Experimental Evaluation and Comparative Study on Energy Efficiency of the Evolving IEEE 802.11 Standards

Presenting: *Giannis Kazdaridis*

Email: iokazdarid@gmail.com

Authors: *Stratos Keranidis, Giannis Kazdaridis, Nikos Makris, Thanasis Korakis, Iordanis Koutsopoulos and Leandros Tassiulas*

Date: *11/06/2014*

Conference: *e-Energy, Cambridge, UK*

CERTH

NITLAB
NETWORK IMPLEMENTATION TESTBED LABORATORY

UNIVERSITY OF THESSALY

Our Direction

- ✓ In this work we characterize the Energy efficiency of 802.11n across varying:
  - ✓ Traffic loads.
  - ✓ Protocol parameters
  - ✓ Topology configurations.

- ✓ We especially compare our findings with the base standard 802.11a/g to show the improvements that it provides.

- ✓ We expect our detailed findings to act as guidelines for the design of novel adaptation algorithms and future protocol versions.

Outline

- ✓ Introduction
- ✓ Measurement Set-Up
- ✓ Realistic Experimentation:
  - ✓ Varying Application Traffic Load
  - ✓ Varying Frame Payload Length in High-SNR environment
  - ✓ Varying Frame Payload Length in Low-SNR environment
- ✓ Conclusions

IEEE 802.11n penetration in the market

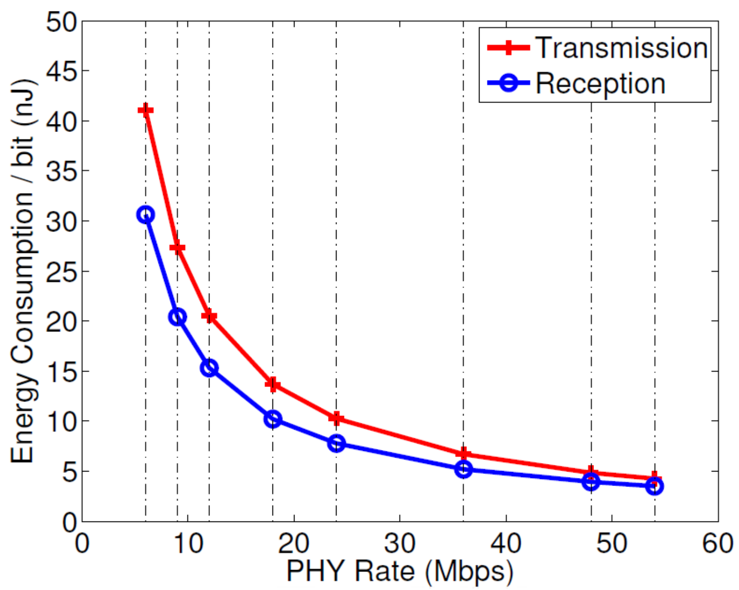
- ✓ During the recent years the "smart" mobile devices existing in the market support the IEEE 802.11n standard in an effort to provide high-throughput performance.

- ✓ Till now, only network performance was the main concern.

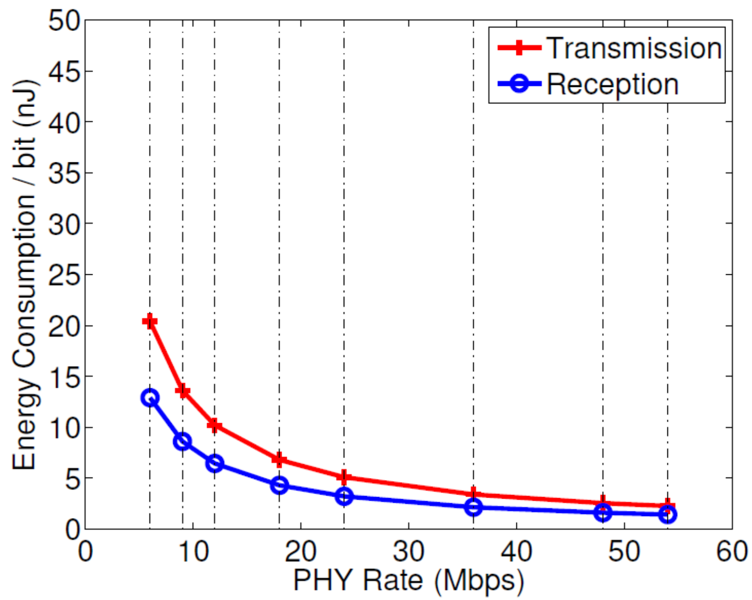
- ✓ However, the **restricted battery autonomy** of mobile devices has raised concerns regarding the energy efficient operation of the wireless transceivers.

IEEE 802.11a/g Energy Profiling

- ✓ The base standard IEEE 802.11a/g is characterized by **linear relationship** between the **energy** consumption per bit and **PHY-layer transmission/reception.**



