Inferring the potential of multi-channel access in the 802.11ac/ax 5-GHz band

- An experimental approach -

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RICE

Rice University (Texas, USA), February 25th 2019

My stay at Rice

- 4 *rocket* intense months
- First time abroad
- Met great researches
- Learned from your way
  - Weekly meetings
  - Intense debates
  - I will try to **copy** that :)
- Not *newbie* anymore in experimental research!
- Get to know TX and NOLA
- Overall, **fantastic** experience

NASA's space center (Houston)

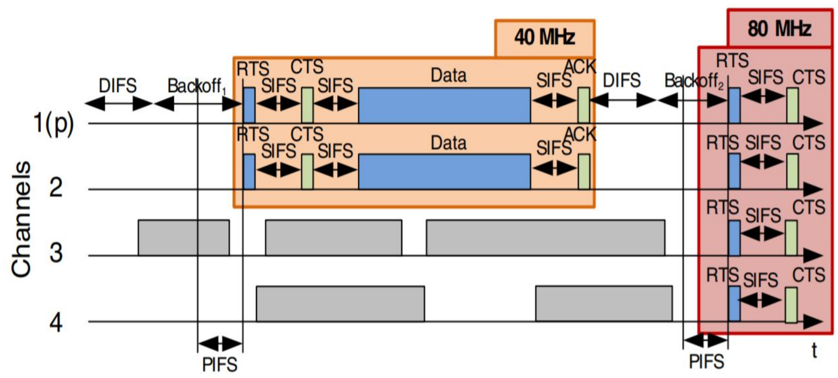
The research stay project

Looking for bandwidth-efficient WLANs

- Common problems in WLANs
  - Rising throughput demand
  - **Crowded** frequency spectrum
  - Rivalry and chaotic WLAN operation
  - **Low channel** utilization at some chunks/times
- Multi-channel access
  - Dynamic channel bonding
  - Preamble puncturing
  - OFDMA

$$C = nWlog_2(1 + \frac{S}{nW})$$

Shannon-Hartley theorem for *n* channels of bandwidth *W*.

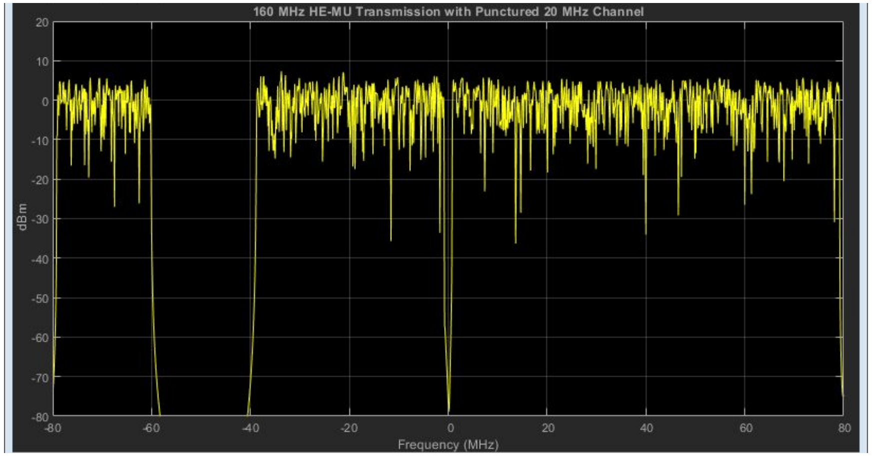


CSMA/CA & dynamic channel bonding

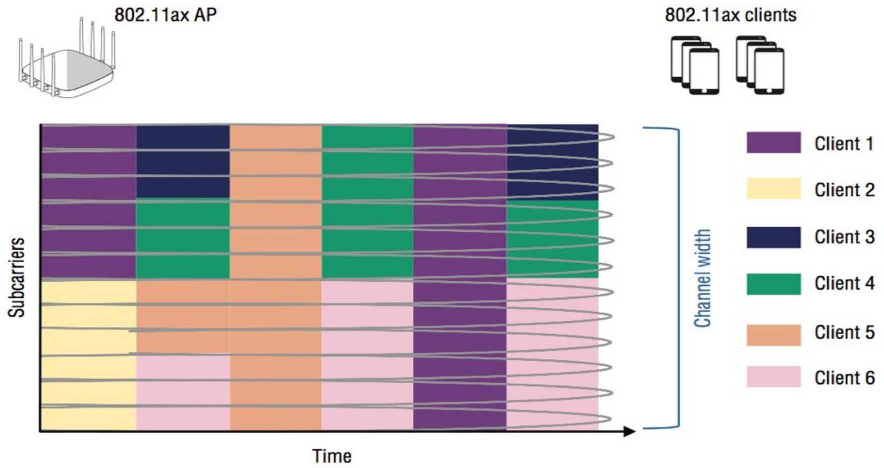
Multi-channel access for 5-GHz WLANs

- **DCB**: significant improvements in sims and testbeds [1,2]
- **Preamble puncturing**: non-contiguous DCB
- **OFDMA**: boost its performance for multi-channel [3]

Coming in 11ax



160 MHz signal with 20 MHz puncturing

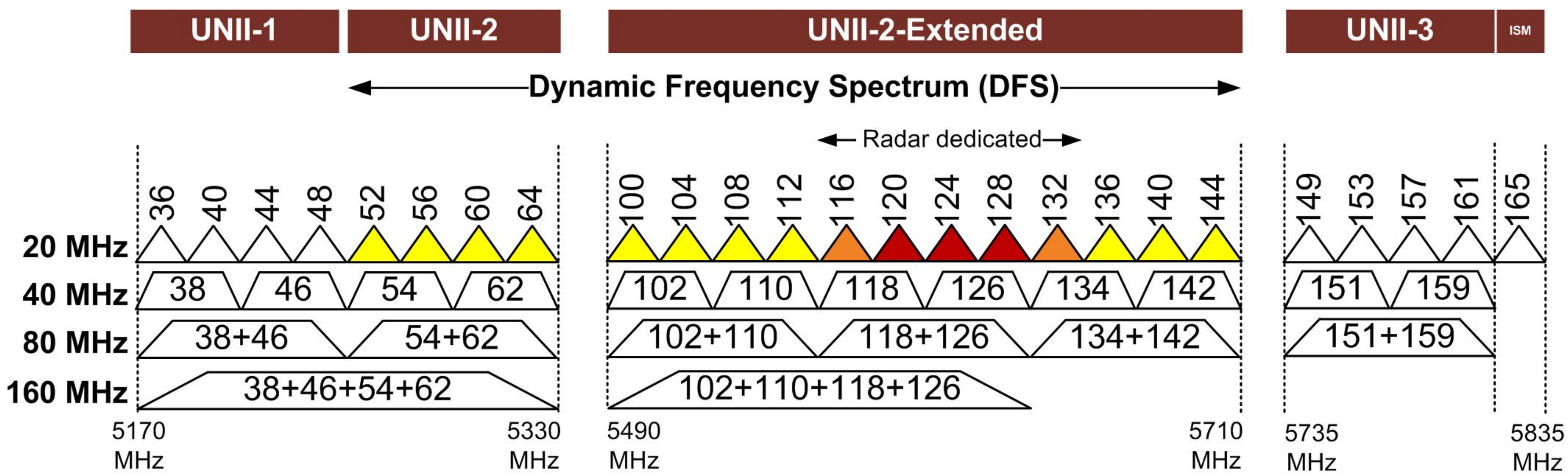


OFDMA resource allocation

[1] Deek, L., Garcia-Villegas, E., Belding, E., Lee, S. J., & Almeroth, K. (2014). Intelligent channel bonding in 802.11 n WLANs. IEEE Transactions on Mobile Computing, 13(6), 1242-1255.
[2] Barrachina-Munoz, S., Wilhelmi, F., & Bellalta, B. (2019). Dynamic Channel Bonding in Spatially Distributed High-Density WLANs. (In press) IEEE Transactions on Mobile Computing, 2019.
[3] Bankov, D., Didenko, A., Khorov, E., & Lyakhov, A. (2018, May). OFDMA Uplink Scheduling in IEEE 802.11 ax Networks. In 2018 IEEE International Conference on Communications (ICC) (pp. 1-6). IEEE.

