Online Energy Consumption Monitoring of Wireless Testbed Infrastructure through the NITOS EMF Framework

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Introduction

- ✓ Energy Consumption Minimization is considered as a major goal in numerous research fields, including Wireless Networking.

1. Unprecedented penetration of ”smart” mobile devices along with their high power consumption profile:
   - ✓ Dramatic increase of exchanged mobile data (~8x till 2017)
   - ✓ Resource-demanding applications
   - ✓ Multi-core processors and high-resolution displays
   - ✓ Multiple communication technologies, supporting increased data rates

2. Existing battery technologies cannot meet the increased energy demands (battery capacity limits double every 10 years).

Researchers require accurate tools to evaluate the energy efficiency of proposed protocols and architectures.

Outline

- Energy Consumption Monitoring
- NITOS EMF (Energy Monitoring Framework)
  - Hardware
  - Software
  - Architecture
- Low-level Experiments
- Realistic Testbed Experiments
- Ongoing Work

Energy Consumption Monitoring

- Traditional Energy Consumption Models consider only the energy consumed during specific operations, such as:
  - the **transmission / reception of a single frame** of specific length and under fixed PHY-layer bitrate configurations
  - operation in specific modes: **idle/sleep, etc.**

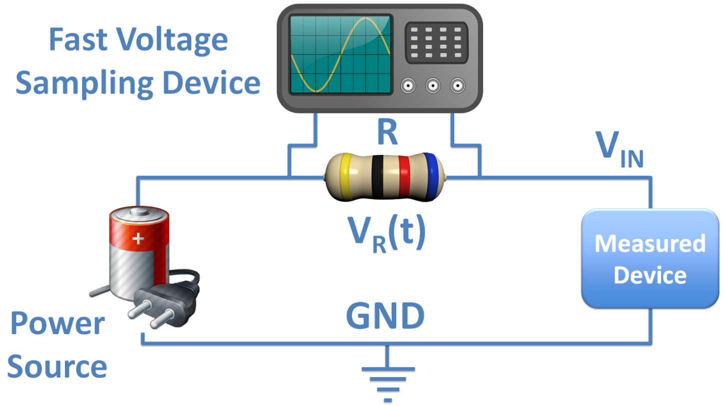
- However, such models cannot realistically take into account effects induced by:
  - External factors (**channel interference**, etc.)
  - Simultaneous operation of several wireless devices (**medium contention, idle listening**, etc.)

- **WE CANNOT** rely just on monitoring of specific events

- **WE HAVE** to be able to measure the total Energy Consumption during the execution of realistic experiments.

Energy Consumption Monitoring

- ✓ Power consumption can be determined by direct measurement of the input voltage and current draw at the device under test.
- ✓ Actual measurements can be taken using a fast voltage sampling device, as follows:



- ✓ The instantaneous **power consumption** is the product of the input voltage and current draw on the current shunt resistor **R**:

$$P(t) = V_{IN} \frac{V_R(t)}{R}$$

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Energy Consumption Monitoring

- Total Energy Consumption over an interval **Δt= t1–t0** is calculated as the integral of power consumption:

$$E_{t_0 \ldots t_1} = \frac{V_{in}}{R} \int_{t_0}^{t_1} v_r(t)dt$$

- **dt** corresponds to the infinitely small observation duration and equals the inverse of the sampling rate

- Duration (**Δt**) of a single Frame Transmission or Reception can be directly obtained as the product of frame length and the configured PHY-layer bitrate.

- In the case that we are monitoring a whole experiment **Δt** corresponds to the total experiment duration.

