is modular and can be placed in different environments.
Where we started
The Result
Nils Torbjörn Ekman
Professor at the Department of Electronic Systems
Norwegian University of Science and Technology

Ingulf Helland
Senior Engineer NTNU
What is the Reconfigurable Radio Network Platform?

- A Software Defined Radio (SDR) lab
- Massive MIMO capabilities at NTNU
  - About 75 SDR units
  - 64 SDR units over 4 racks give a BS with 128 antennas
    - NI USRP-2943R
  - 7 SDR units as mobile terminals
    - NI USRP-2953R
  - 5-6G Massive MIMO demonstrator
- National infrastructure project
  - Four 20MHz frequency bands in 1.4-6.0 GHz
  - Implement and test communication systems in environments of Norwegian interest
  - Funded by the Research Council of Norway
Where is ReRaNP?
The Norwegian University of Science and Technology (NTNU) in Trondheim

Over 42 000 students
Why an USRP Based Massive MIMO Platform?

"All the proof of a pudding is in the eating."

- SDR Base Stations
- SDR Mobile Terminals
- Full control of the whole stack
  - Run whatever PHY you want
    - LabView implementation
  - Run whatever MAC you want
    - Open Air Interface
  - Run whatever experiment you want
    - Integrated network experiments
    - How changes in network layers and PHY interact

- We want to make ReRaNP available to External Users
- Large community using USRP
- LabVIEW Communications MIMO Application Framework
  - Portable development from 4-128 antennas

“All the proof of a pudding is in the eating.”
Scientific Motivation

- Massive MIMO can give spatio-temporal focusing

- Massive MIMO can give less variability of channels
From First Test to Current Testbed
An Iterative Process
“Non-Scientific” Challenges when Building a Massive MIMO Testbed

- Power
- Heat
- Weather and water proofing
- Mechanical strength
- Transportation / Vibrations
- Expansions
- Cost

- Data handling
- Service friendly
- Reconfigurable
  - (128, 64, 32..)
- Cable management
- Symmetrical design
  - Phase coherence
- Design / wow-factor
- … Documentation
# Power Consumption Estimates

<table>
<thead>
<tr>
<th>Description</th>
<th>Power (W)</th>
</tr>
</thead>
<tbody>
<tr>
<td>64 x USRP @ 44W</td>
<td>2800</td>
</tr>
<tr>
<td>7 x UT @ 100W</td>
<td>700</td>
</tr>
<tr>
<td>6 PXIe + 2 controllers + FPGAs</td>
<td>1200</td>
</tr>
<tr>
<td>6 rack x support system @ 250W</td>
<td>1500</td>
</tr>
<tr>
<td>UPS power loss</td>
<td>1000</td>
</tr>
<tr>
<td>6 racks x fans @ 400W</td>
<td>2400</td>
</tr>
<tr>
<td>Cooling (air condition)</td>
<td>3000</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>13000</strong></td>
</tr>
</tbody>
</table>

- **Annual power consumption 113 MWh**
  - (Annual power consumption of 6 residences or 13 apartments.)

Approx 110 switching power supplies.
- 10A inrush => 1110A, **30A in-rush => 3300A**
Rack Power Overview

**Full remote control**
- Controller cards: autonomous / remote override
- USRP: individual power control
  - Startup delay and interval: programmable
- UPS: controlled for soft generator start.
- Operate from 10A /16A outlet.
- Modular design with focus on reuse.

**Power Distribution Unit**
1U PDU, controlling power/cooling.

**Sub-rack** (Control module)
- Power control module
- Raspberry Pi
Heat & Cooling

Solution with Uniform Temperature on all USRPs

- Uniform temperature on all USRPs.
- Two USRPs share one cooling zone.
- Each zone has separate fan speed regulation
- Airfoil guide cool outside air to regulate intake air on USRP sub-racks.
- Air gap and air flow between USRPs ensure cooling from both fan and USRP case.
Heat & Cooling

Airflow in Sub-rack

- USRP sub-racks (8 SDR)
  - 4 in fans
  - 4 out fans
- Original USRP cooling operates
- Fan control for each fan
  - Speed control
  - Monitoring
- 278 cooling fans

Cooling zone with 1 in fan, 1 out fan and 2 USRPs
Heat & Cooling

Airflow in Rack

- Controlled airflow inside sub-racks and rack
- During warm up, air-flow is reduced for rapid heat-up and stabilization
  - Preheating optional
- Individual control of all fans allow for setting over pressure to prevent dust and water ingressation.
- Air guides to control air flow
Weather and Water Proof Cooling
Filtering approx. 600 m³/h (21 200 ft³/h) of air

Air funnel
Reduce air speed in intake filter. Larger filter last longer

Slope up to fans
Prevents water from reaching the fan. Any water flow along the door and do not come in contact with the equipment

IP55 (or IP54) filter
Filters dust, rain and snow

Angled air “grades”
Prevents heavy rain from direct contact with air filter. Mechanically protects the filter
Weather and Water Proofing