5-GHz channelization in 802.11ac/ax

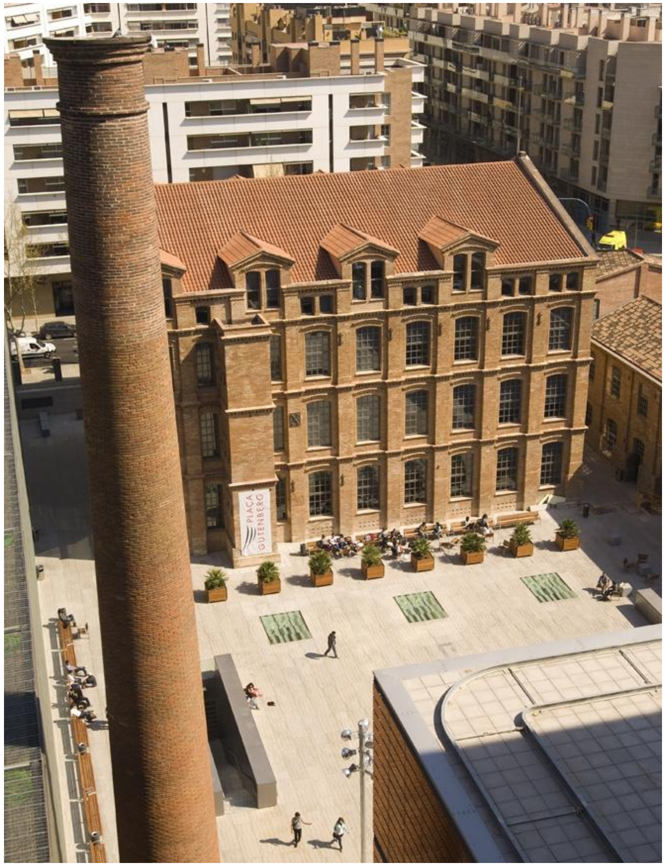
- Available channels depend on country regulations
- Dynamic Frequency Spectrum (DFS) may play a key role
  - Only **x9** non-DFS channels in -A region
  - Only **x4** non-DFS channels in -E region



IEEE 802.11ac/ax channelization for North America (-A region)

RQ: what about the real world?

- How is the spectrum **today**?
  - No datasets available
  - Are DFS channels vacant?
- Where is multi-channel beneficial?
  - Temporal multi-channel correlation
  - Are there common patterns?
  - Can we categorize places?
    - Outdoor/indoor
    - Domestic/workplace
    - Coordinated/Uncoordinated



Gutenberg square at UPF, Barcelona

Equipment for sniffing the spectrum

665 MHz to be **simultaneously** sniffed

Spectrum analyzer

- High BW analyzers are expensive.
- Resolution (bin size) tends to decrease as BW increases.
- *Difficulty* in gathering historic data.

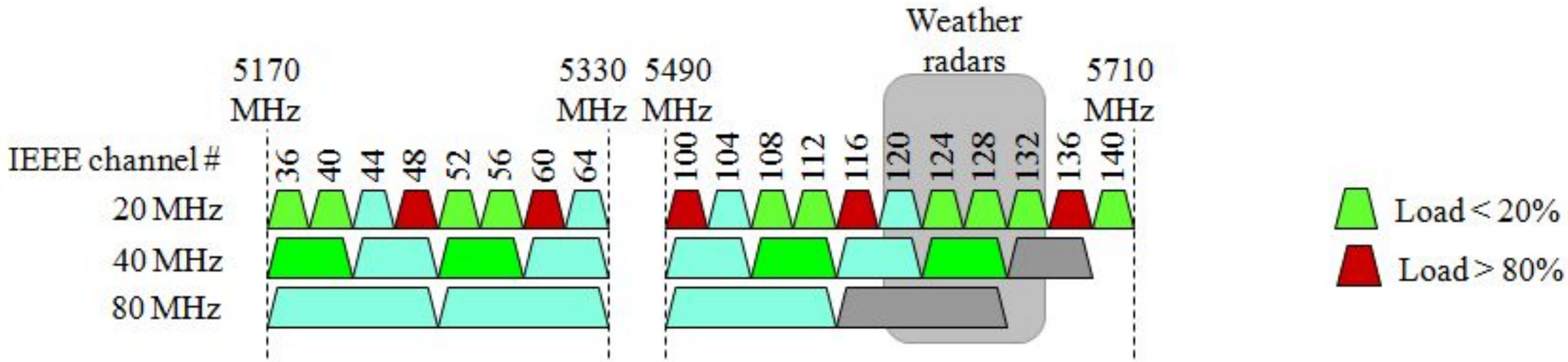
Multiple wireless cards

- x24 wireless cards required.
- Synchronization and management issues.
- Connectivity bottleneck (USB).
- OS RAM issues?

Channel sweeping is **not** an option!

Related work (in progress)

- Studies on spectrum occupancy
  - Most of them for 2.4 GHz [4]
  - 5 GHz in outdoors [5-6]
    - 5 GHz activity is mostly caused by WiFi [5]
  - **Channel sweeping** in all the works. **Sweep time > 3 sec!**



Example of fragmented usage of 5 GHz band in Europe/Japan [7].

[4] Hanna, S. A. (2014, April). A 3-state hypothesis test model for cognitive radio systems. In 2014 IEEE International Symposium on Dynamic Spectrum Access Networks (DYSPAN) (pp. 291-302). IEEE.

[5] Rademacher, M., Jonas, K., & Kretschmer, M. (2018, April). Quantifying the spectrum occupancy in an outdoor 5 GHz WiFi network with directional antennas. In 2018 IEEE Wireless Communications and Networking Conference (WCNC) (pp. 1-6). IEEE.

[6] Taher, T., et. al.. (2014, June). Global spectrum observatory network setup and initial findings. In 2014 9th International Conference on Cognitive Radio Oriented Wireless Networks and Communications (CROWNCOM) (pp. 79-88). IEEE.

[7] IEEE 802.11-10/1274r3 Nov. 2010 Non-contiguous 40-40Mhz for Europe, Japan and Global

Expected contributions

1. Design and development of the custom sniffer
2. Dataset of real IEEE 802.11 5-GHz band measurements
3. High-level results:
   a. Av. utilization including DFS impact
   b. Categorization of locations
4. Modeling and inference of multi-channel techniques
   a. Dynamic channel bonding
   b. Preamble puncturing

Outline

1. WARP spectrum analyzer

2. Experimental methodology

3. Preliminary data

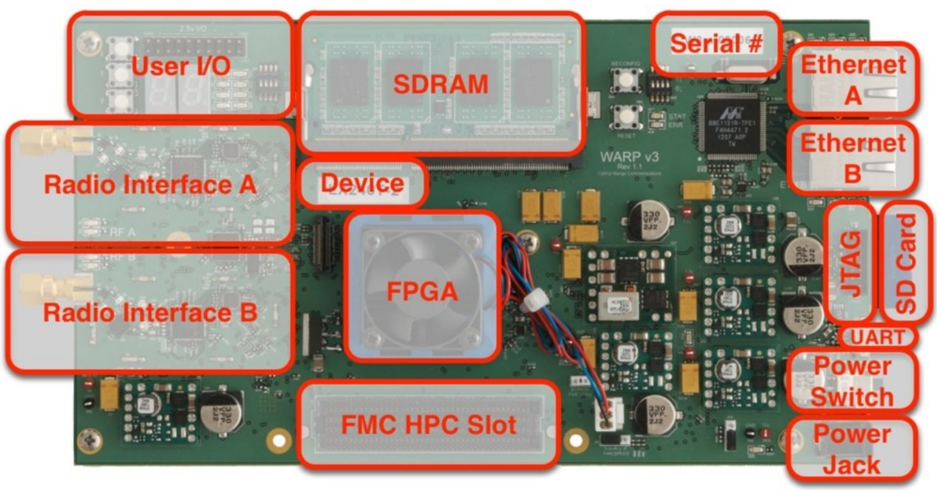
4. Inference model

ONE.