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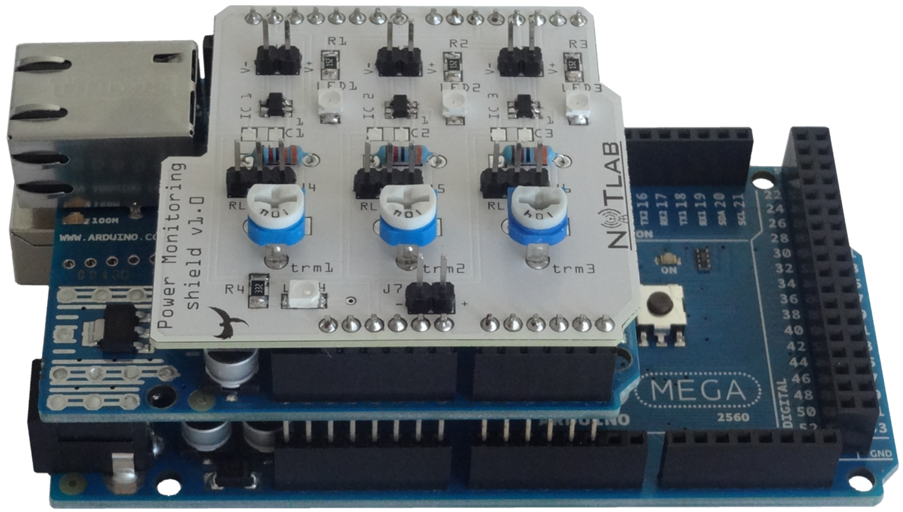
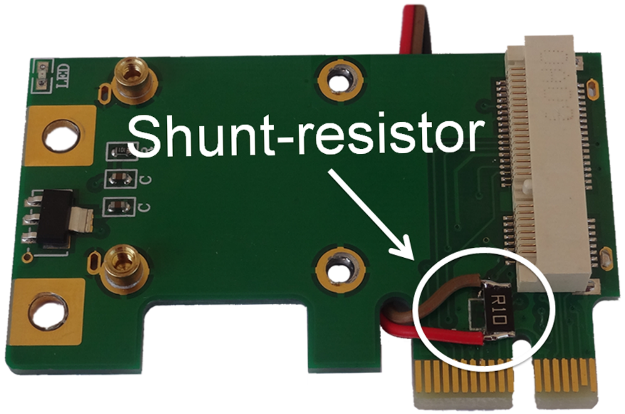
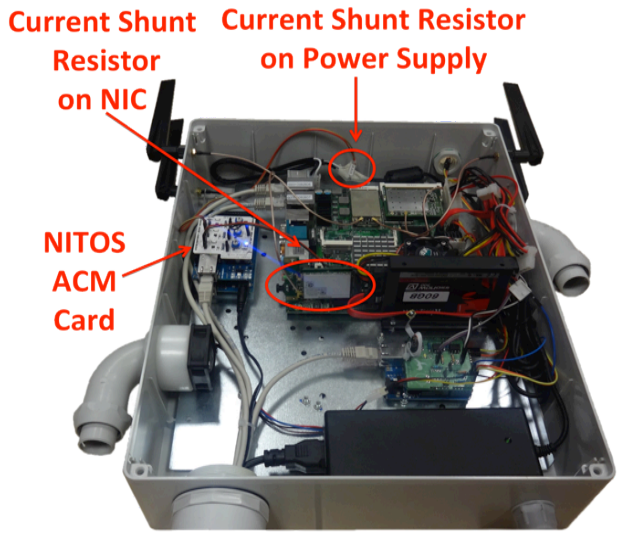
NITOS EMF - Hardware



- We developed the Advanced version of the NITOS CM card, which is composed of several commercial and custom components:
  - **Arduino Mega 2560**
  - **Ethernet Shield with SD card**
  - **Custom Shield integrated with the INA139 IC**
  - **Custom mini-PCIe adapters**

NITOS EMF - Hardware





- The Arduino Mega 2560 faces three significant disadvantages:
  - **Low accuracy (10-bit in the 0-5V range)**
    (2W -> 60mV voltage drop on a resistor of 0.1Ω => 12 discrete values)
  - **Low sampling rate of 10 KHz**
    (IEEE802.11n frame transmission at 450Mbps lasts 27μs, which corresponds to the lowest required sampling rate of 37KHz)
  - **Low measurements transfer rate of 115 Kbps**
    (restricted due to the BW limitation of the Serial Arduino interface)

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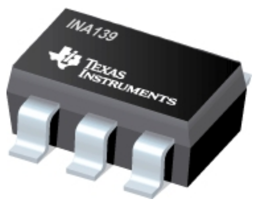
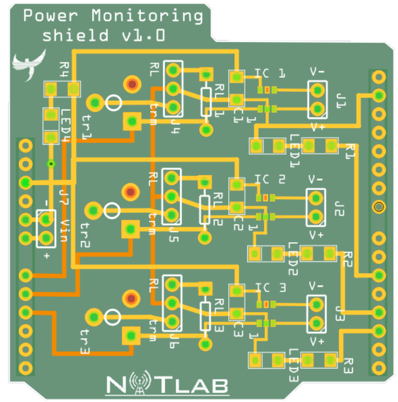
NITOS EMF - Hardware