AR5424 chipset

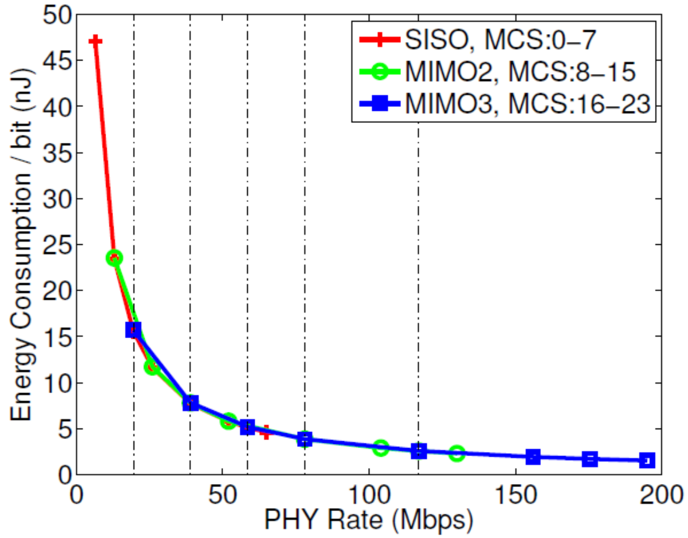


AR9380 chipset

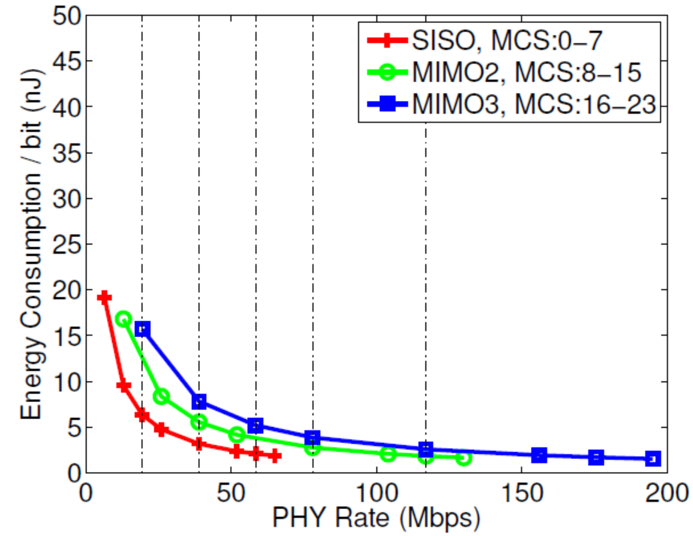
Energy Consumption per bit of IEEE 802.11 compatible NICs

IEEE 802.11n Energy Profiling

- How is the consumption of the MIMO enabled 802.11n affected, across varying physical-layer rates?



All chains active



Only required chains active

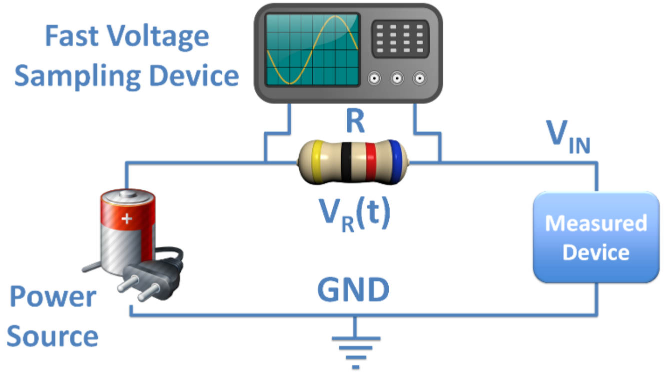
- **Activation of additional RF chains** that enables MIMO communication results in remarkably increased power consumption saving (up to 2.5x at the NIC level).
- Those are the nominal energy per bit values.
- What happens under realistic environments in complex configurations?

Outline

- Introduction
- Measurement Set-Up
- Realistic Experimentation:
  - Varying Application Traffic Load
  - Varying Frame Payload Length in High-SNR environment
  - Varying Frame Payload Length in Low-SNR environment
- Conclusions

Energy Monitoring Framework (EMF)

- ✓ 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:

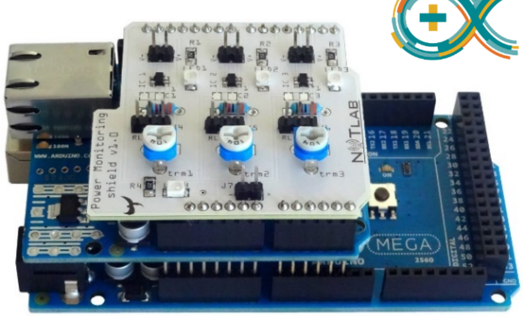


- ✓ The instantaneous power consumption is the **product** of the **input voltage** and **current draw** on the current shunt resistor **R**:

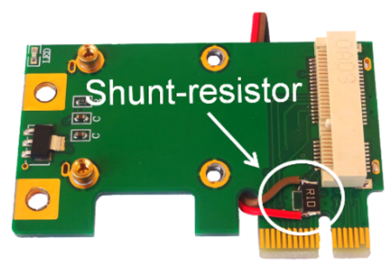
$$P(t) = V_{IN}\frac{V_R(t)}{R}$$

Energy Monitoring Framework (EMF)

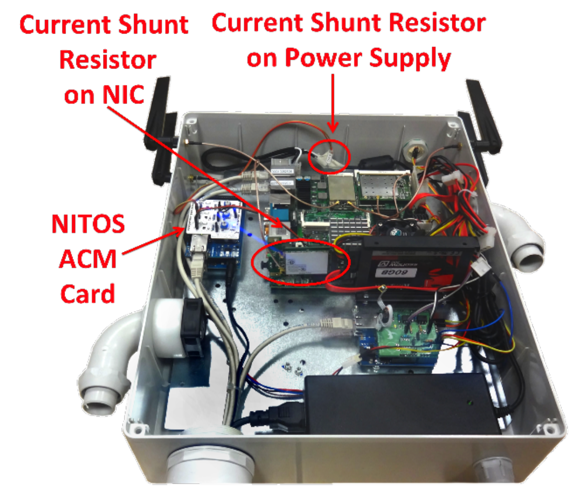
- ✓ We developed a special card that allows online monitoring of wireless testbeds infrastructure.
- ✓ The developed card is composed of open-source commercial and custom-made components, mainly based on Arduino compatible modules.
- ✓ The developed card is installed in NITOS testbed nodes and together with the developed OMF service allows remote experimentation to NITOS users.



Developed Energy Monitoring Device



Modified mini-pcie adapter that allows monitoring of Wireless Interfaces



Monitoring Device Installed in NITOS node

Equipment employed for the experiments

- In the experimental phase we employed two wireless interfaces:
  - An Atheros IEEE 802.11a/g compatible:
    - AR5424 chipset.
    - madwifi open-source driver.
  - An Atheros IEEE 802.11n compatible:
    - 3x3 MIMO.
    - AR9380 chipset.
    - Ath9k open-source driver.