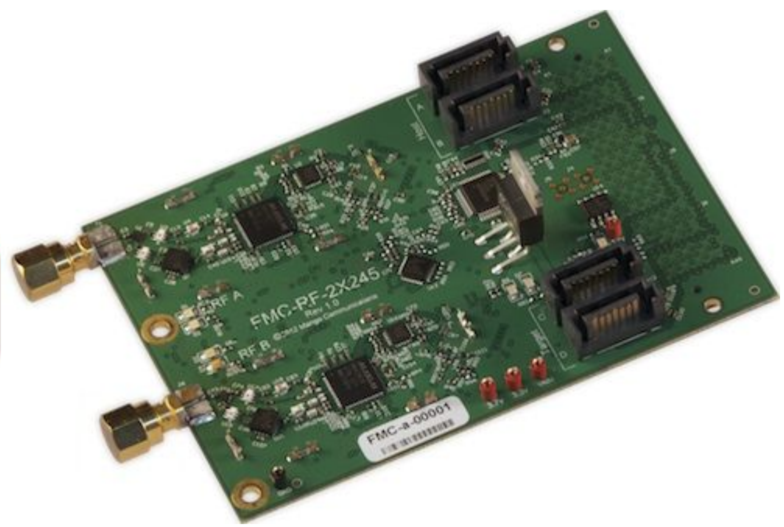
WARP spectrum analyzer

The WARP board

- Commercialized by Mango Communications
- WARP v3 [8] is the latest generation of WARP
  - Integrates a Virtex-6 FPGA
  - 2 programmable RF interfaces
  - Variety of peripherals



Key components of WARP v3

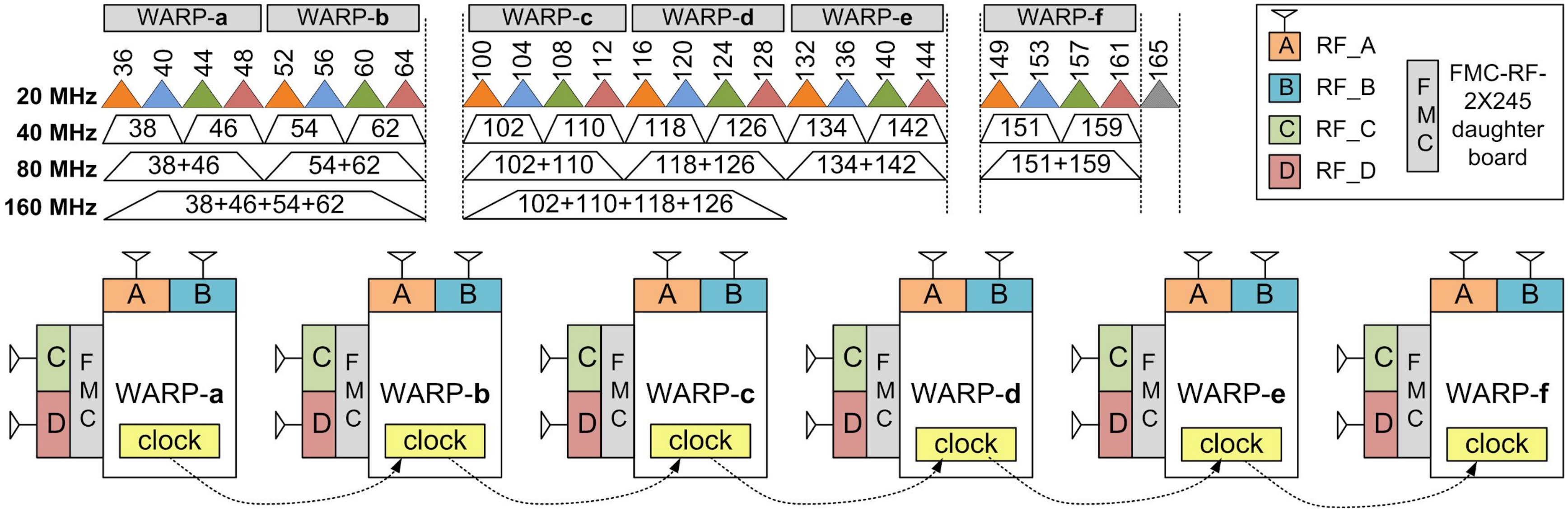


FMC-RF-2X245: Dual-Radio FMC Module

[8] WARP Project. [Online]. Available: http://www.warpproject.org

WARP custom sniffer system

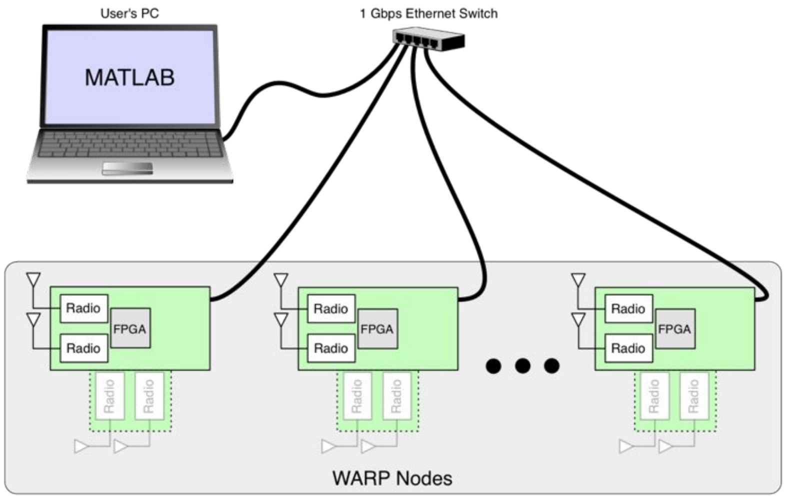
- Components:
  - x6 WARPs (x2 RFs each: A & B)
  - x6 FMC daughter boards (x2 extra RFs each: C & D)
  - x24 5-GHz antennas (one for each 20-MHz channel)