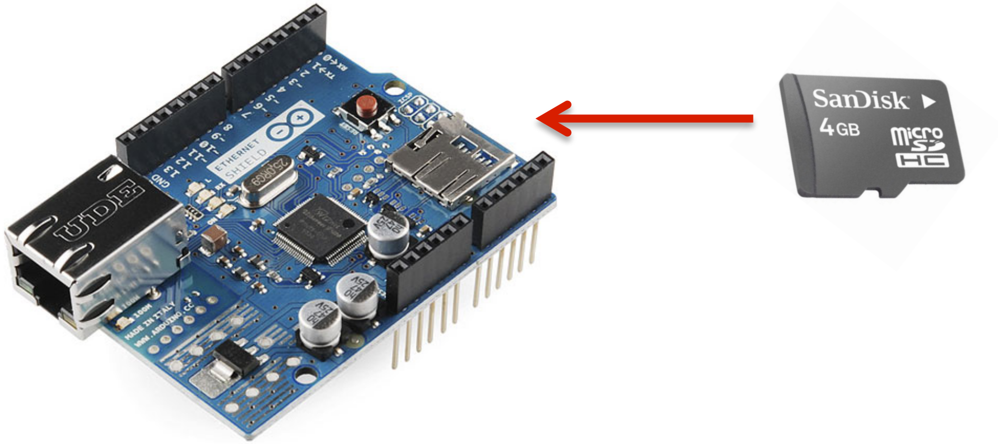
Texas Instruments INA139



Designed PCB

- **Solution to the low accuracy performance:**
- Custom shield integrating the **INA139** module, which converts a differential input voltage to an amplified value, where the amplification level is controlled through an external load resistor (RL) and can be set from **1 to over 100**.
- The amplification level is selected based on the maximum consumption of the measured device (27KΩ for 2.5W wireless transceivers)
- Reduced the reference voltage from **5V to 2.65V (~2x accuracy in the selected range)**

NITOS EMF - Hardware



Ethernet Shield with attached SD card

- **Solution to the low transfer rate issue:**

- Enable online fast data logging to the Ethernet Shield’s SD card

- Subsequent transfer of measurements in an asynchronous distributed way through the Ethernet interface, in the end of the observation period

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NITOS EMF - Software

ARDUINO

- **Solution to the low sampling rate performance:**
- Modified the ATmega2560 ADC through low-level configurations:
  - Enable free-running mode
  - Increase ADC Prescaler clock speed from 125KHz to 1MHz

- Increased sampling rate to **63 KHz**,
with 10-bit resolution in the **0-2.65V** range.

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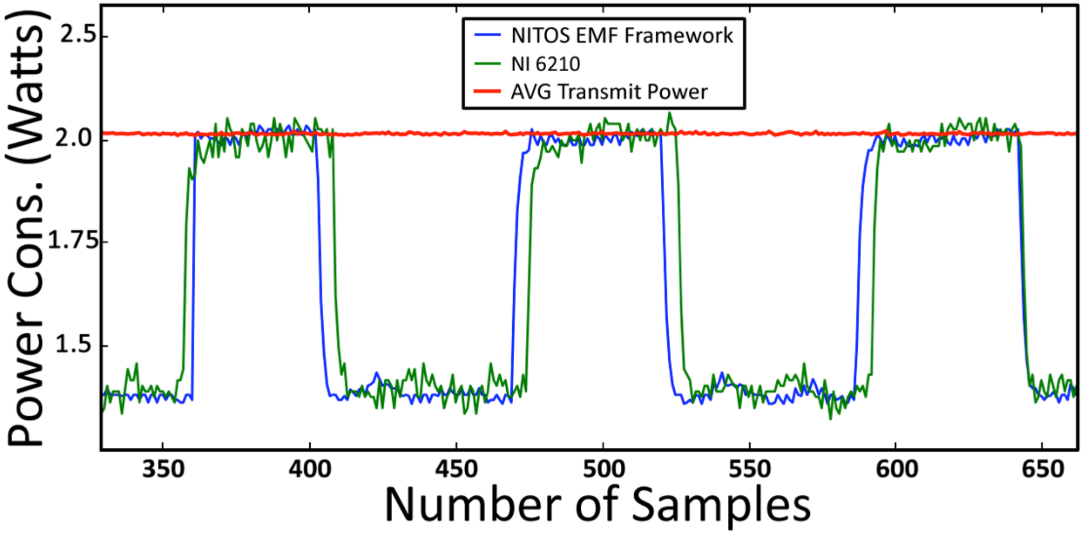
NITOS EMF - Software



- **Python-based software:**
  - Direct access to the collected results
  - Precise Power and Energy consumption calculations.
  - Plotting component depicting comparisons between measurements gathered through the developed framework and the high-end **NI-6210** device.