Atheros 802.11 a/b/g

QUALCOMM ATHEROS

Atheros 802.11n 3x3

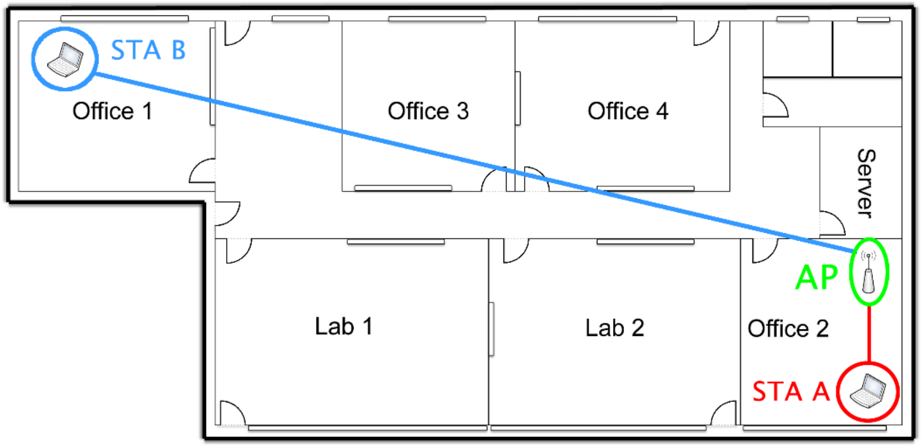
Component	Type
Motherboard	Commell LE-575X
CPU	Intel Atom D525 (1.8 GHz)
RAM	Kingston HYPERX DDR3 - 4GBs
Hard Drive	Samsung SSD - 64 GBs
Power Supply	60W - 12V
OS	Ubuntu 13.04
Wireless cards	Atheros 9380 / 5424
Wireless Drivers	madwifi-0.9.4 / backportsv3.12.1

Node specifications

Icarus Node

Measurement setup – Experimental Topology

- We create two different setups:
  - One with **high-SNR**:
    - Nodes closely located.
    - Tx power at maximum (20dBm).
    - Illustrates the benefits of spatial multiplexing in terms of energy.
  - And one with **low-SNR**:
    - Nodes far located.
    - Tx power at minimum (0dBm).
    - Illustrates the benefits of spatial diversity in terms of energy.



Experimental Topology

Outline

- Introduction
- Measurement Set-Up
- Realistic Experimentation:
  - Varying Application Traffic Load
  - Varying Frame Payload Length in High-SNR environment
  - Varying Frame Payload Length in Low-SNR environment
- Conclusions

Varying application traffic load

- In this experiment we **vary** the **application traffic load** and measure the power consumption in each setup on **both the NIC and total node level**.

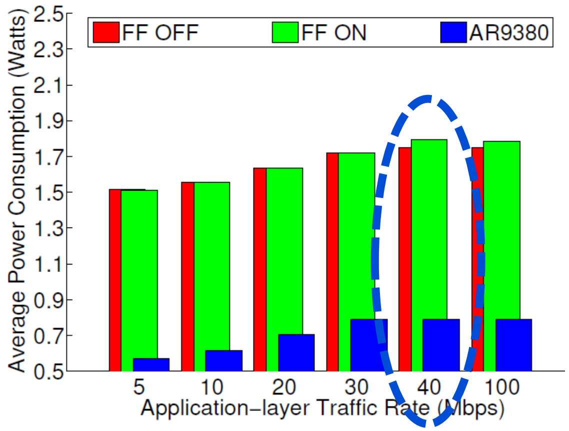
- We repeat the same experiment by activating the supported **MAC-layer aggregation** mechanisms of each setup:

  - 802.11a/g: **Atheros Fast Frames**:
    - Combines two MAC-frames into the payload of a single aggregated frame.

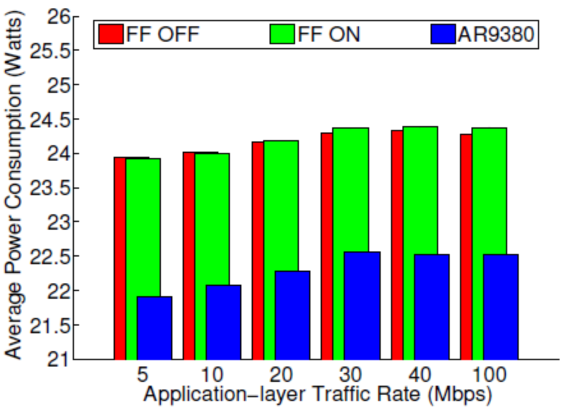
  - 802.11n : **A-MPDU**:
    - Combines multiple frames into a single MAC layer frame without exceeding the 65.536 bytes.

