

Master's thesis

# Radio activity optimisation for Wireless Personal Communications

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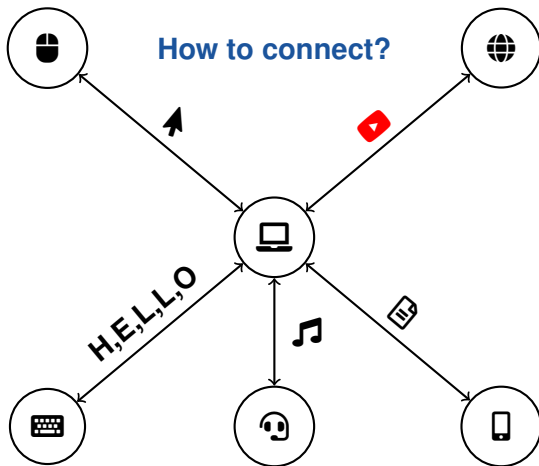
Reader: **Mathieu XHONNEUX**

June 2021

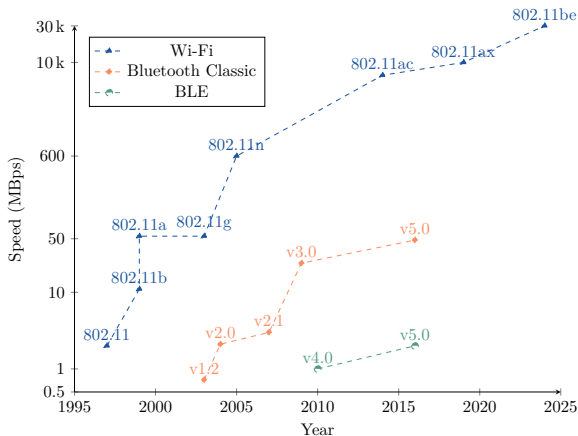
Master [120] in Electro-mechanical Engineering

# A connected world

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# Many wireless technologies



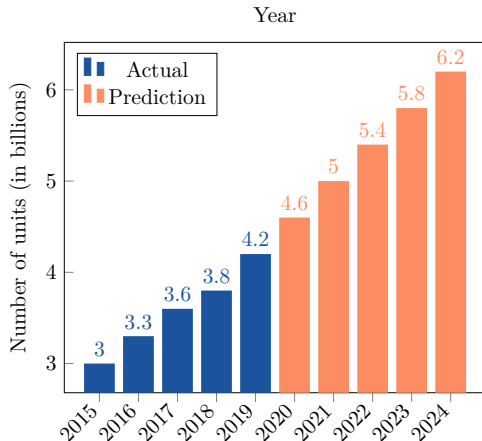
Wi-Fi, Bluetooth, Bluetooth Low Energy (BLE), ZigBee, etc.

Speed, power, cost, range, ...  
A matter of trade-offs!

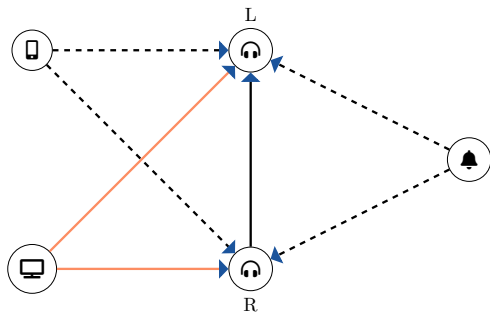
# BLE: a technology with a bright future...

**Main pros:** low power,  
decent range and data rate,  
robust and cheap.

**Typical applications:**  
wireless earbuds, portable  
speaker, sensors, Internet of  
Things (IoT), and hearing  
aids.



## BLE: ... and a lot of challenges!



**Excellent designs should minimise:**

- 1 interference with other technologies;
- 2 packet collisions;
- 3 Packet Error Rate (PER);
- 4 radio usage;
- 5 and many others.