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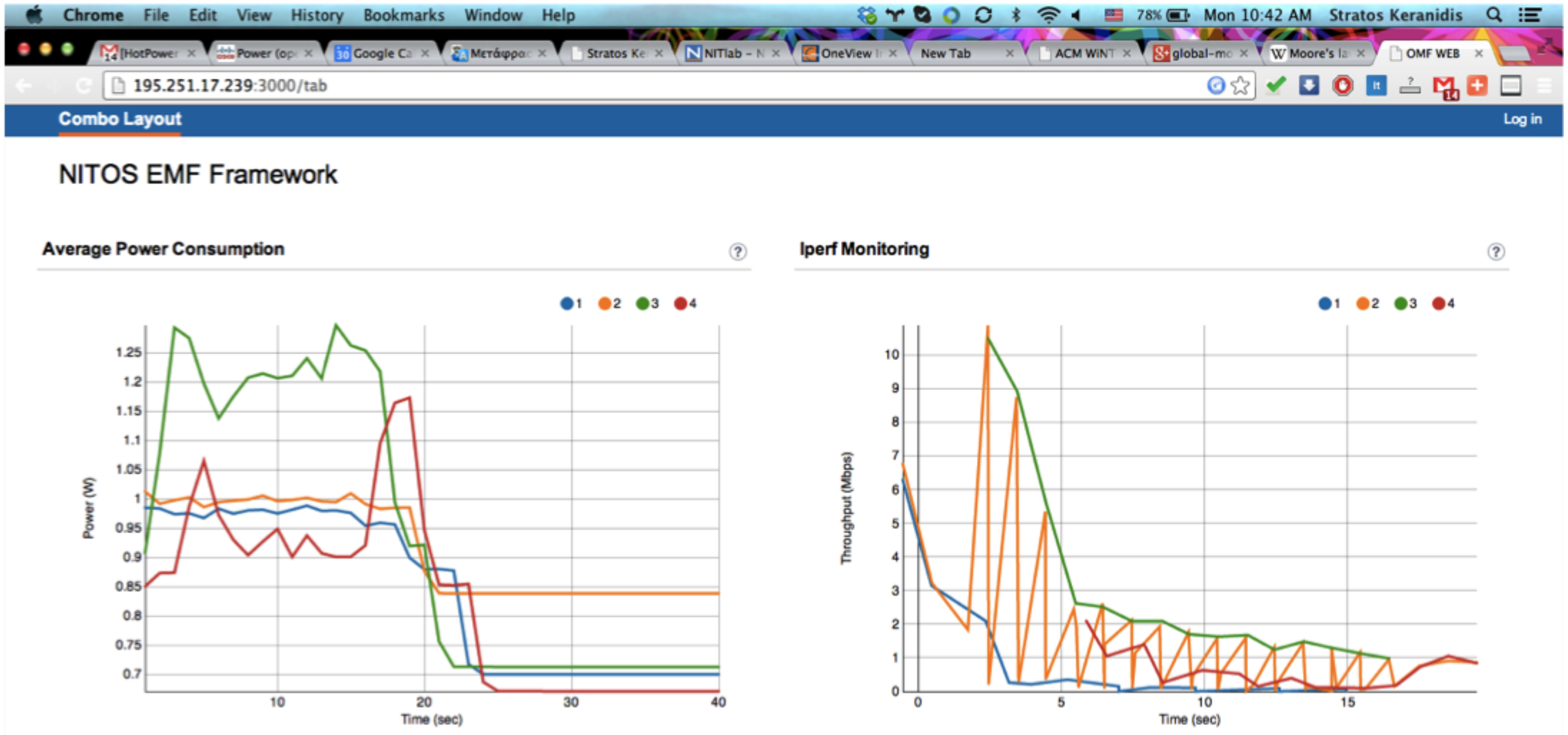
NITOS EMF - Software

