A “brief” introduction to myself and my research

Sergio Barrachina-Muñoz

Wireless Networking (WN) Research Group
Universitat Pompeu Fabra (UPF), Barcelona (Spain)

Rice University, Houston (TX, USA)

Outline

Outline

Myself at a glance

- Bio
    - 27 years old
    - Born in Barcelona, Spain
- Studies at UPF
    - 2011 B.S. Telematics Engineering
    - 2015 M.S. Intelligent and Interactive Systems
    - 2016 Ph.D. at WN
- Internships
    - 2014 QA at VendoServices
    - 2015 Java developer at Ricoh
    - 2016 Research assistant at WN

UPF's communications campus.

Born and live in Barcelona

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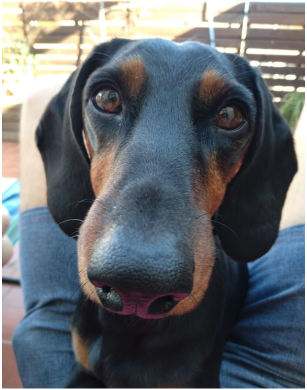
Hobbies

- Music, cinema, series, etc.
  - I play a bit the guitar
  - American culture lover
- Animals
  - This dog owns me →
  - Documentary watcher
  - Can't stand bullfighting
- Sports
  - I play soccer (*fútbol*)
  - NBA fan
  - *Frontón* champion :D



Wilco, the dog.

What the heck is *frontón*?

Jorge and I playing *frontón* at El Cuervo, Aragón, Spain (August 2018).

Teaching Arduino to high-school students

Descobrint l'IoT a través d'Arduino at Campus Junior 2017, UPF.

Outline

LPWANs/IoT

Low Power Wide Area Networks: **large coverage** & **low consumption**.

- **ENTOMATIC**: monitor olive tree orchards to prevent plagues.
- Design/develop communication protocol.
- Hardware issues and Contiki OS.

[1] Barrachina-Muñoz, S. et al., 2017. Multi-hop communication in the uplink for LPWANs. Computer Networks, 123, pp.153-168.

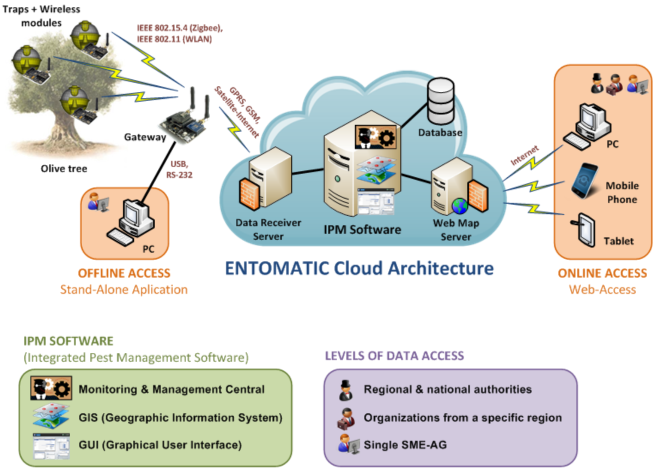
[2] Barrachina-Muñoz, S. et al., 2017, October. Learning optimal routing for the uplink in LPWANs using similarity-enhanced e-greedy. In Personal, Indoor, and Mobile Radio Communications (PIMRC), 2017 IEEE 28th Annual International Symposium on (pp. 1-5). IEEE.

[3] Adame Vázquez, T. et al., 2018. HARE: Supporting efficient uplink multi-hop communications in self-organizing LPWANs. Sensors, 18(1), p.115.

[4] Barrachina-Muñoz, S. et al., 2018. Towards Energy Efficient LPWANs through Learning-based Multi-hop Routing for the Uplink. arXiv preprint arXiv:1803.11010.