Channel allocation to the 24 RFs

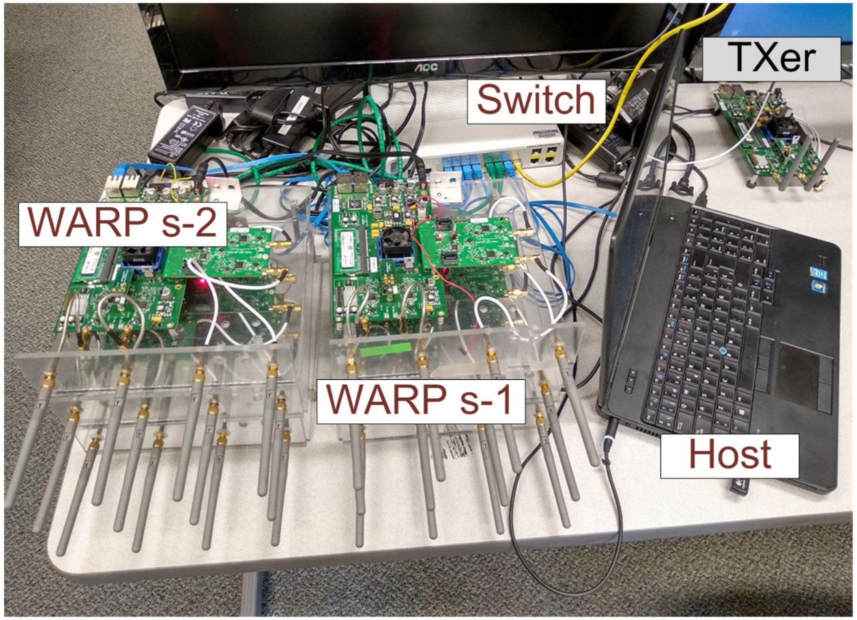
WARP/WARPLab custom sniffer system

Logical topology



WARPLab implementation overview

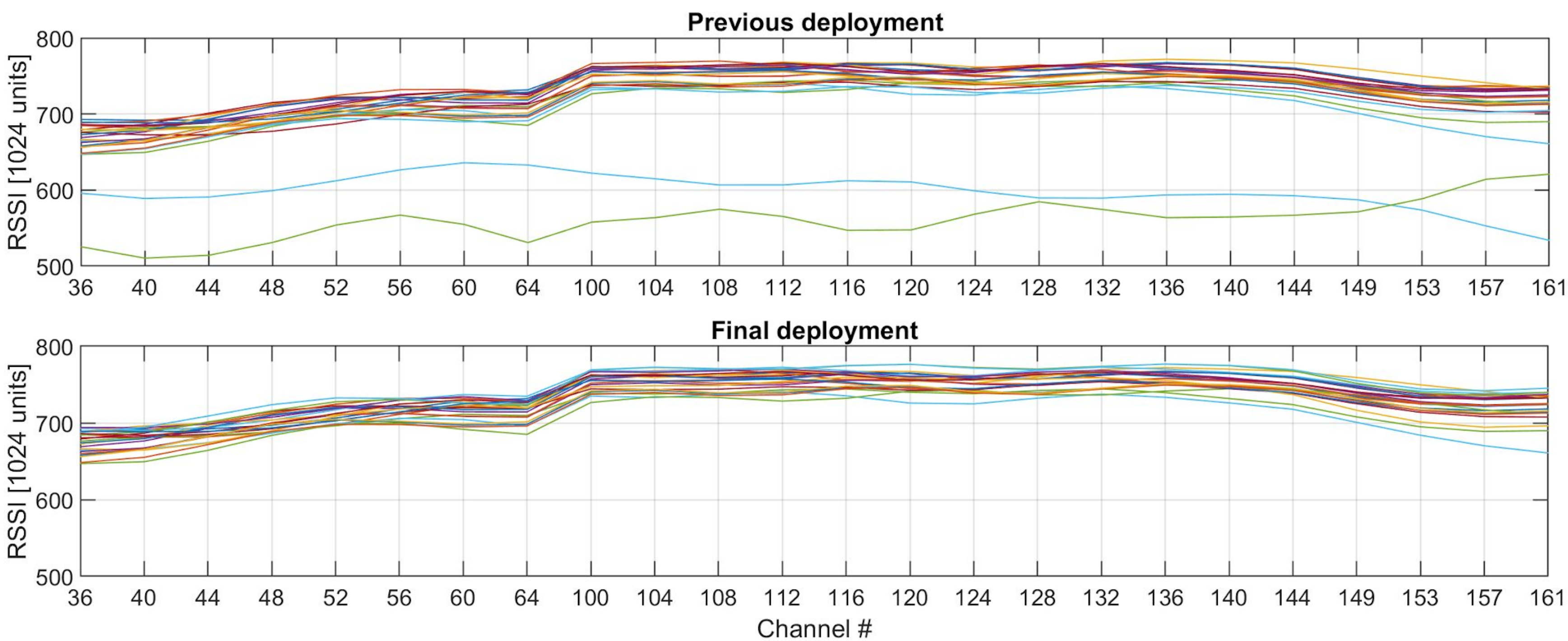
Physical topology



Final deployment of the custom sniffer

Calibrating the RFs: RSSI(f)

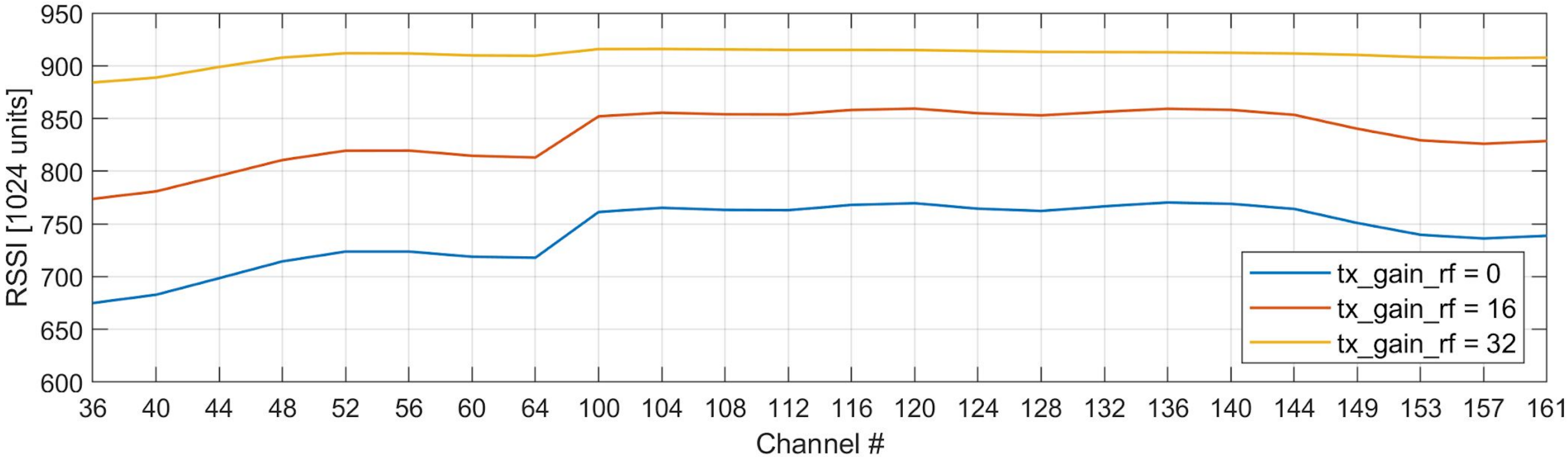
- We use an RF cable to connect a pair TXer and RXer
- Test RSSI for at every channel (f) for a fixed P_{TX}



Empirical RSSI as a function of channel's central frequency

Calibrating the RFs: RSSI(f,P_{TX})

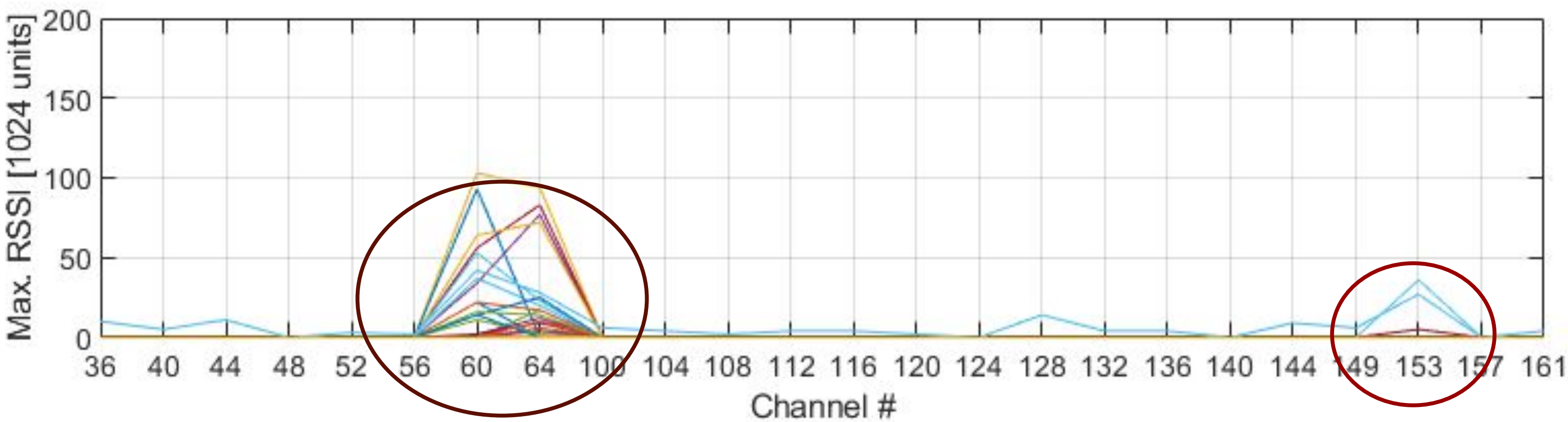
- Same approach: RF cable to connect a TXer and RXer
- Test RSSI in every channel (**f**) for different trans. power P_{TX}



Empirical RSSI of RF a-D as a function of the frequency and transmitted power

Thermal noise

- Average impact is too low (**negligible**)
- However, some peaks may rarely appear
  - On average, less than 1 peak every 4E6 samples



Empirical RSSI of every RF as a function of the frequency

TWO.

Experimental methodology

Timeline diagram

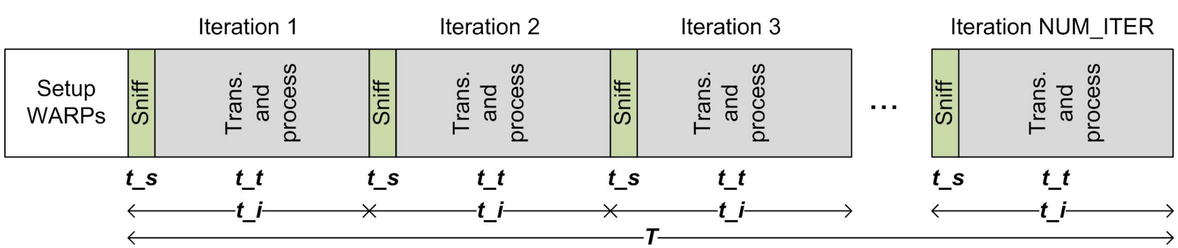
Deploy system → **Set up** → **Run/Monitor** → **Pots-process**

1. Set Switch
2. 1 Gbps Eth. cable for the host.
3. Check connectivity (ARP tables)

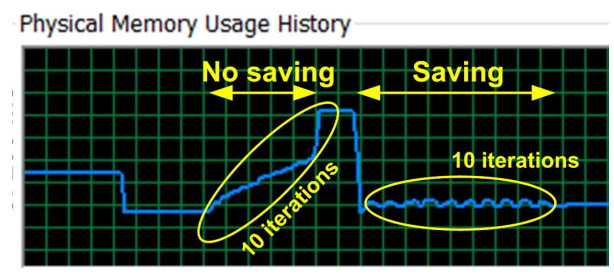
- No. of iterations.
- Sniffing time
  - x1 sec → 70 MB
  - x1 min → 4.2 GB
- Downsample