NITOS EMF is fully integrated with the

OMF Control and Measurement Framework



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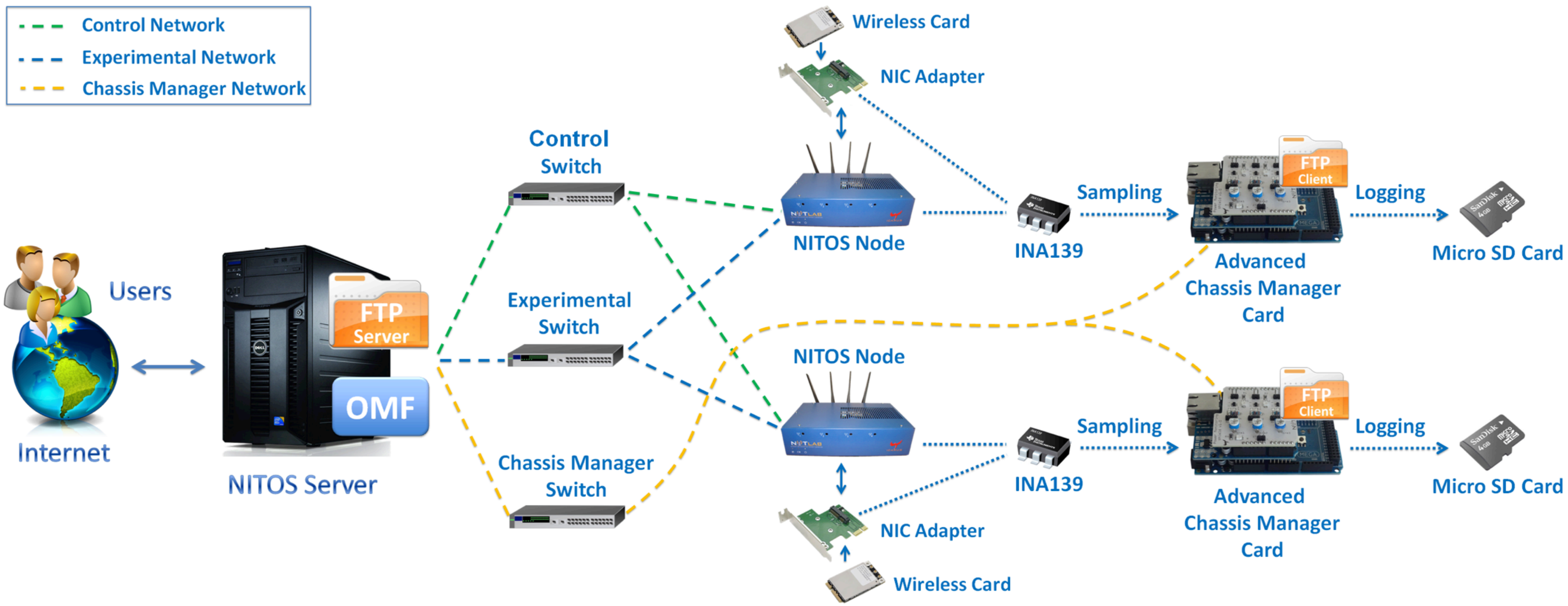
NITOS EMF - Architecture

Integration with NITOS Testbed architecture



NITOS EMF - Advantages

- ✓ Online Monitoring of realistic testbed experiments
- ✓ Distributed Architecture through Network communication
- ✓ High Accuracy (comparable with high-end devices)
- ✓ High Sampling Rate (63 KHz)
- ✓ Highly Adaptable to heterogeneous devices
  (wireless nodes/ cards, sensors, mobile phones, etc.)
- ✓ Low-cost (less than 80€)

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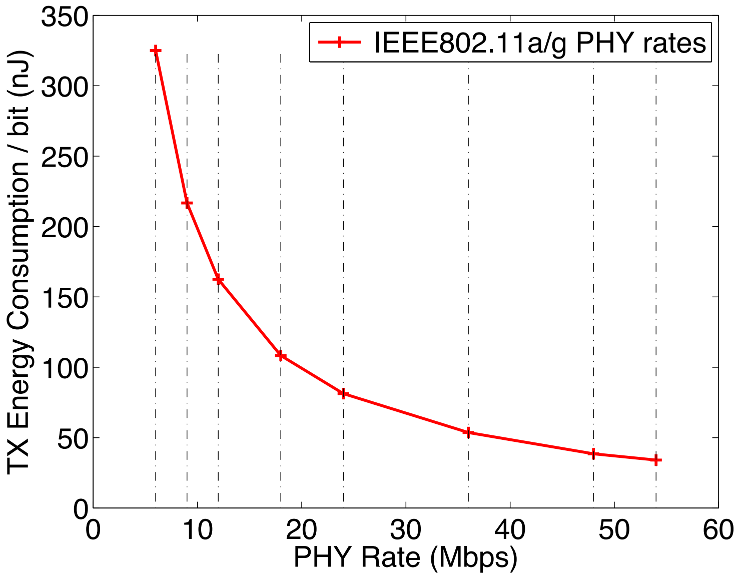
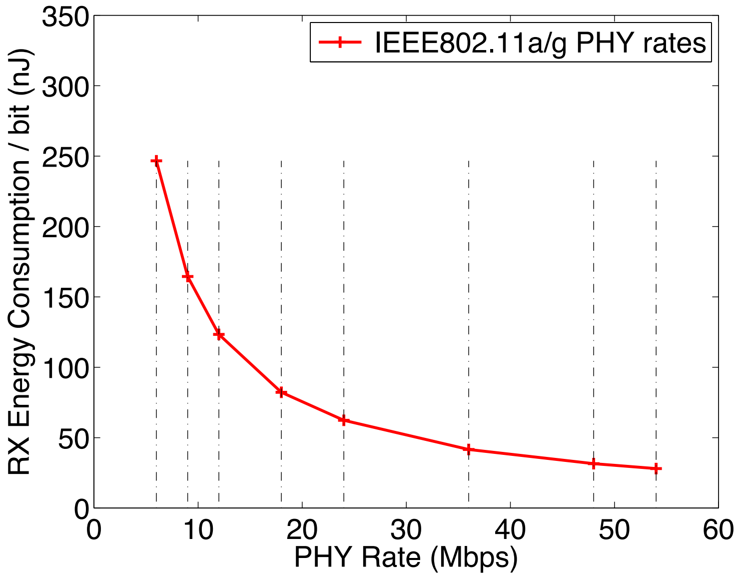
Low-level Experiments