Varying application traffic load – Pow. Consumption

802.11a/g



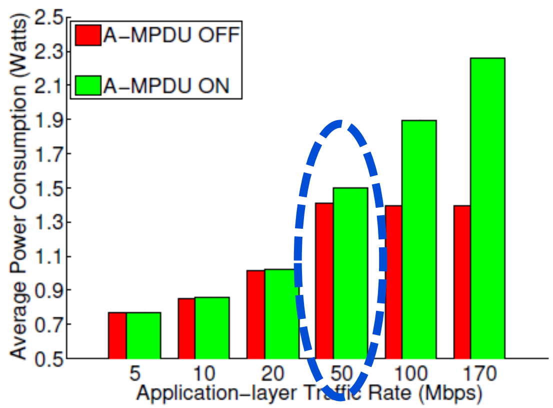
NIC level



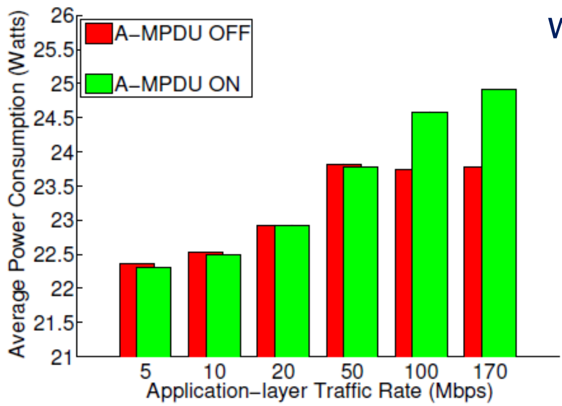
Node level

To arrive at safe results we plot the Eb

802.11n



NIC level



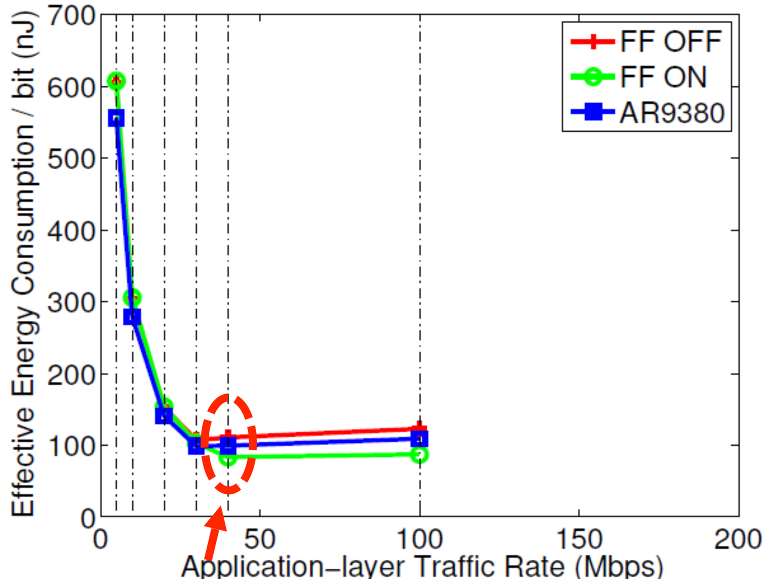
Node level

- ✓ We observe that Aggregation is activated after 40Mbps (on saturation).

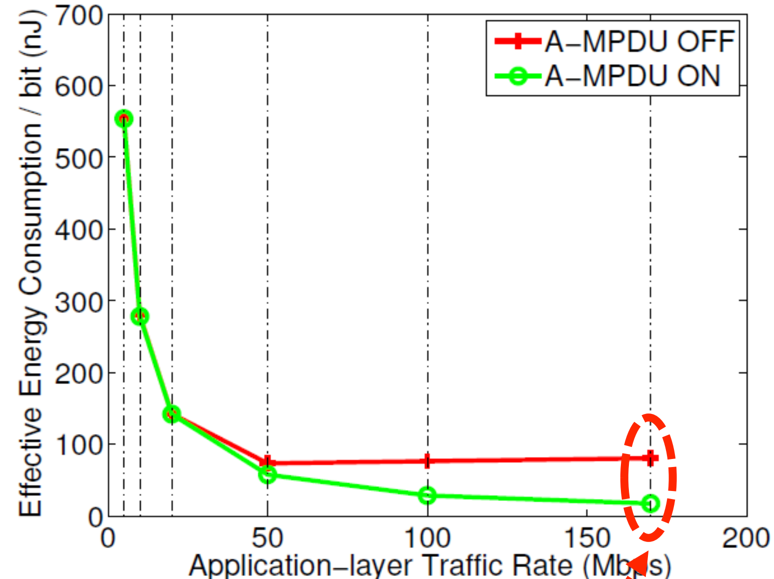
CERTH NITLAB NETWORK IMPLEMENTATION TESTBED LABORATORY UNIVERSITY OF THESSALY

Varying application traffic load – Energy/bit

- ✓ We plot the Eb.



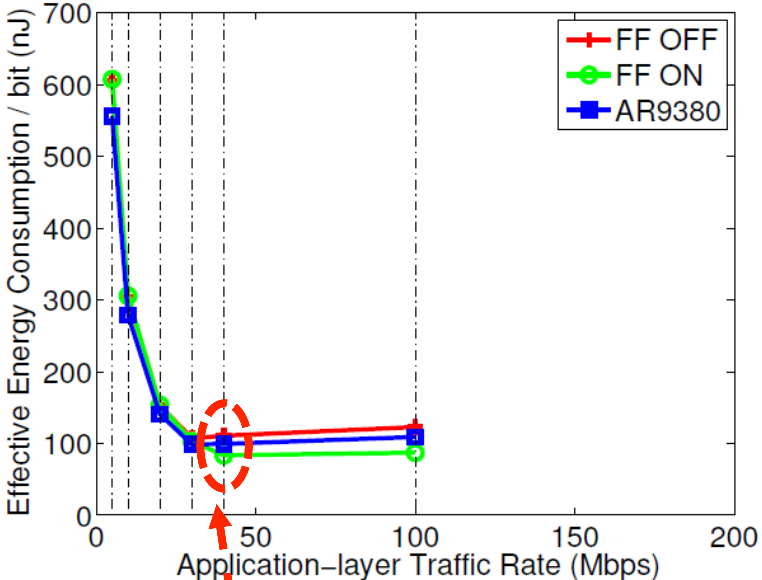
802.11a/g – Node level



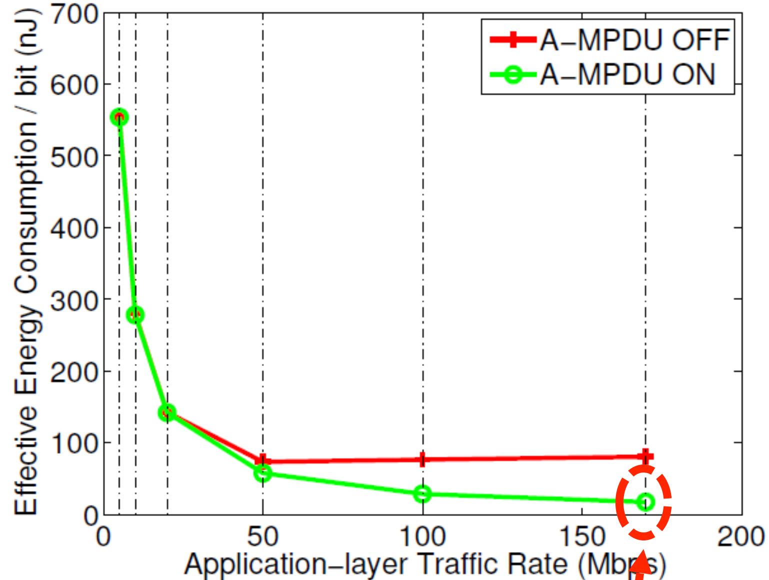
802.11n – Node level

- ✓ FF Aggregation saves up to 28% energy at node level.
- ✓ A-MPDU aggregation saves up to 78% at node level.