- Check **at least** the first iterations
- Multiple sources of failure
  - Cables
  - Memory

- Offset corrections
- CCA assessment
- Apply multi-channel models



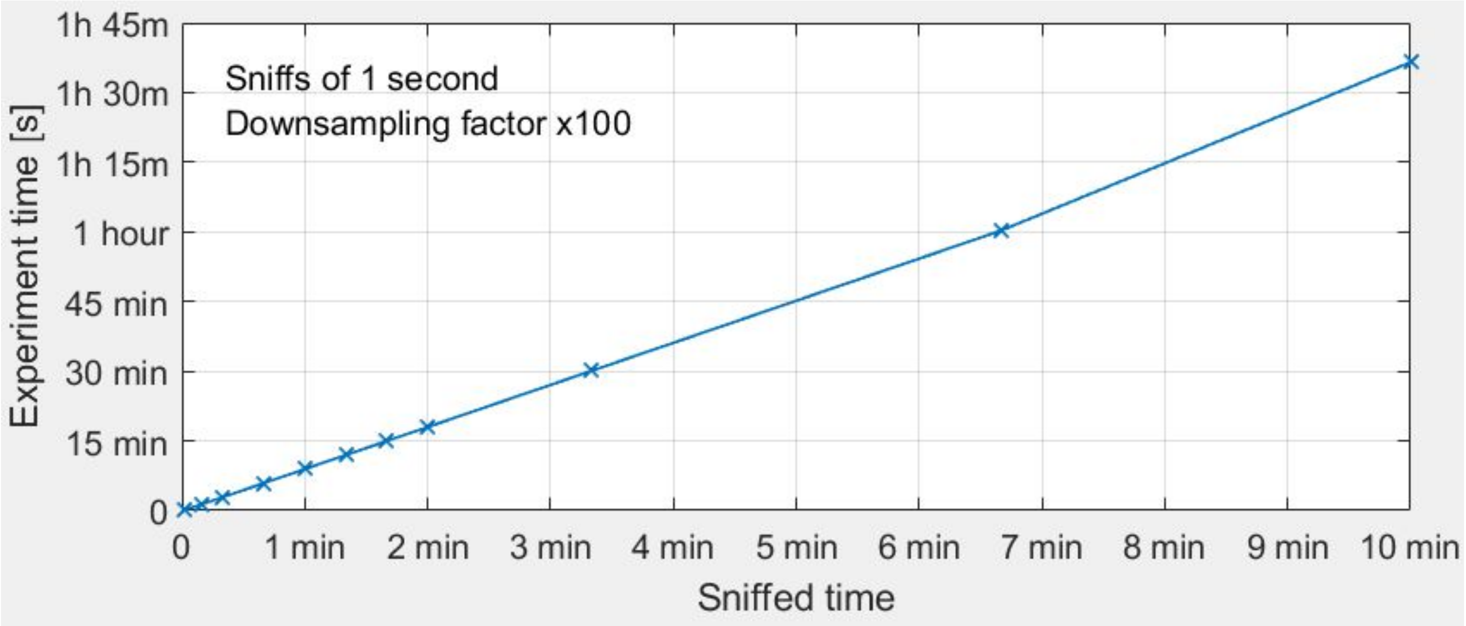
Iterative procedure: sniff-process



Evolution of memory consumption

Experiment duration tradeoffs

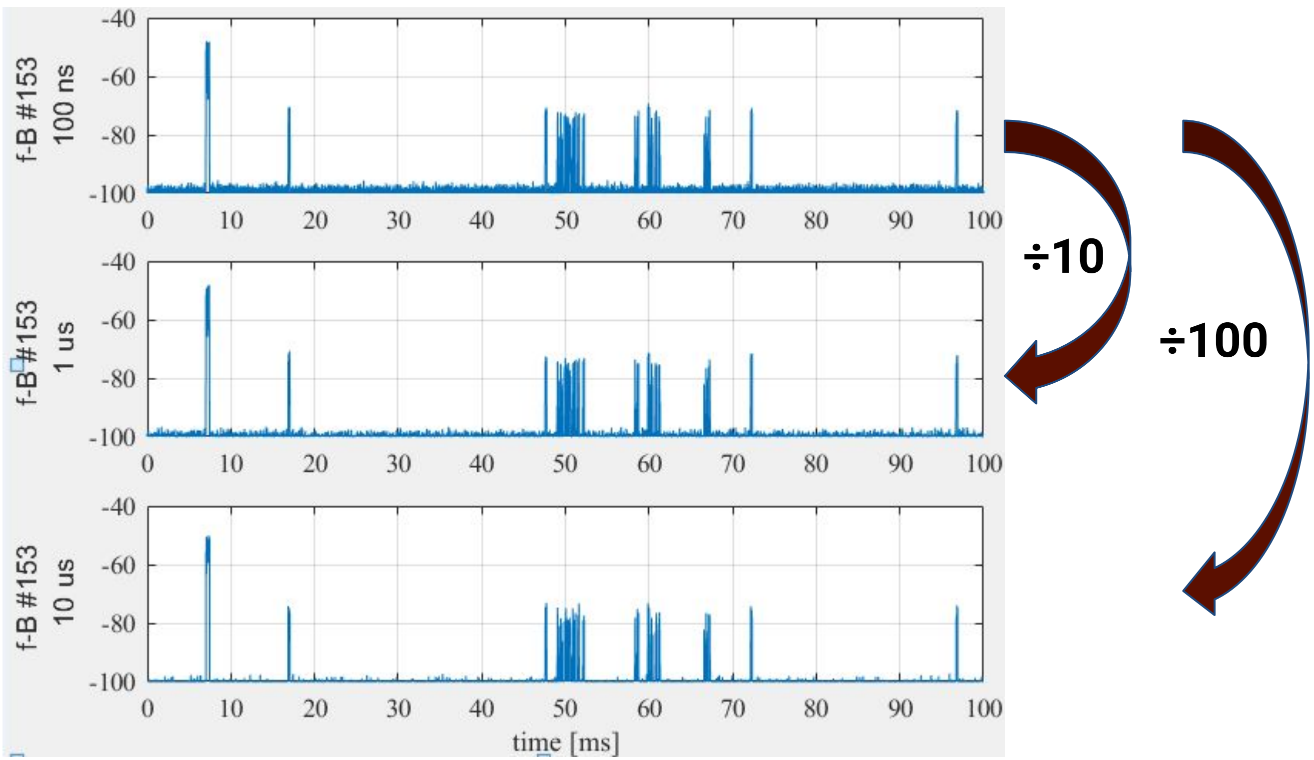
- Unfortunately, overhead durations are important
  - RSSI sampling rate is 10 Msps. **Cannot be modified**.
  - Post-RSSI measurement downsampling helps



Experiment time vs. sniff duration

Downsampling to reduce memory

- Downsampling for saving memory
  - 1 RSSI sample every 10 microseconds seems accurate
  - We decrease memory by a x100 factor

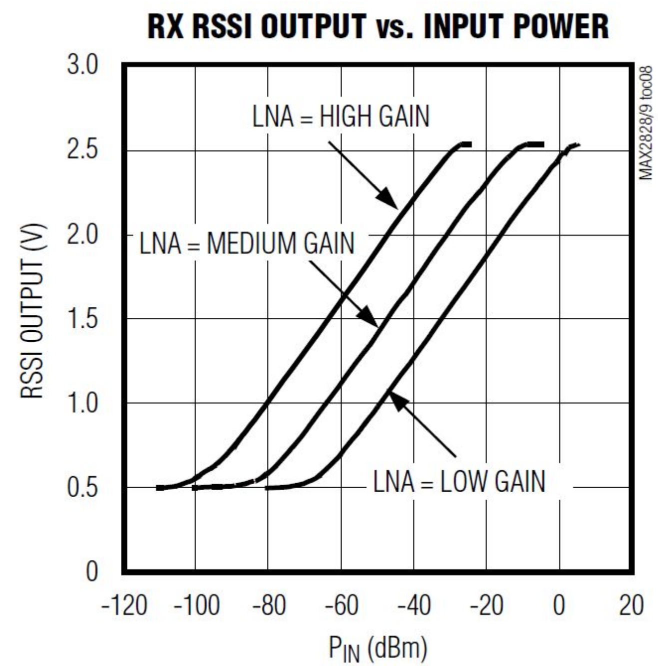


RSSI curves for different downsampling factors

CCA assessment: from RSSI to power

- **MAX2829** transceiver:
  - Provides a 10-bit RSSI
  - Values: [0, 1023]
- Power depends on the waveform:
  - Mapping Power(RSSI) provided for 802.11g 20 MHz waveforms
- CCA assessment:

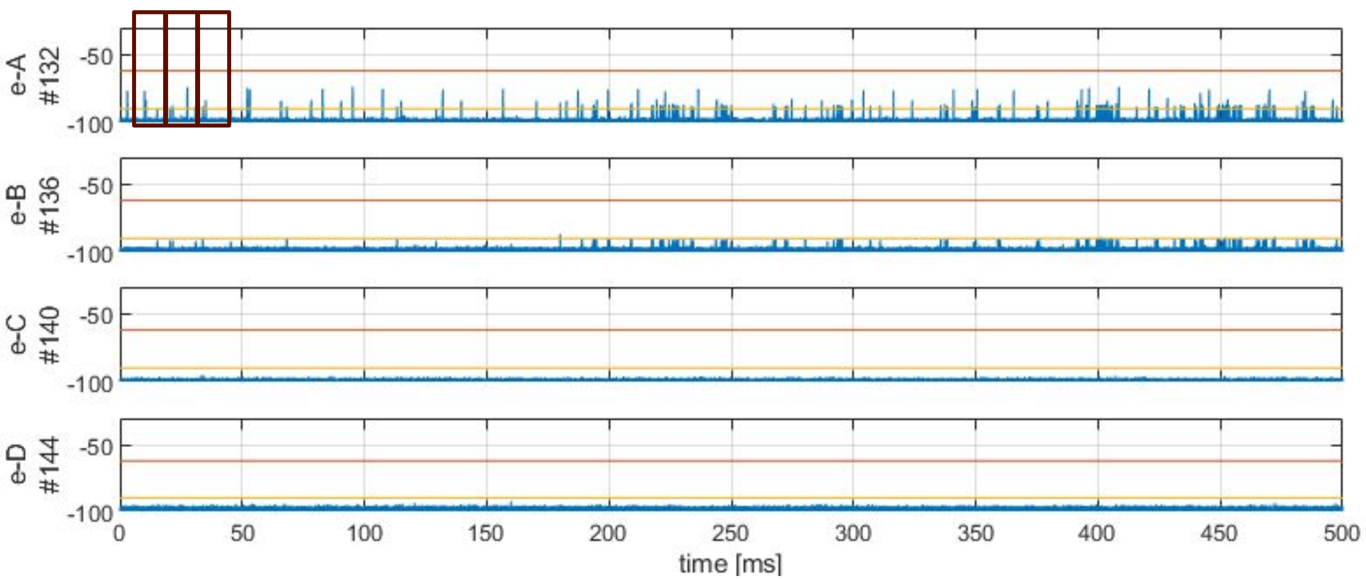
$$\text{busy} = \begin{cases} \text{true} & \text{if } P_{\text{rx}} \geq \text{CCA} \\ \text{false} & \text{otherwise} \end{cases}$$



Power received vs. RSSI for 802.11g waveforms according to MAX2829 datasheet.

Data post-processing

- Parameters
  - CCA threshold
  - Samples slot assessment:
    - a) CCA assessment per sample (raw data) → $\mathrm{CCA}(s_i)$
    - b) CCA on the peak in a set of *k* samples → $\mathrm{CCA}(\max[s_i, s_k])$
    - c) CCA on the average per set of *k* samples → $\mathrm{CCA}(\mathrm{E}[s_i, s_k])$



Pack samples for post-processing purposes

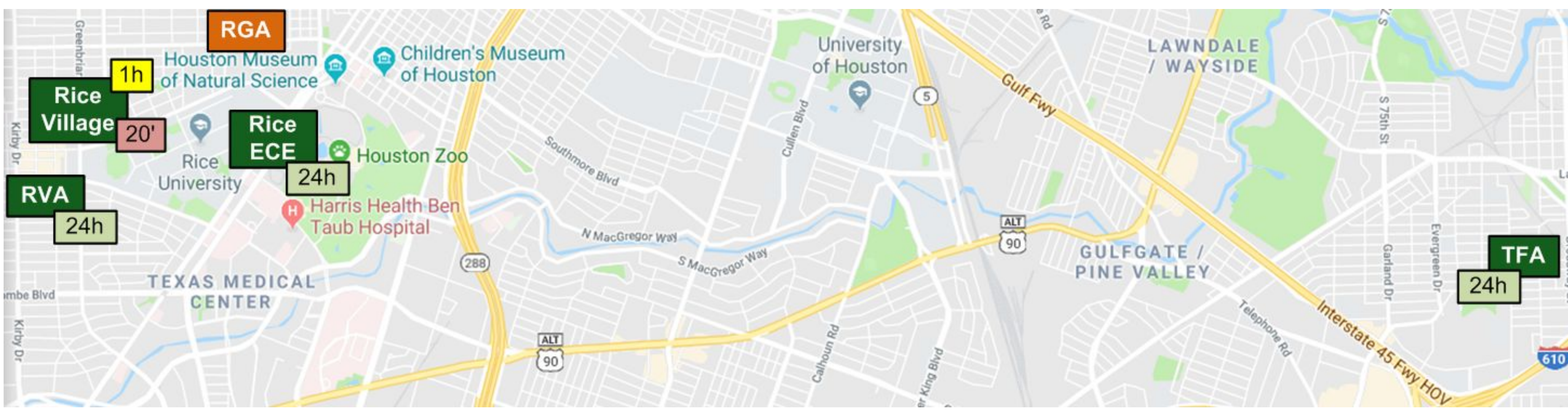
THREE.

Preliminary results

Desired dataset

- Specifications:
  - Target:
    - 15 min to 24 hours duration
  - International (USA & Spain)
  - High/low densities
  - Organization/adversarial

Les Glòries shopping mall (Barcelona, Spain)



Experiment locations in Houston

Experiment's common parameters

Experiment

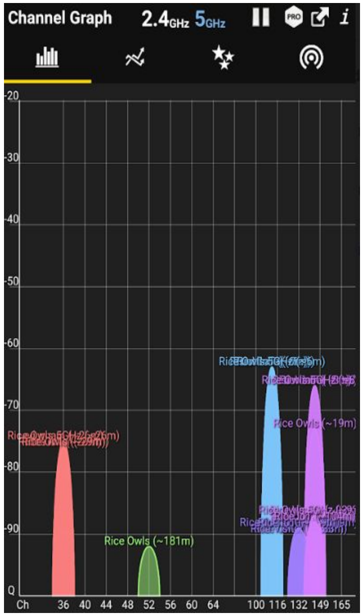
- Duration: <= 24 hours
- x1 second samples per band sniff
- x100 downsampling ratio
  - Sampling rate: 1/10 us
- x9600 iterations
  - ~2.5 hours of samples in a 24 hours experiment

Post-processing

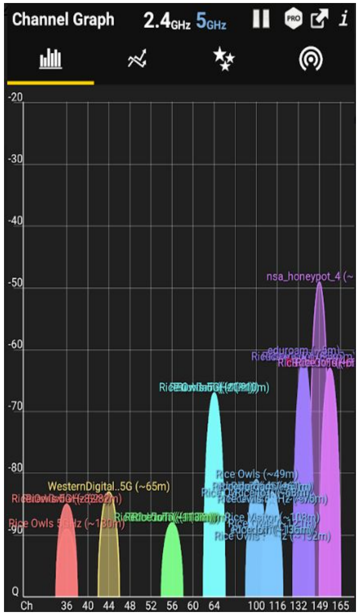
- CCA threshold
  - 125 RSSI 1024-value
  - ~ **-85 dBm**
- CCA assessment per sample
- Occupancy metric:
  - busy sample if Prx > CCA
  - occ = no. busy samples / no. samples