802.11a/g – AR5424

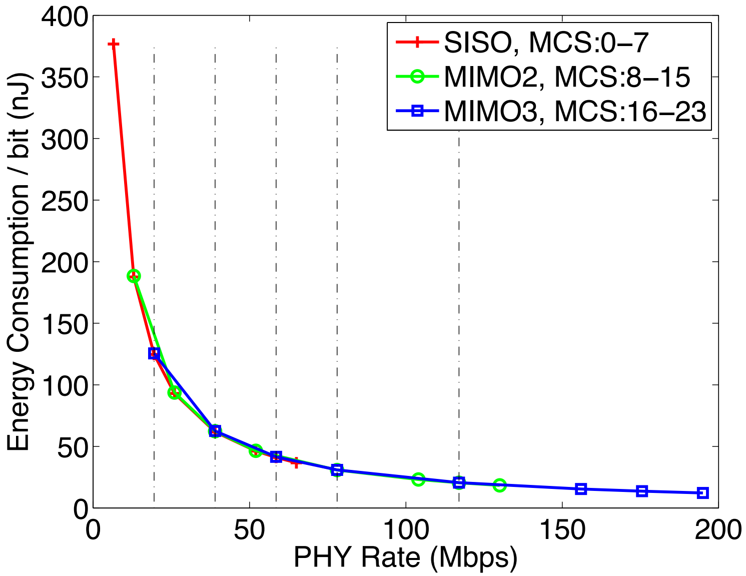


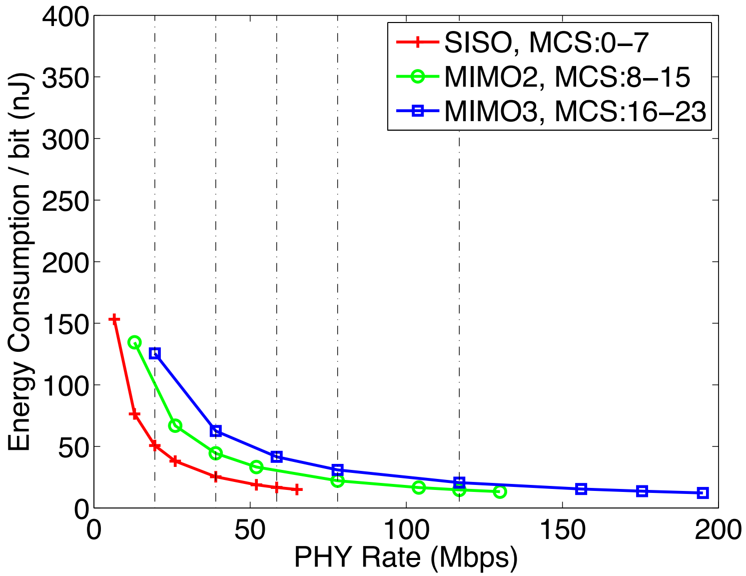


Increase of PHY bit-rate efficiently reduces Energy consumption/bit

Low-level Experiments

802.11n - MIMO – AR9380

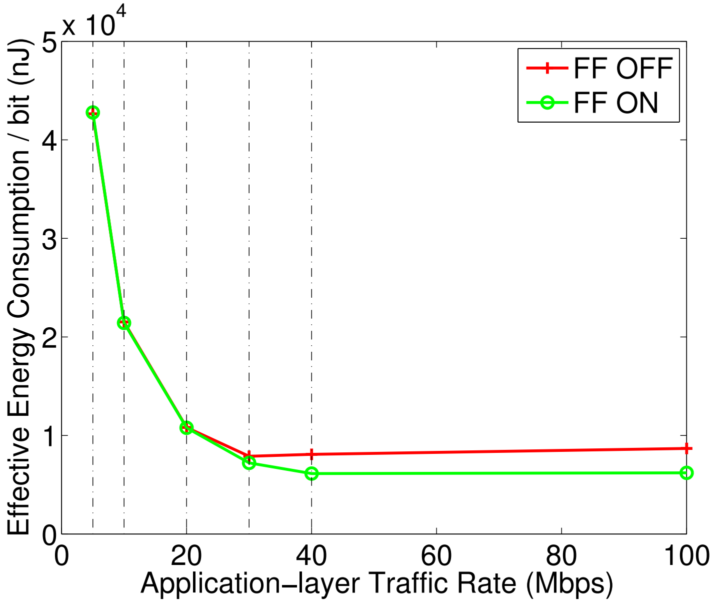


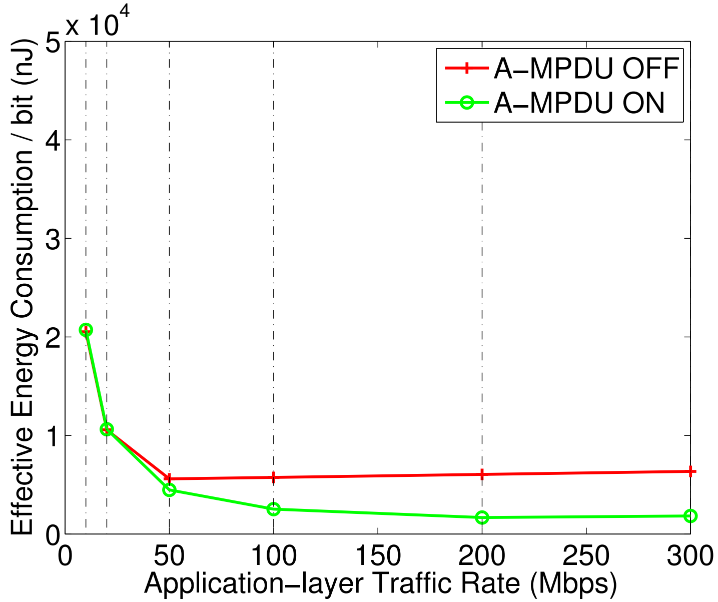


Proper Activation of the required number of RF-chains can increase energy savings up to 60%