Varying application traffic load – Energy/bit



802.11a/g – Node level



802.11n – Node level

- ✓ The comparison of the Eb values of each standard at their **saturation points** shows that 802.11n standard offers more than **80%** energy reduction.

CERTH

NITLAB
NETWORK IMPLEMENTATION TESTBED LABORATORY

UNIVERSITY OF THESSALY

Outline

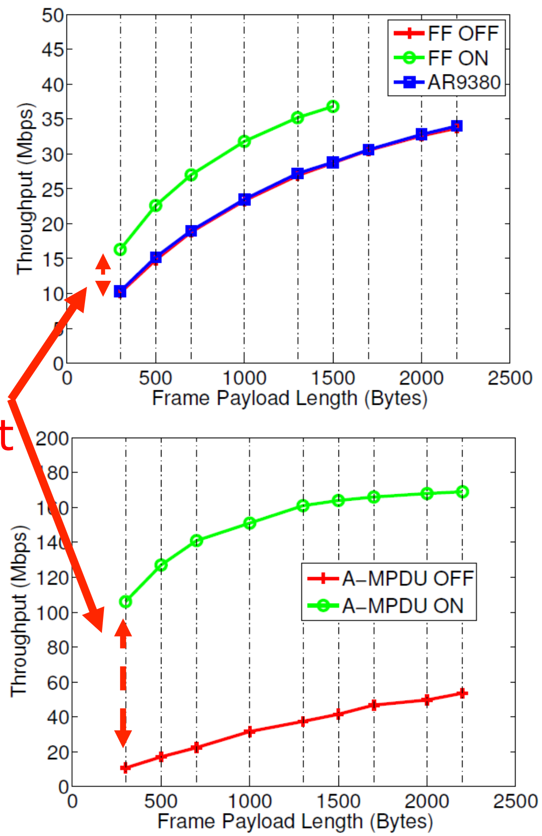
- Introduction
- Measurement Set-Up
- Realistic Experimentation:
  - Varying Application Traffic Load
  - Varying Frame Payload Length in High-SNR environment
  - Varying Frame Payload Length in Low-SNR environment
- Conclusions

Varying frame payload length – High SNR

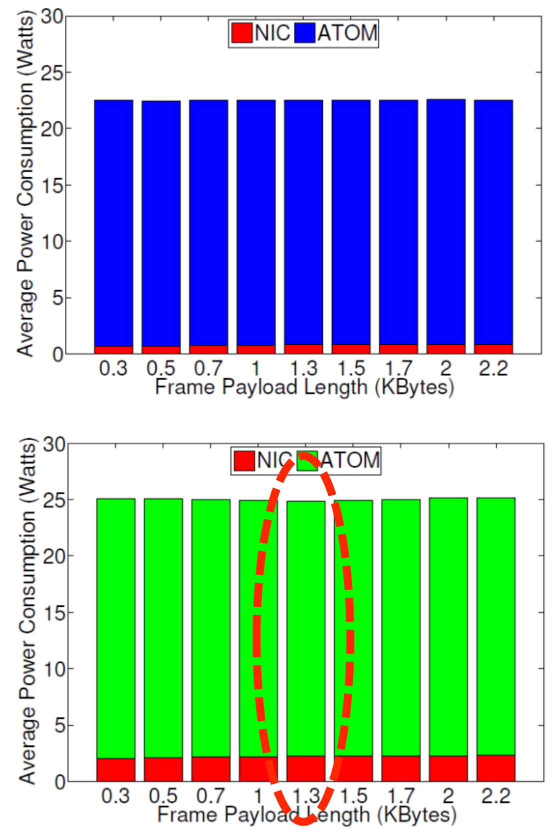
802.11a/g

802.11n

Different performance of throughput affects Eb



Throughput



Average Pow. Consumption

802.11a/g

Common Internet packet length: 576 bytes

802.11n

Frames processing costs energy

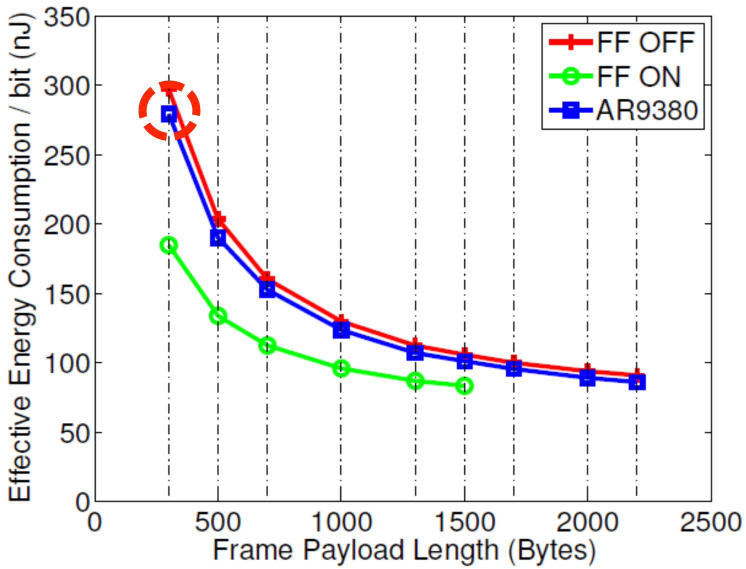
✓ We observe a reduction of **0.5W** at the node level although we achieved **an increase of 60Mbps** on throughput performance.