# Table of contents

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- ◆ Introduction
- ◆ C.1 Slot finder
- ◆ C.2 Enhanced Wi-Fi interoperability
- ◆ Conclusion

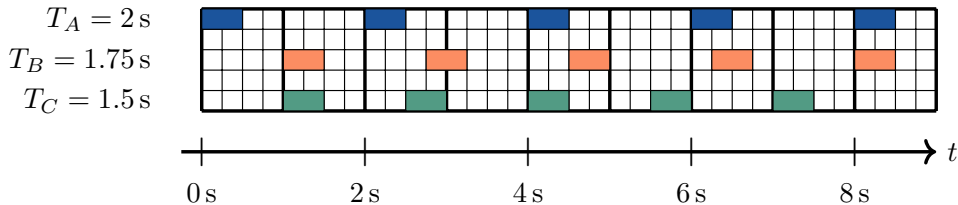
## C.1 Slot finder - contents

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- ◆ Introduction
- ◆ C.1 Slot finder
  - The packet collisions problem
  - A minimisation problem
  - A simple but efficient solution
  - Results
- ◆ C.2 Enhanced Wi-Fi interoperability
- ◆ Conclusion

## The packet collisions problem

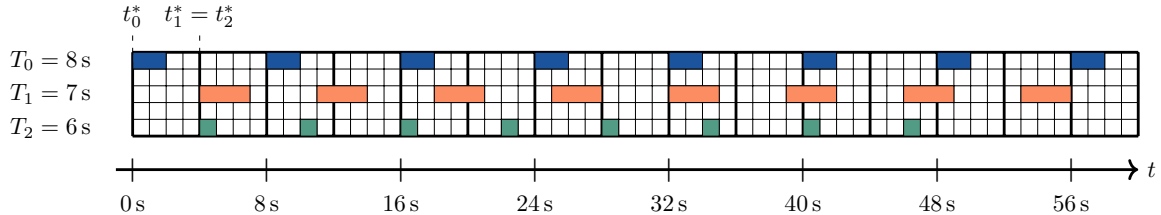
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In some situations, collisions can occur: either at **random** or **deterministic** time instants.



# A minimisation problem



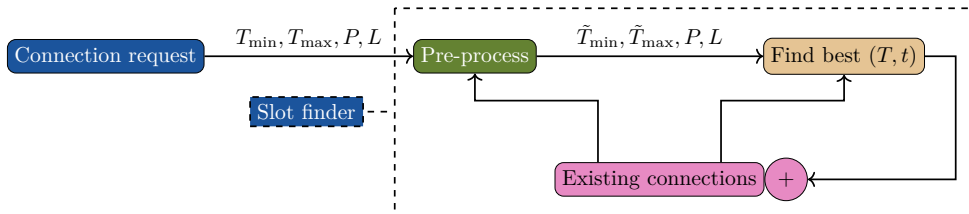
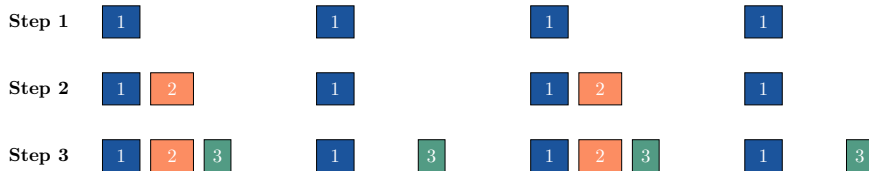
## Cost function

$$C = \sum_{i,j>i} \#_{i,j} \left( \frac{P_i}{N_{i,j}} + \frac{P_j}{N_{j,i}} \right)$$

## Find best:

- interval value  $T$ ;
- and anchor timing  $t$ .

# A simple but efficient solution



# Results

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Some key aspects:

- always runs under 100 ms<sup>1</sup>;
- can easily be reduced to 10 ms or 1 ms;
- highly customisable;
- excellent for similar connections.

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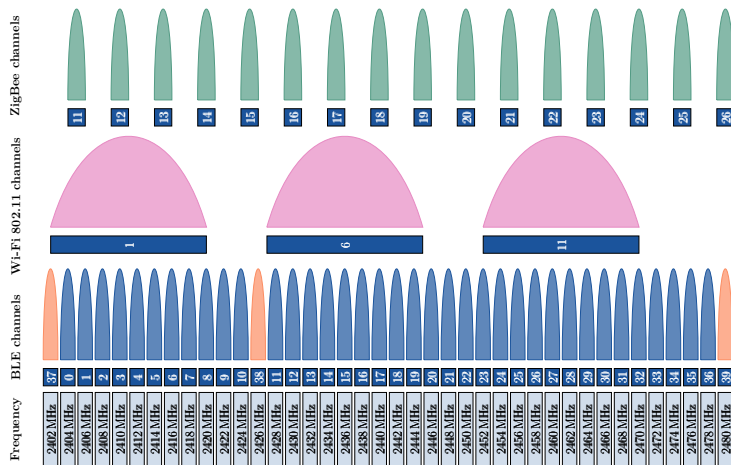
<sup>1</sup>For less than 16 connections.