Low-level Experiments

Energy efficiency comparison between
802.11a/g – 802.11n





802.11n reduces Energy consumption/bit,
on the total node level, by more than 75%

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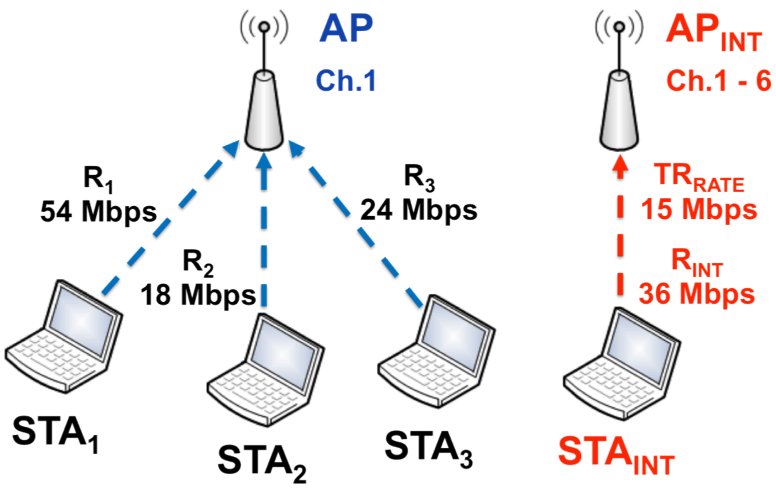
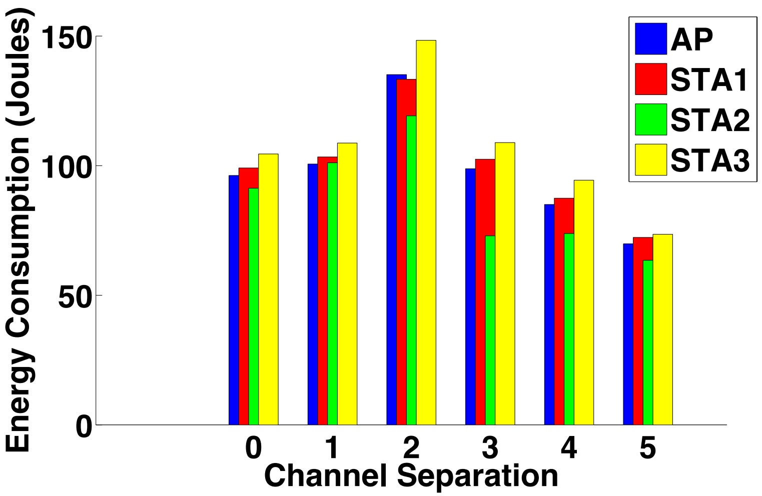
Realistic Testbed Experiments