CERTH

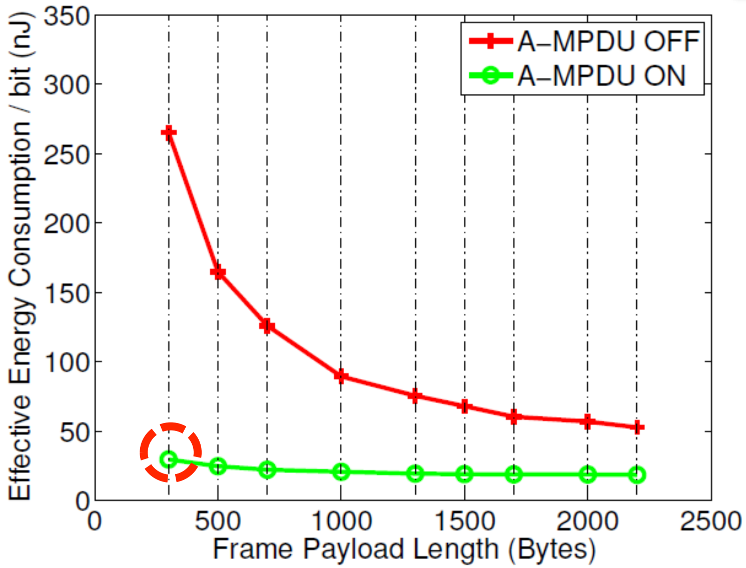
NITLAB
NETWORK IMPLEMENTATION TESTBED LABORATORY

UNIVERSITY OF THESSALY

Varying frame payload length – High SNR



802.11a/g – Eb at node level



802.11n – Eb at node level

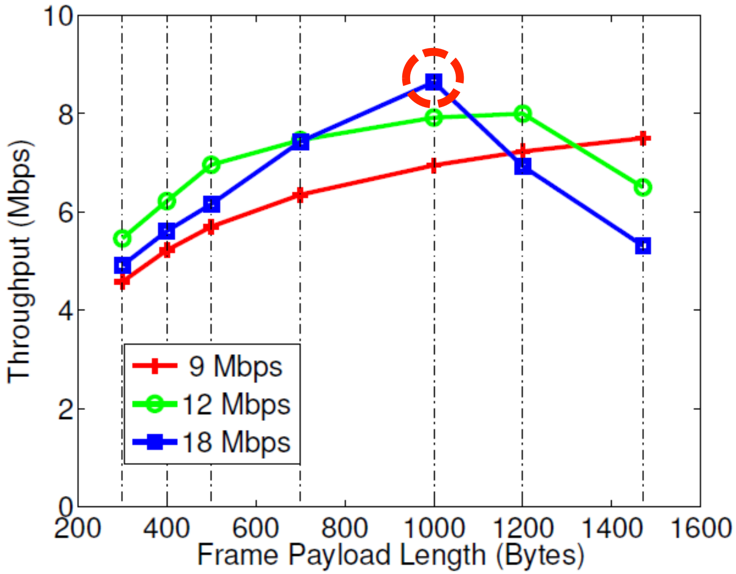
- ✓ A-MPDU assisted 802.11n protocol can **reduce Eb** at the node level by **90%** in comparison with 802.11a/g when transmitting **low-payload lengths**.

Outline

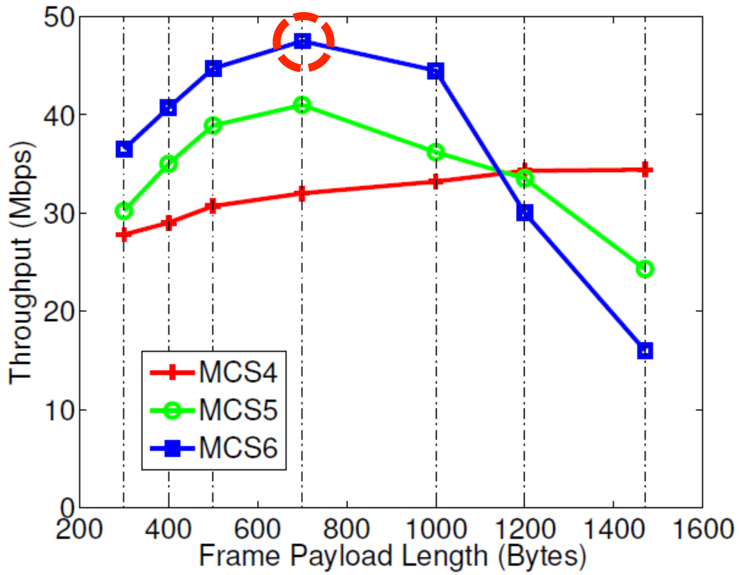
- ✓ Introduction
- ✓ Measurement Set-Up
- ✓ Realistic Experimentation:
  - ✓ Varying Application Traffic Load
  - ✓ Varying Frame Payload Length in High-SNR environment
  - ✓ Varying Frame Payload Length in Low-SNR environment
- ✓ Conclusions

Varying frame payload length – Low SNR

- ✓ We vary the frame payload length in the supported PHY rates when in low-SNR conditions.