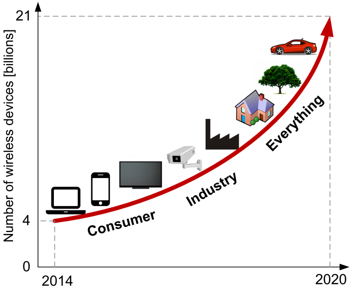
Testing ENTOMATIC traps in Falset, Tarragona, Spain (April 2017)

ENTOMATIC project



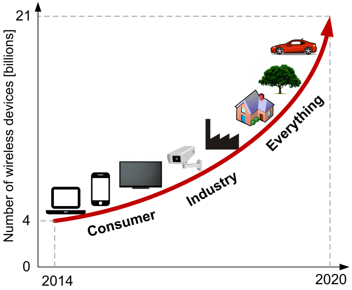
ENTOMATIC architecture.

Thesis topic: Next-generation Wireless Networks



1) Highly increasing number of wireless devices (Gartner)

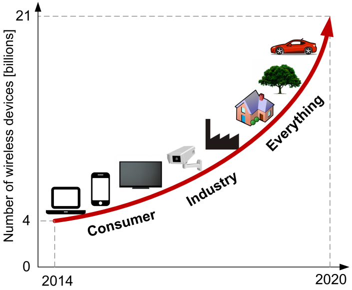
Thesis topic: Next-generation Wireless Networks



1) Highly increasing number of wireless devices (Gartner)

2) Rising throughput demand ($>$ 10 Gbps)

Thesis topic: Next-generation Wireless Networks

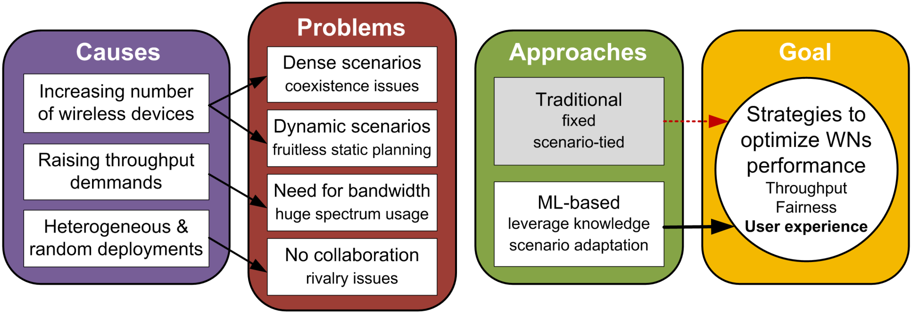


1) Highly increasing number of wireless devices (Gartner)

2) Rising throughput demand ($>$ 10 Gbps)