- ReRaNP is meant to be placed **outdoor**
  - in all kind of Norwegian weather
  - to do real life measurements.
- Ingress Protection (IP) **IP44** as a minimum.
- 128 antenna cables, and a handful system cables, IP-ed
  - Allowing for easy disassembly and assembly
- Weather proofing of all access areas.
Weather and Water Proofing

Rubber seal on all doors

Modular rubber seal for cable transits
- Allows for terminated cable to be installed.
- Reconfigurable according to needs.
Weather and Water Proofing Antennas

- Water proof glass fiber domes for antennas
  - Horizontal or vertical mounting
  - Cable transit pipe and back plane hatch allows re-cabling and water ingress protection.
Maritime Radio Measurements
Service Friendly

- Measurement campaigns are expensive.
  - Downtime must be kept as short as possible.
- Experimental equipment require constant tweaks and reconfigurations.

GOAL: Any failure should take less than an hour to fix.
  - Given availability of spare parts

Measures taken:
  - Easy access to equipment
  - Modular design and reuse of parts.
  - Spare parts made and bought
All units are rack mounted.

All USRPs are sub-rack mounted.
- USRP mounted on metal panel
- 8 USRPs in a sub-rack
- 2 sub-racks in a rack
- Total of 8 sub-racks
Service Friendly Cable Management

- “All” cabling in front
- Cables crossing modules kept to a minimum.
- Each cable type mainly kept in its dedicated area

- Data cables
- Synchronization cables
- Radio cables
Service Friendly Patch Panel for Antenna Cables

- Easy connect / disconnect
- No mechanical stress on USRP connectors
- Saves SMA connectors for wear.
- Aligned with cable transit modules.
- Easy replacement of patch cable

QMA connectors
- Push – click – locked
- Mechanically rigid
Mechanical Challenges

- 6 racks at approx. 200-300kg pr rack
- Stable mounting for USRPs, controllers and support equipment.
- Secure cable mounts.
- Vibration and resonance in transport.
- Crane lifting
- Compact design?
  - Fit in a container on the back of a truck
Mechanical

Custom made Schroff rack
- Rigid rack design with hoisting lug
- Double rail design
- Compact short design (fit in container)

Extra back mounts on heavy units
<table>
<thead>
<tr>
<th>Fan Holder</th>
<th>Backplane Control Module Interface holder v1.1</th>
<th>PSU Bracket</th>
</tr>
</thead>
<tbody>
<tr>
<td>Terminal block holder backplane</td>
<td>Backplane Control Module Interface holder id v1.1</td>
<td>PSU Bracket mDIN</td>
</tr>
<tr>
<td>Conduit 6d C34</td>
<td>Maxi-cable tray backplane v1.2</td>
<td>Fan airflow guide</td>
</tr>
<tr>
<td>Conduit 6d</td>
<td>US6E holder top back</td>
<td>C6 PSU holder</td>
</tr>
<tr>
<td>Min-Cable holder</td>
<td>US6E holder bottom back</td>
<td>Terminal tab block holder v1.1</td>
</tr>
<tr>
<td></td>
<td>Terminal blockalsholder v1.4</td>
<td>Control module backplane interface holder v1.4</td>
</tr>
<tr>
<td></td>
<td>Intake fan airflow guide v1.1</td>
<td>12mm to 52mm fan adapter v1.1</td>
</tr>
</tbody>
</table>

Mechanical 560 3D Printed Parts

National Instruments
Data Handling
Data Flow  2 GB/s measurement data

Level based data storage
In house for security (GDPR, etc.)
Re-use of existing computing solution

Each level solve a specific part of the data handling

- **L0  Controller**  3TB @ 3GB/s
- **L1  Measurement stream**  6TB @ 7.5GB/s
- **L2  Campaign storage**  96TB @ 1.2GB/s
- **L3  Post proc./pre-archive**  40TB @ 1.2GB/s
- **L4  Archiving**  423TB @ 0.3GB/s
ReRaNP Configurations

- Log-periodic elements
  - Gain 6 dBi
  - Frequency range 1.4-6GHz
- Element separation $\geq \lambda/2$
- 4 sub-array of 32 elements (8x4)
  - One sub-array per SDR-rack

Antennas

- Vary vertical / horizontal sub-array separation and direction
- Antenna polarization in 45º increments.
ReRaNP Configurations

Racks

- 1 x 128 antennas
- 2 x 64 antennas
- 4 x 32 (28) antennas
ReRaNP Fun-Facts

- 3D printed
  - 30 different designs.
  - 560 3D printed parts
  - 655 hours of continuous printing (given no breakdowns)
  - Total about 20kg of plastic.

- 124 custom made metal parts.

- 7728 bolts and nuts
  - for the sub-racks only.

- 1216 self-made wires and cables.
  - 597 bought cables

- >1 mile of RF cables

- 50 self-made circuit boards.
- 272 cooling fans.
- 7041 technical design files. (522 GB)
- 70 FPGAs for data processing.
  - 5.5M LUTs
  - 27k DSP modules
- Capable of generating 1.4Tb/s of network traffic

13 kW consumed to generate 13W of RF power.