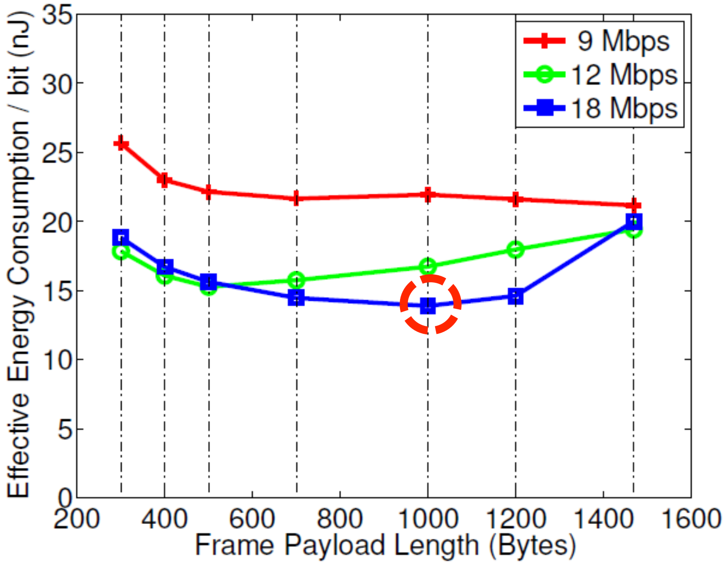
802.11a/g – throughput



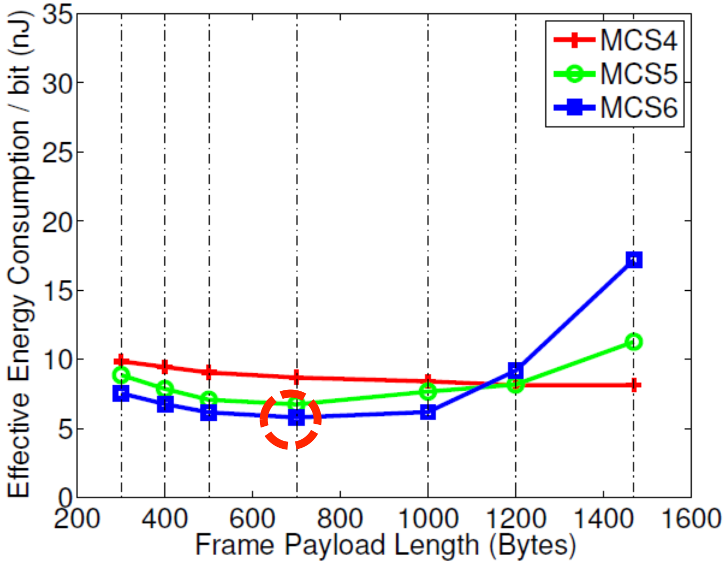
802.11n – throughput

- ✓ We observe that higher throughput in each different PHY rate is attained in different frame payload size.

Varying frame payload length – Low SNR



802.11a/g – Eb at NIC level



802.11n – Eb at NIC level

- ✓ We observe that lower Eb is attained when transmitting with the most efficient frame payload size in terms of throughput performance.
- ✓ Which implies that it is important to take under consideration both the **MAC frame length** and the **PHY bit rate,** towards achieving higher throughput and lower energy consumption.

Outline

- ✓ Introduction
- ✓ Measurement Set-Up
- ✓ Realistic Experimentation:
  - ✓ Varying Application Traffic Load
  - ✓ Varying Frame Payload Length in High-SNR environment
  - ✓ Varying Frame Payload Length in Low-SNR environment
- ✓ Conclusions

Conclusions

- We illustrated that:
  - Proper activation of RF chains drives at significant energy savings.
  - Application of MAC-layer Aggregation mechanism delivers increased throughput resulting in considerable energy savings.
  - A-MPDU assisted 802.11n protocol can **reduce Eb** at the node level by **90%** in comparison with 802.11a/g when transmitting **low-payload lengths**.
  - Several factors need to be taken under consideration in order to design a novel energy efficient protocol.

THANK YOU!!

Presenting: *Giannis Kazdaridis*

Email: iokazdarid@gmail.com

Experimental Evaluation and Comparative Study on Energy Efficiency of the Evolving IEEE 802.11 Standards

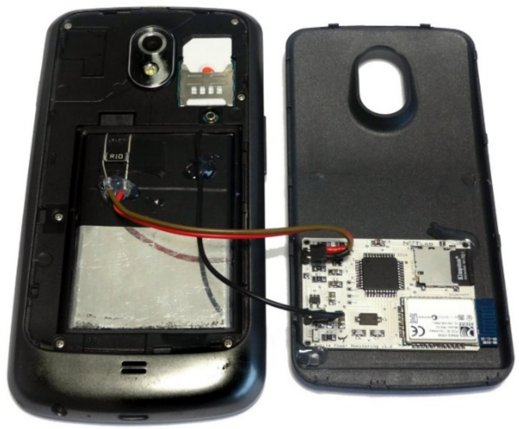
Date: *11/06/2014*

Conference: *e-Energy, Cambridge, UK*

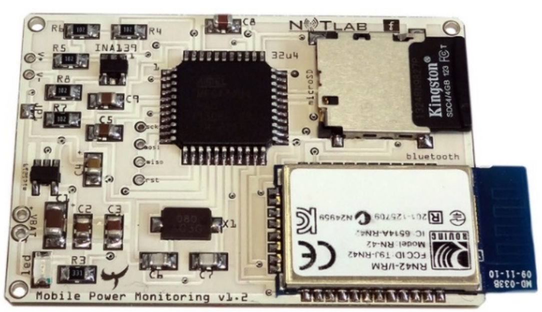
Demo Invitation: Realistic Energy Consumption Profiling of Mobile Devices

- ✓ We enable online power consumption monitoring of portable devices through the integration of a tiny custom-designed board, in order to provide energy efficiency evaluation under realistic mobile scenarios.

- ✓ Advantages:
  - ✓ Ultra low-size able to fit in the battery pack of smartphones.
  - ✓ **Online monitoring of realistic mobile scenarios.**
  - ✓ Long-term monitoring (SD card storage).
  - ✓ Low-cost fabrication (35 e).
  - ✓ Based on Arduino open source hardware and firmware.