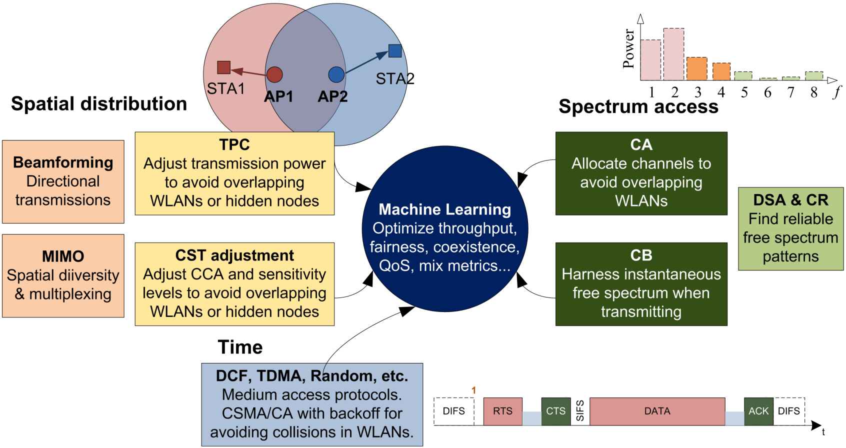
3) Complex and changing dynamics

Thesis' research problem



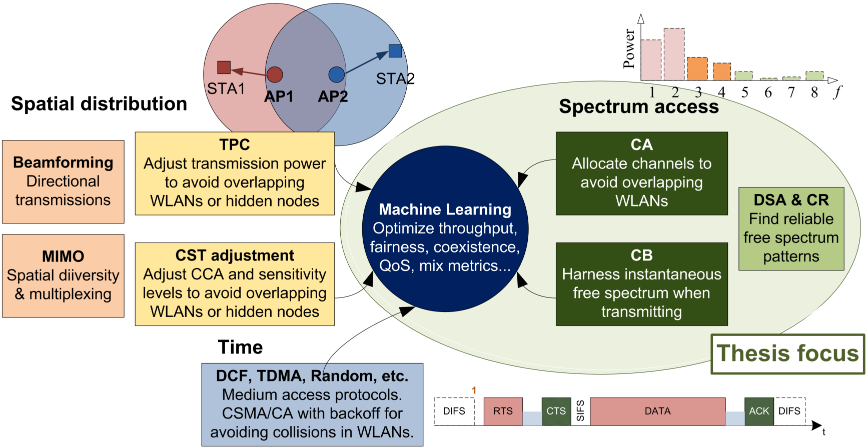
Conceptual diagram of the research problem.

Thesis focus



Conceptual map of approaches to manage WLAN networks.

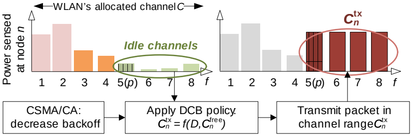
Thesis focus



Conceptual map of approaches to manage WLAN networks.

Summary of my thesis work up to now

- Dynamic channel bonding (DCB) for WLANs.
- Tools development.
    - Komondor simulator.
    - SFCTMN framework.
- Collaborations in spatial reuse and ML.
- Contribution to projects like WIFIX.
- Member of the IoTLAB.[1]

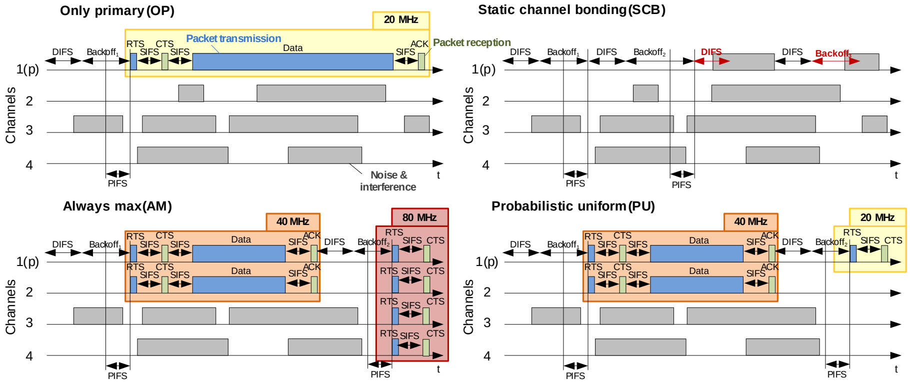


Flowchart of the transmission channel selection.

1. IoTLAB website: `https://www.upf.edu/web/iot-lab`

Outline

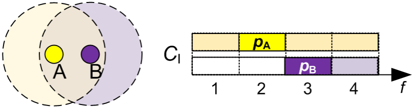
Dynamic channel bonding and CSMA/CA

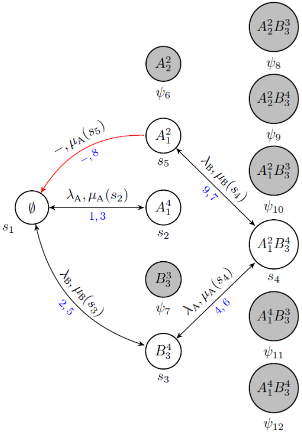


CSMA/CA temporal evolution of a node operating under different DCB policies in the IEEE 802.11ax channelization scheme.