WLANs detected at each location

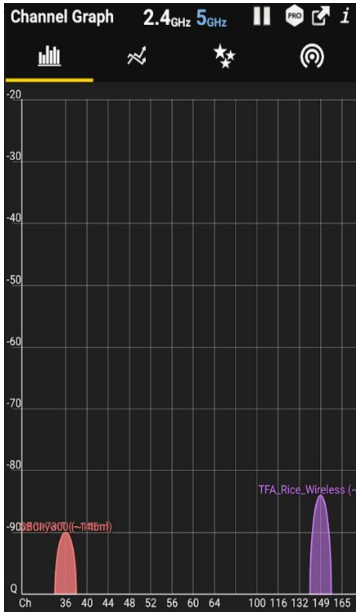
#1. RVA



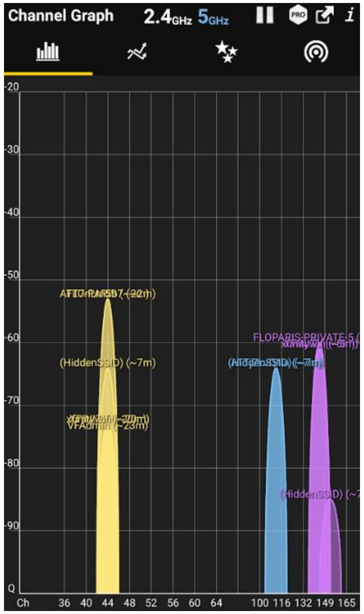
#2. LAB



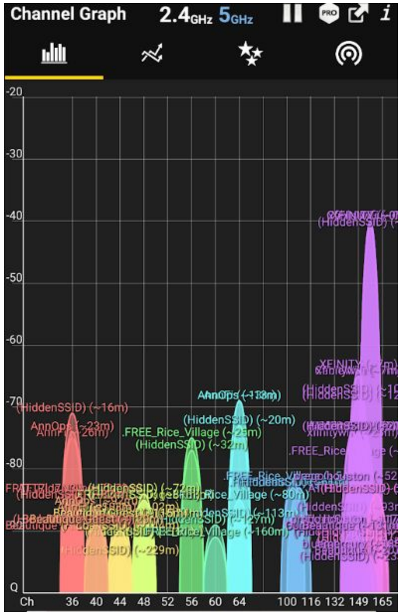
#3. TFA



#4. Flo Paris



#5. Village

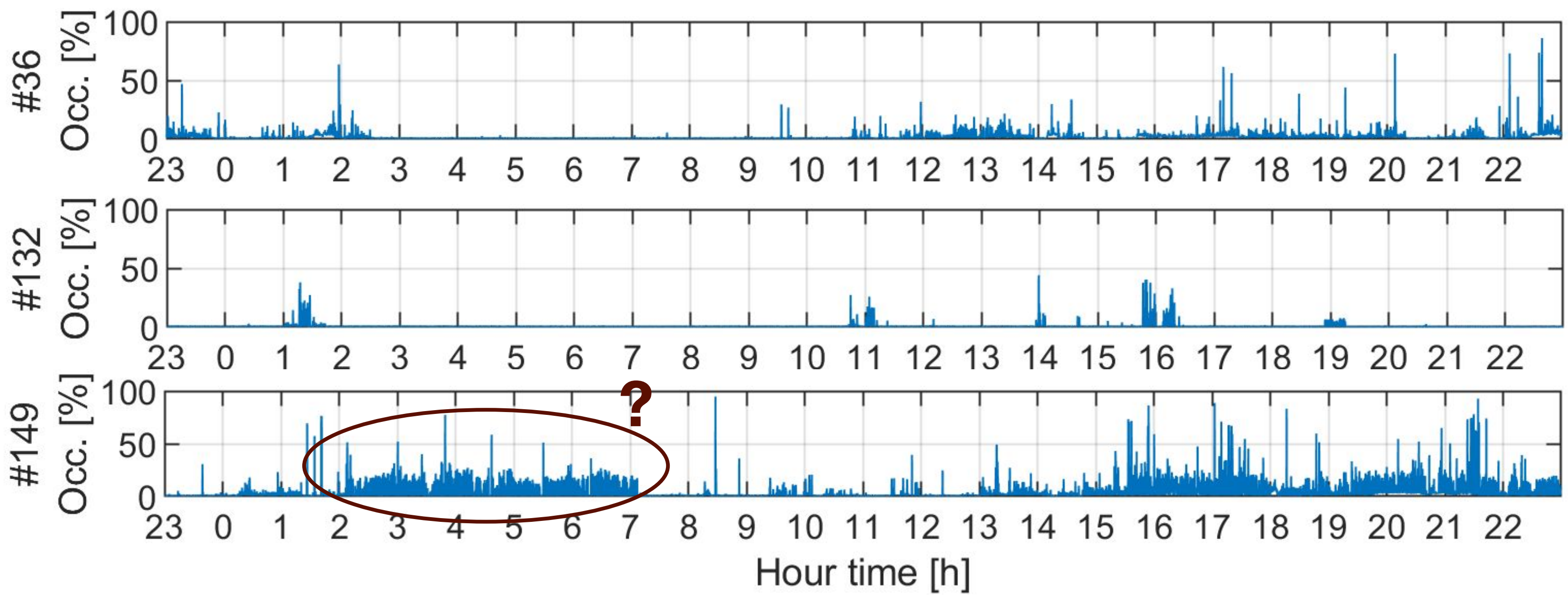


*Channel graphs gathered by a Xiaomi Mi A1 smartphone and **WiFi Analyzer** app for Android

Experiment #1: Rice Village Apartments

- Location:
  - Residential
  - Coordinated APs by RVA
  - User own hotspots not expected but may be

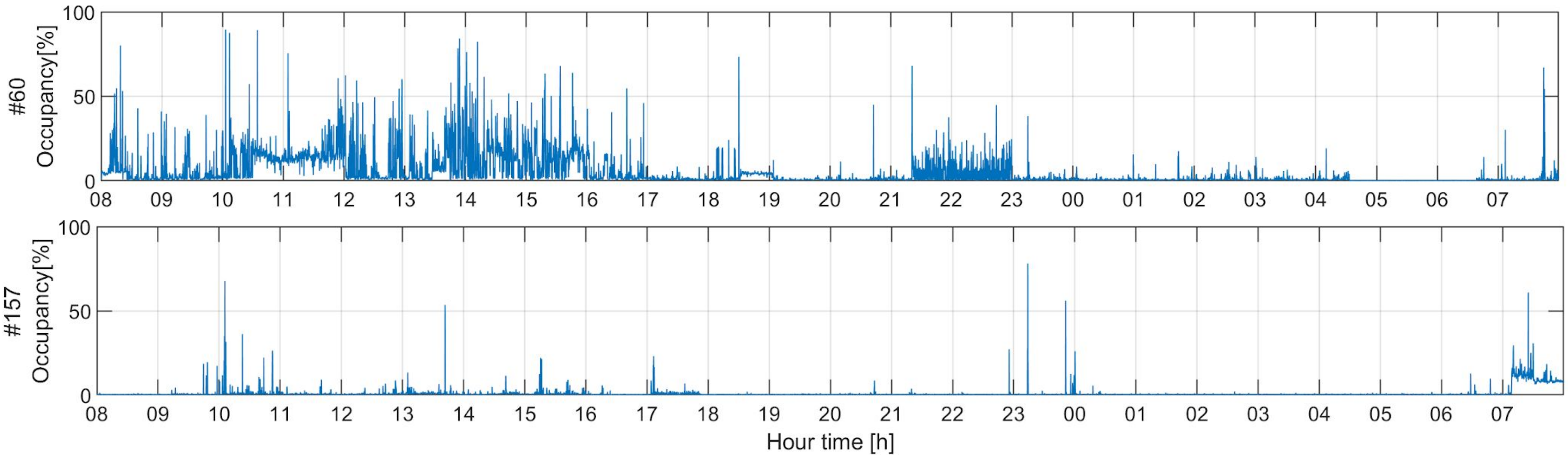
Rice Village Apartments (Houston)



Experiment #2: Duncan Hall 2nd floor

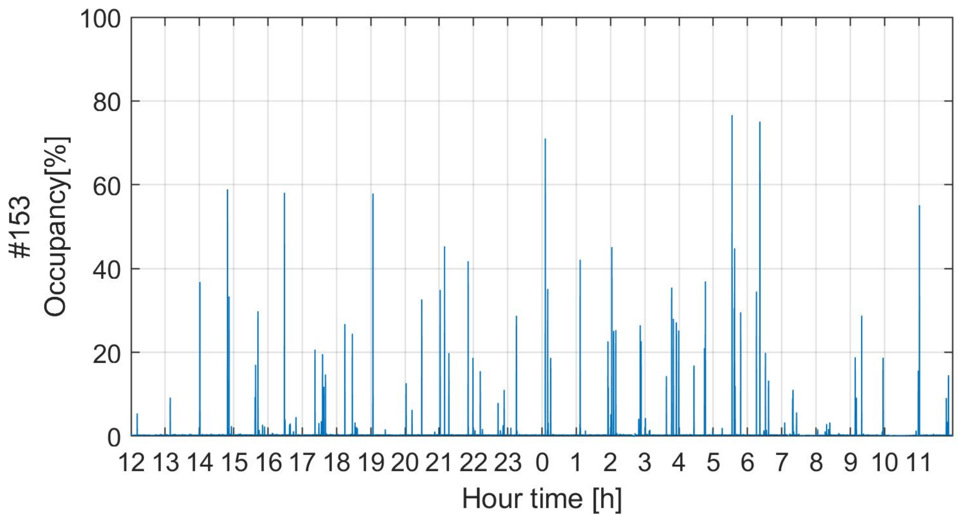
- Location (*ICT guys*):
  - Duncan Hall is representative
  - No challenging areas in **5-GHz**
  - Use of 40-MHz CB
  - 2,300 **coordinated** APs!