Monitoring Device deployed on a smart-phone



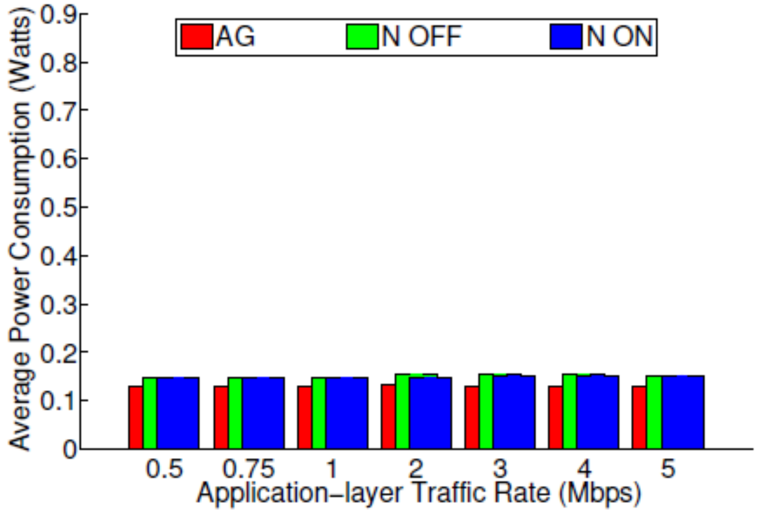
Energy Monitoring Device

- ✓ Specifications:
  - ✓ 8-bit MCU runs at 8MHz.
  - ✓ High sampling rate of 17kHz.
  - ✓ 10-bit resolution.
  - ✓ Low-power consumption (20mA).

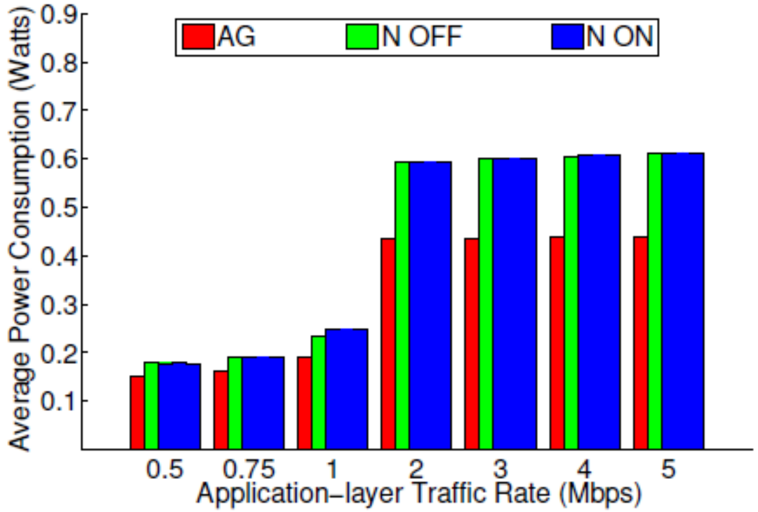
ARDUINO OPEN-SOURCE COMMUNITY

CERTH NITLAB NETWORK IMPLEMENTATION TESTBED LABORATORY UNIVERSITY OF THESSALY

Power Saving Mode Findings

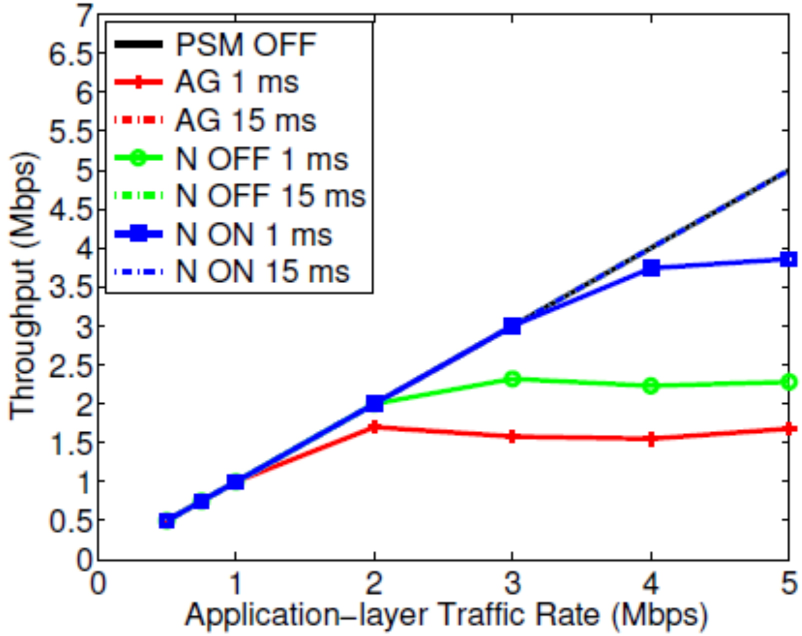


(b) PSM ON - Timeout 1 ms

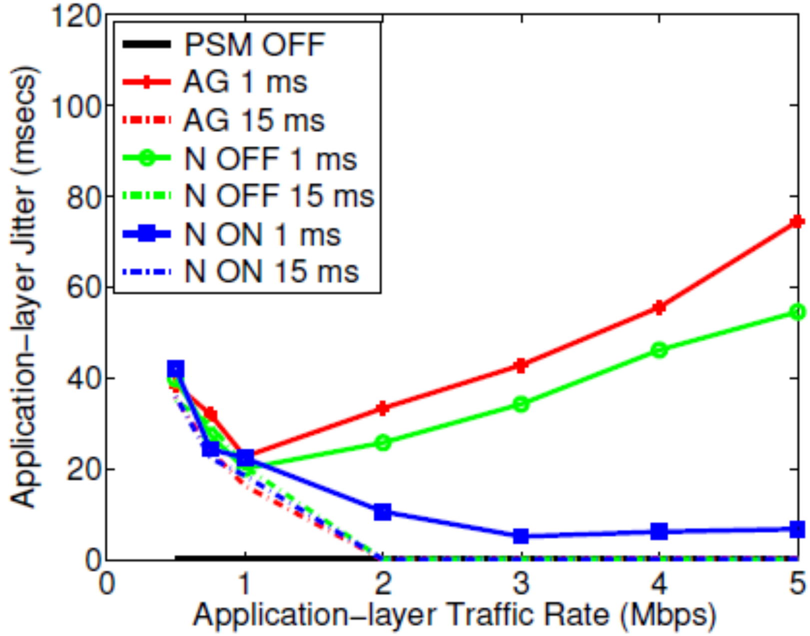


(c) PSM ON - Timeout 15 ms

Power Saving Mode Findings



(a) Throughput



(b) Jitter