[5] Barrachina-Munoz, S. et al., 2018. Performance Analysis of Dynamic Channel Bonding in Spatially Distributed High Density WLANs. arXiv preprint arXiv:1801.00594.

Modeling of DCB policies through CTMNs [5]

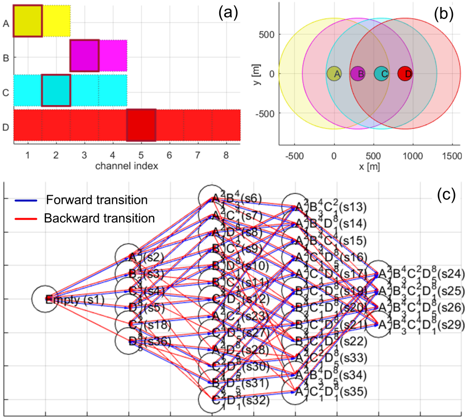




Two partially overlapping WLANs under AM DCB. Some global states are not reachable due the policies.

[5] Barrachina-Munoz, S. et al., 2018. Performance Analysis of Dynamic Channel Bonding in Spatially Distributed High Density WLANs. arXiv preprint arXiv:1801.00594.

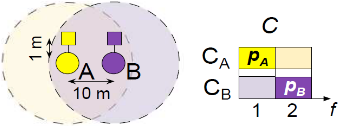
SFCTMN: CTMNs for spatially distributed WLANs

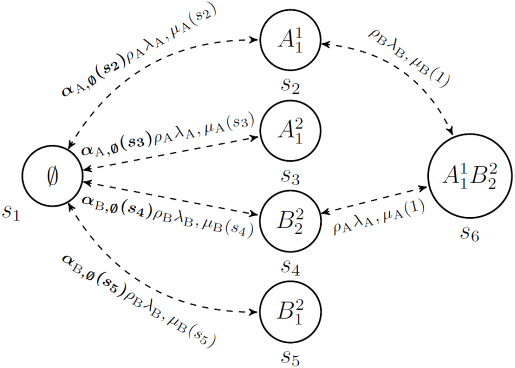


Generation of CTMNs using the SFCTMN framework.

* SFCTMN GitHub repository: `https://github.com/sergiobarra/SFCTMN`

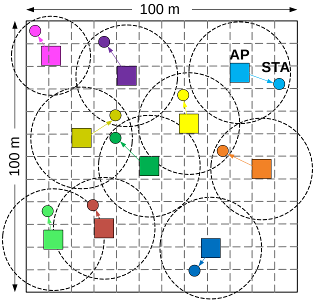
DCB policies define states and transitions



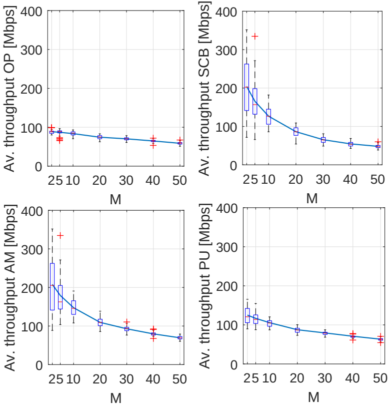


States and transitions depend on the DCB policies.

DCB & node density effect [5]



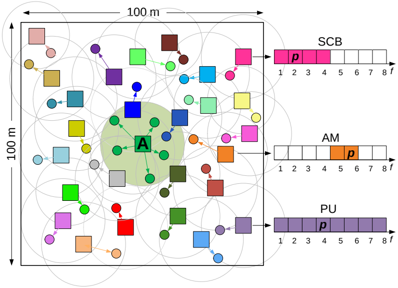
Example deployment consisting of 10 WLANs spread uniformly at random in a 100x100 m^2 map. All WLANs implement the same DCB policy.