## C.2 Enhanced Wi-Fi interoperability - contents

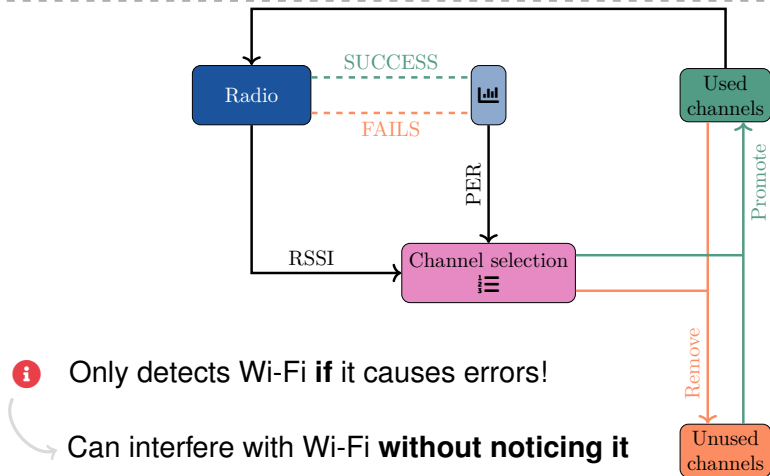
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- ◆ Introduction
- ◆ C.1 Slot finder
- ◆ C.2 Enhanced Wi-Fi interoperability
  - Coexistence in the 2.4 GHz ISM band
  - Current CA implementation
  - Proposed enhancement
  - Results
- ◆ Conclusion

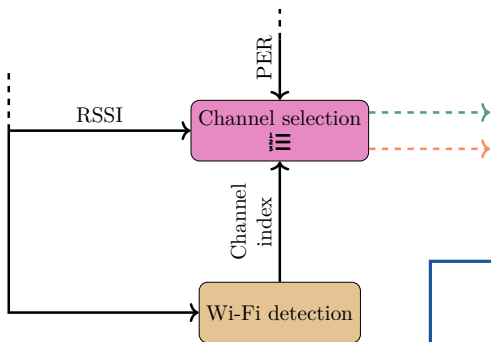
# Coexistence in the 2.4 GHz ISM band



## Current CA implementation



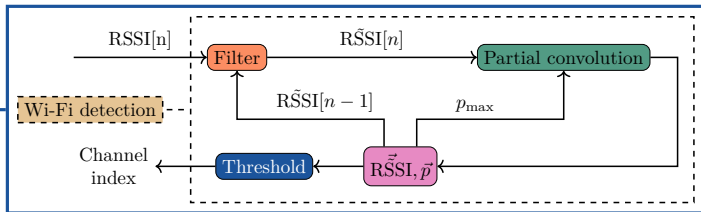
## Proposed enhancement



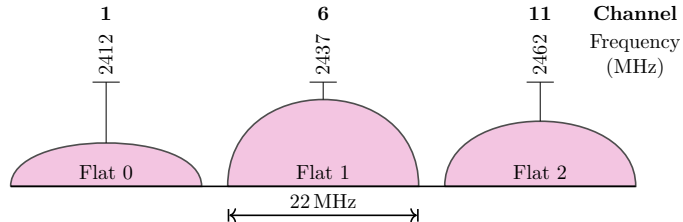
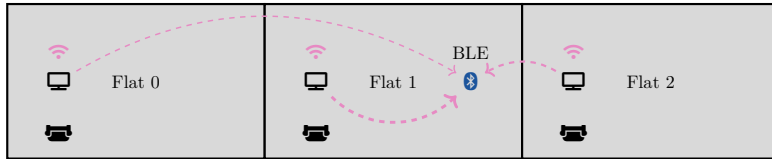
Executes in less than  $20\ \mu\text{s}$ ,  
i.e., roughly 2 % of one RSSI measure

Main ideas:

- ① (re-)use RSSI measures;
- ② perform very few add. computations;
- ③ detect strongest Wi-Fi signal only.