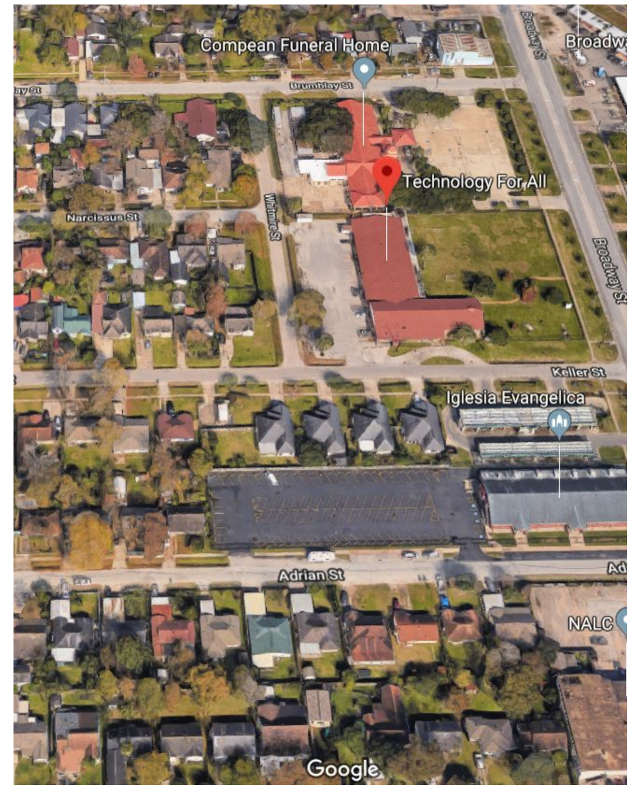
Duncan Hall building (Rice University)



Experiment #3: Technology for All

- Location:
  - Low-income community
  - Low population density
  - Just 3 WLANs detected
  - Weird pattern at #153

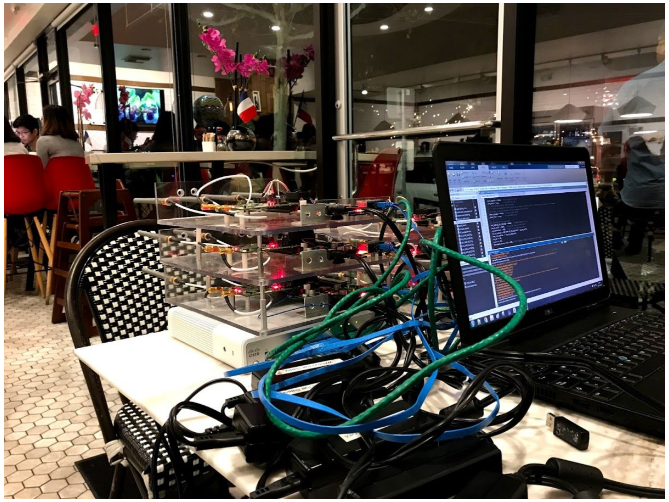




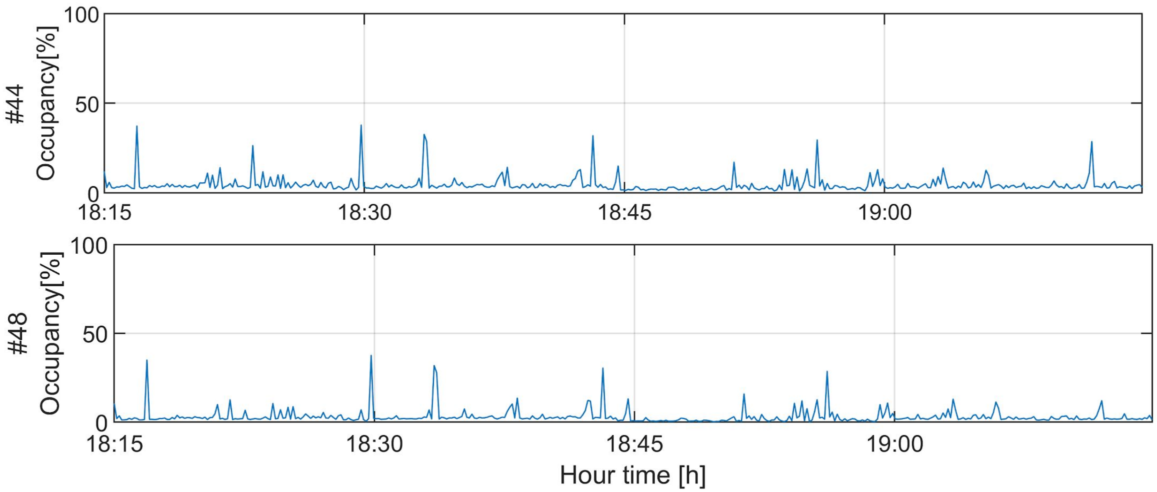
Technology For All (Houston)

Experiment #4: Flo Paris

- Location:
  - 1 hour of measurements
  - Comercial
  - Low and sporadic traffic
  - Uncoordinated APs
  - Channel bonding detected

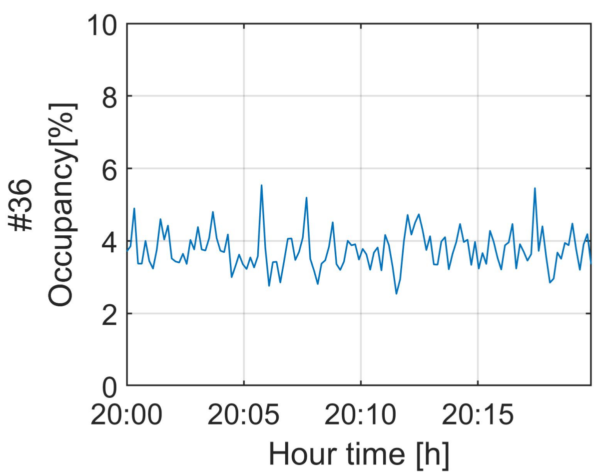


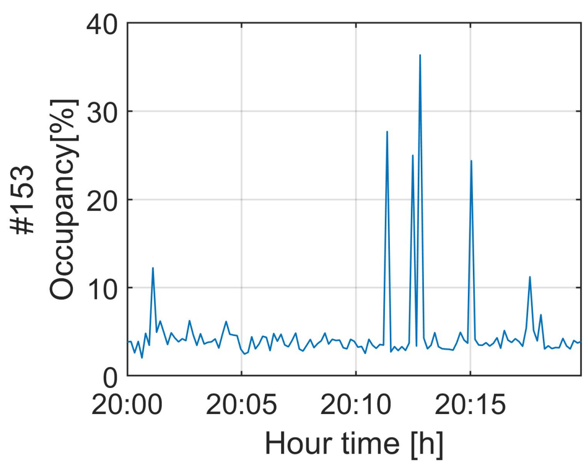
Flo Paris at Rice Village (Houston)



Experiment #5: Rice Village parking lot

- Location:
  - Rice Village bars zone
  - **x1** Car + **x1** Power inverter + **x2** UPS
    - 20 minutes!
  - Lots of APs in the area
  - Moderate (but **constant**) activity





Rice Village parking lot (Houston)

FOUR.

Inferring the performance of multi-channel access

Possible models

- Channel access:
  - Consider CCA for accessing and granting the channel
- Worst case:
  - Consider only empty channels for the whole transmission
- Baselines
  - Evaluate multi-channel for every possible primary
  - Fix primary and then evaluate
- *More to come...*

Making the dataset open

- About **50 Gbytes** of data expected
- Different platforms to consider
  - Zenodo
  - Github
  - Bitbucket
  - University servers
- Make it open source
  - Copyleft/Public license
  - Proper documentation
  - Promotion

Any questions?

?

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