File uploading of multiple 802.11a/g clients across different channels





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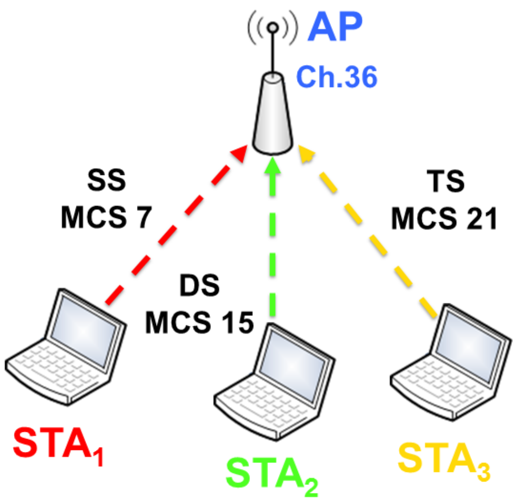
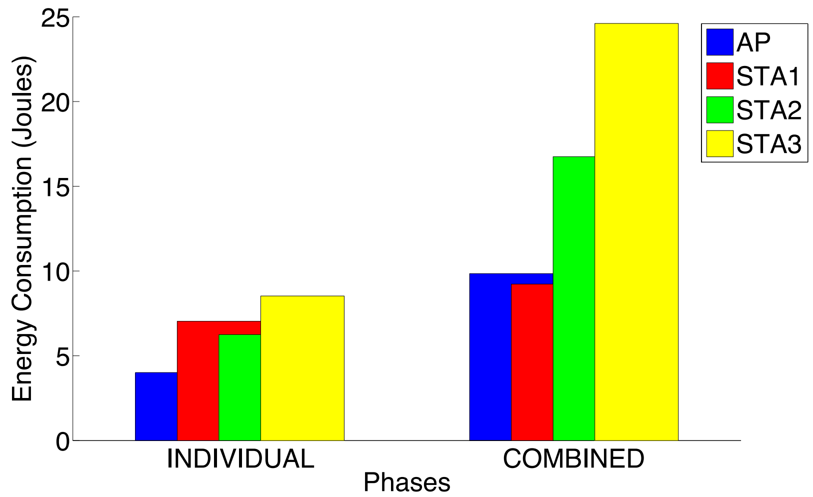
Realistic Testbed Experiments

File uploading of multiple 802.11n clients
Both individually and simultaneously





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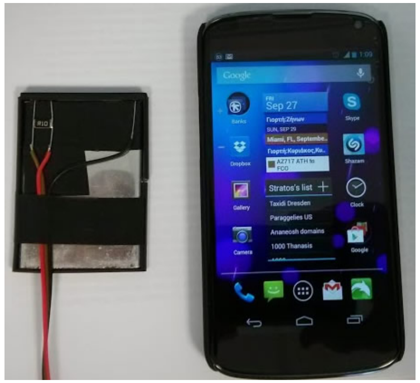
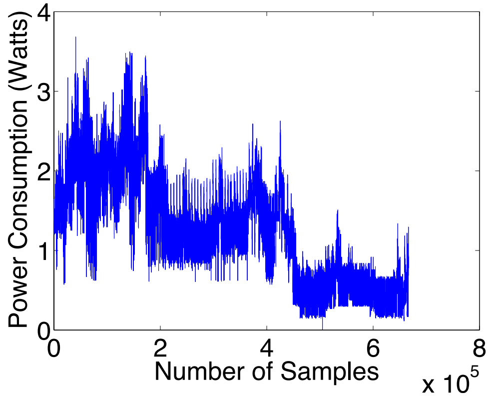
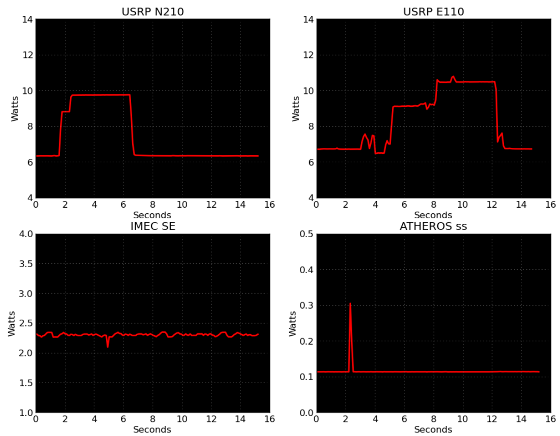
Ongoing Work

Power Consumption Characterization of Mobile Phones and Spectrum Sensing Devices





USRP N210 | USRP E110 | IMEC SE | ATHEROS SS



Thank You!