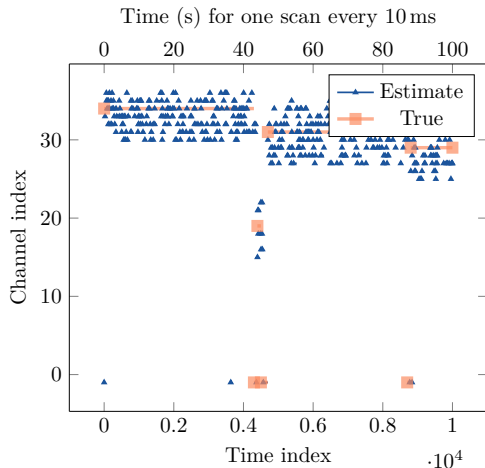
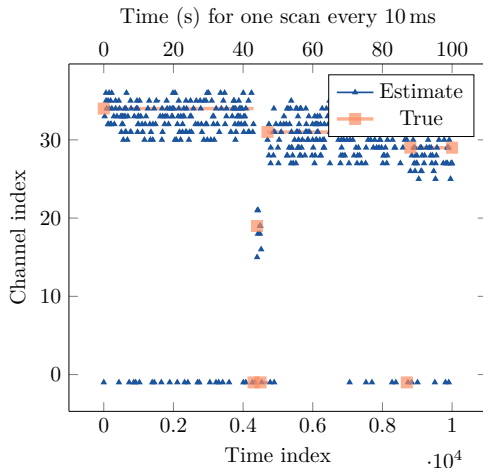


## Proposed enhancement - why only one Wi-Fi signal?





## Results - one Wi-Fi - no filter vs filtering



## Conclusion - contents

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- ◆ Introduction
- ◆ C.1 Slot finder
- ◆ C.2 Enhanced Wi-Fi interoperability
- ◆ Conclusion
  - Two contributions
  - Status of work and future

## Two contributions

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### C.1 - Slot finder

- **Problem** - packets can collide;
- **Solution** - smart connection scheduling.

### C.2 - Enhanced Wi-Fi interoperability

- **Problem** - BLE can deteriorate Wi-Fi's experience;
- **Solution** - upgrade current CA with Wi-Fi detection.

## Status of work and future

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### Status of work

- good view of modern challenges;
- thorough testing and promising results.

### Future work

- validate on hardware;
- tune for specific applications.

Conclusion

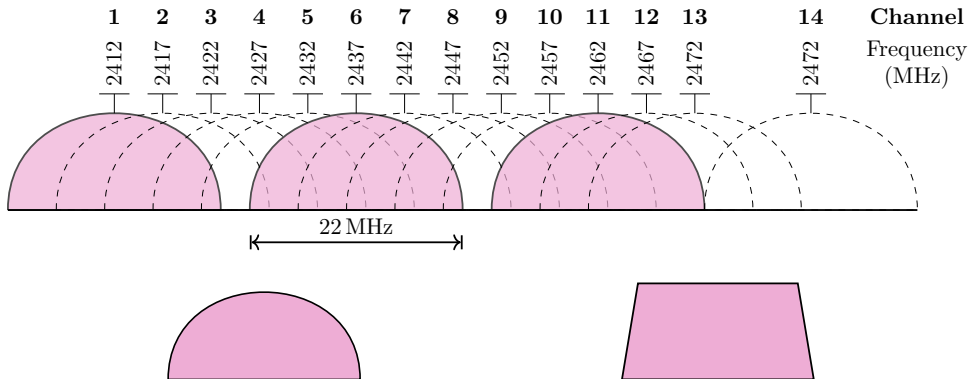
**Thanks for listening!**

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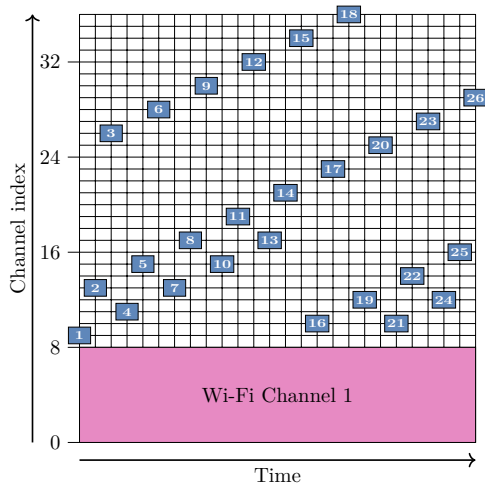
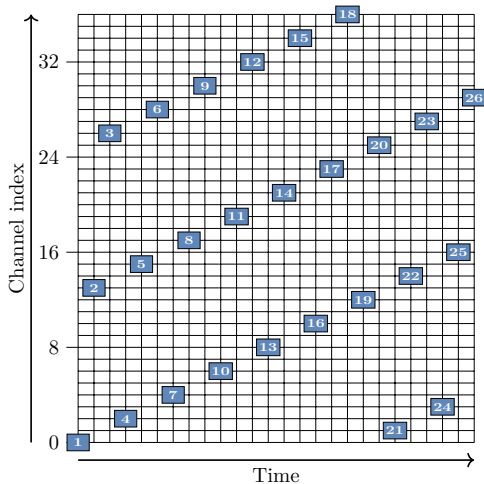