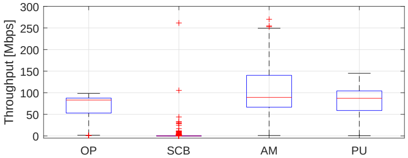
Av. WLAN throughput under saturation.

[5] Barrachina-Munoz, S. et al., 2018. Performance Analysis of Dynamic Channel Bonding in Spatially Distributed High Density WLANs. arXiv preprint arXiv:1801.00594.

DCB & optimal individual policy [5]



Central HD WLAN scenario.



A's throughput distribution per policy under saturation regimes.

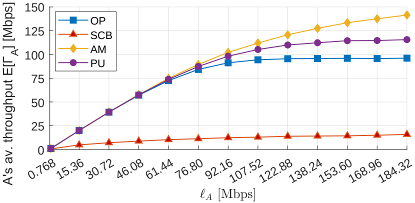
$E[\Gamma_A^{PU}] > E[\Gamma_A^{AM}]$	$E[\Gamma_A^{PU}] \approx E[\Gamma_A^{AM}]$	$E[\Gamma_A^{AM}] > E[\Gamma_A^{PU}]$
28/400 (7 %)	47/400 (12 %)	325/400 (81 %)

Share of scenarios where AM or PU provide the highest throughput for A.

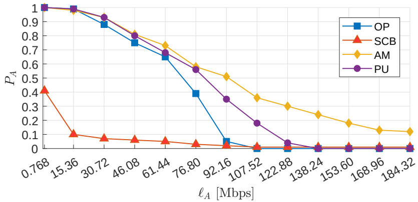
[5] Barrachina-Munoz, S. et al., 2018. Performance Analysis of Dynamic Channel Bonding in Spatially Distributed High Density WLANs. arXiv preprint arXiv:1801.00594.

DCB & optimal policy under unsaturated regimes [6]

Bursty traffic: a burst of $n_b = 10$ data packets is generated each $t_b \sim \text{Exponential}(\frac{n_b}{\ell})$



A's av. throughput.

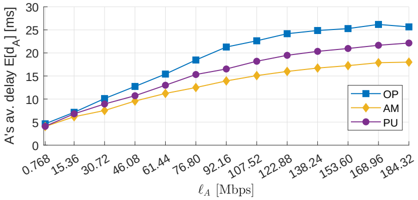


A's probability no packets dropped.

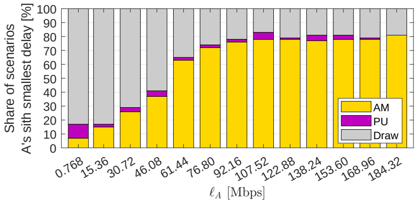
[6] Barrachina-Muñoz, S. et al., 2018. To overlap or not to overlap: Enabling Channel Bonding in High Density WLANs. arXiv preprint arXiv:1803.09112.

DCB & optimal policy under unsaturated regimes [6]

Delay: timestamp of packet acknowledgment minus timestamp of packet generation (added to buffer).



A's av. delay.



Delay AM vs. PU.

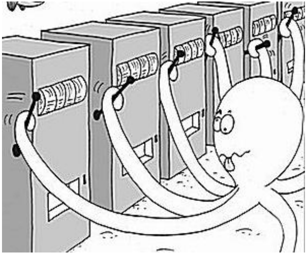
* For the delay, we consider only those scenarios where A does not get saturated in order to fairly compare policies.

[6] Barrachina-Muñoz, S. et al., 2018. To overlap or not to overlap: Enabling Channel Bonding in High Density WLANs. arXiv preprint arXiv:1803.09112.

Reinforcement Learning (RL) for WLANs

Multi-armed bandits (MABs):

- Exploration-exploitation trade-off in face of uncertainty.
- The expected cumulative regret quantifies the performance of a given action-selection strategy.
- MABs are **stateless**. Other approaches are MDP and POMDP.
- Nice tutorial on MABs.[1]

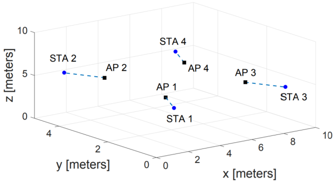


Classic example: a gambler attempts to maximize the profits among a set of slot machines.

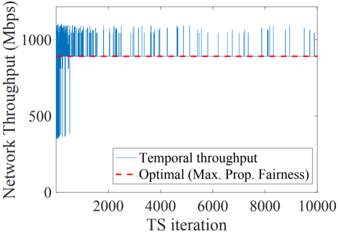
[1] `https://fwilhelmi.github.io/presentation_mabs_wireless_communications/`

Collaborative Spatial Reuse & MABs [7]

- Tutorial-like implementation of MABs for decentralized SR in dense WNs.
- Decentralized **selfish** learning improves SR in symmetric WN scenarios.
- Temporal throughput variability may affect higher layers (TCP).
- Thompson sampling achieves fairness with low temporal variability.



Grid scenario.

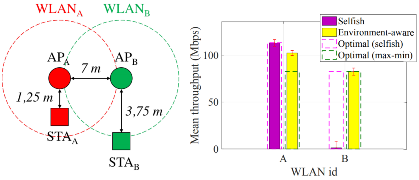


Aggregate throughput evolution.

[7] Wilhelmi, F. et al. Collaborative Spatial Reuse in Wireless Networks via Selfish Multi-Armed Bandits. arXiv preprint arXiv:1710.11403.

MABs for Decentralized Spatial Reuse [8]

- Potential of applying decentralized online learning to WLANs.
- Selfish vs. environment-aware learning.
- Unfair vs. fair.
- Convergence and design of the reward generation system.



Selfish vs. environment-aware.

[8] Wilhelmi, F. et al., 2018. Potential and Pitfalls of Multi-Armed Bandits for Decentralized Spatial Reuse in WLANs. arXiv preprint arXiv:1805.11083.

Outline

Primary channel allocation for DCB

Working on a basic idea to be evaluated:

- **What?** Iteratively change primary when AP is not *happy*.
- **How?** Estimating occupancy of the whole bandwidth.
    - Cost of listening and switching
    - Approaches:
        - Random
        - Channel-wise
        - (*) Learning approach

1	2	3	4	5	6	7	8
99%	5%	2%	p_c	88%	87%	92%	88%

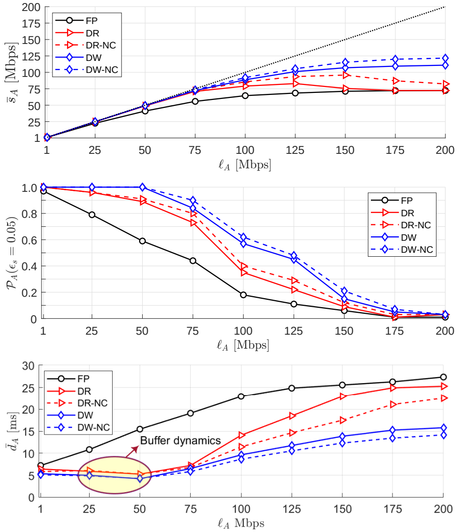
Probabilities of finding each of the channels free in last iteration.

$$\underset{p_{w,t+1} \neq p_{w,t}}{\operatorname{argmax}} \ \hat{r}_{w,t+1}, \text{where } \hat{r}_{w,t+1} = \sum_{n_c \in \mathcal{N}_c} P_{w,t+1}(n_c) r_w(n_c)$$

Primary channel allocation for DCB

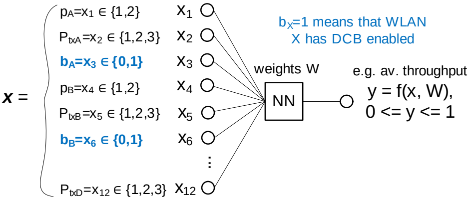
Evaluated scenario:

- Dense deployment: 10 WLANs in a 50x50 m^2 map.
- WLAN A able to change primary channel.
- Cost of new configuration: 100 ms.
- One iteration per second.
- Happiness ratio: 90%.

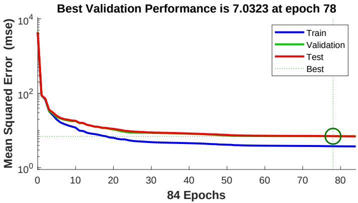


ANNs for WLANs configuration (too preliminary)

The idea is to leverage the power of ANNs to optimize complex scenarios.



ANN for optimizing the configuration of a centralized WLAN network.



Precision evolution for 57 hidden nodes and just 8745/331,776 evaluated actions (2%) of $\prod_f |f|^N$ possible.

Research stay at Rice

- I'll be around for 4 months.
- Preliminary interests:
  - **Drones**: data-driven missions.
  - **MIMO**: little knowledge but really important technology.
  - **IEEE 802.11ay and mmW**: extend my work on DCB to new standards and bands.
  - **Cross-layer**: effect of DCB in TPC flows.
  - **Explore ML/ANN potential**.
- I want to learn from your work and I'm open to broad my fields of research.

RICE

Outline

What does WN do?

Universitat Pompeu Fabra Barcelona

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Roc Boronat 138
08018, Barcelona

WN

Members: 1 faculty member, 5 PhD students, 1 MSc students, several undergrad students, 1 project manager / post-doc researcher, 1 Research Engineer

Research

Open spectrum bands → Adversial & uncoordinated interactions between networks

Resource Allocation → Multiuser communication, Spatial Reuse, Spectrum efficiency, Channel access

Machine Learning / Data Analytics → (on line) Network configuration / Resource Allocation

Technologies: WIFI, WSNs, LPWANs, etc.

Projects

Towards Deterministic Channel Access in High-Density WLANs, Cisco University Research Program

WIFIX: Creating an intelligent WiFi Ecosystem, project funded FON

Wireless Networking through Learning: Searching for Optimality in Highly-dynamic and Decentralized Scenarios, MdM Excellence Program

INTER-HARE platform: Integration of multiband IoT technologies, EU H2020

1

Members' work

- **Sergio Barrachina-Muñoz, PhD student**: machine learning-based WLAN configuration (focus on DCB and CA).
- **Kostis Dovelos, PhD student**: resource allocation in MU (packet based) networks (OFDMA, MU-MIMO, multi-AP cooperative solutions).
- **Álvaro López, PhD student**: large WIFI network simulations using MAC abstractions, and network optimization using hierarchical ML techniques (cloud and edge cooperation).
- **Francesc Wilhelmi, PhD student**: spatial reuse (TPC, CCA, directional transmissions) using reinforcement learning.
- **Marc Carrascosa, MSc student**: AP-selection, WIFI tests / measurements, etc.
- **Toni Adame, Research Engineer**: IoT / WSNs architectures, MAC & network developer
- **Albert Bel, Post-doc researcher & project manager**: IoT / WSNs architectures

Software

We have been developing two main tools for analyzing WLANs.

- **SFCTMN**: Continuous Time Markov Network (CTMN) based framework for analyzing WLANs implementing DCB policies in spatially distributed scenarios.

- **Komondor**: simulator being developed to support 11ax features like CSMA/CA, RTS-CTS, packet aggregation, spatial reuse, etc. Working on learning agents to endow the WLANs with ML capabilities.

https://github.com/sergiobarra/SFCTMN

https://github.com/wn-upf/Komondor

Thank you!

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References

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