**Do you have any question?**

## Wi-Fi channels

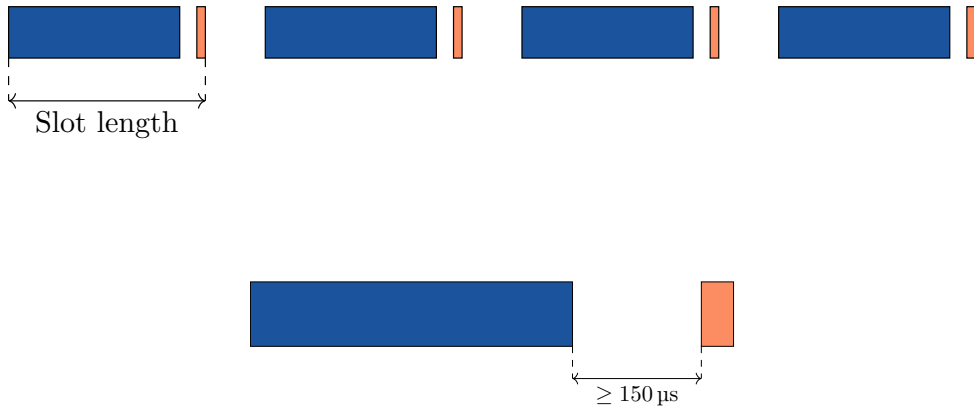


# Frequency Hopping



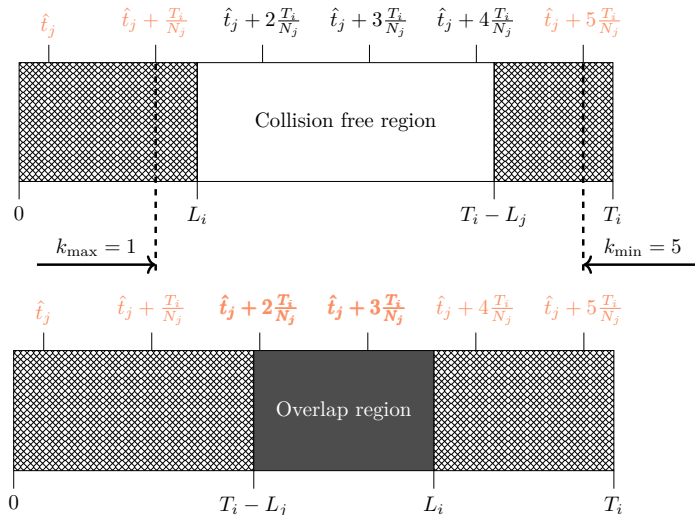
## Slot definitions

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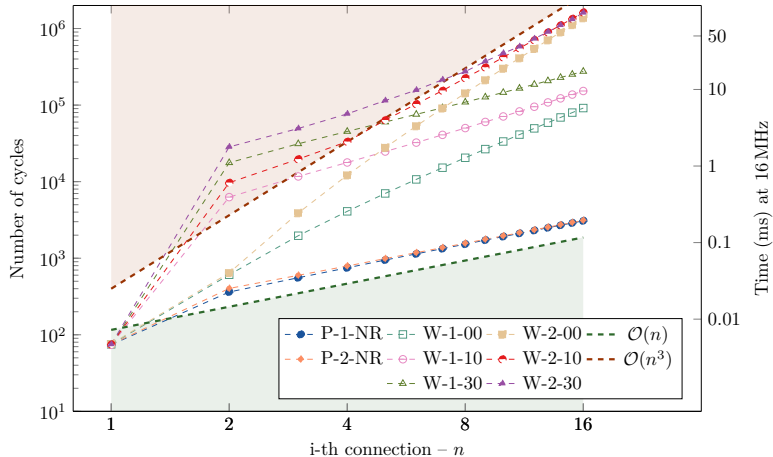


# Collision bounds



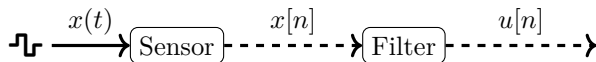
# Slot finder - perfect (P) and worst (W) cases

Cost of finding best slot for  $i$ -th connection, plus asymptotic min. and max. bounds



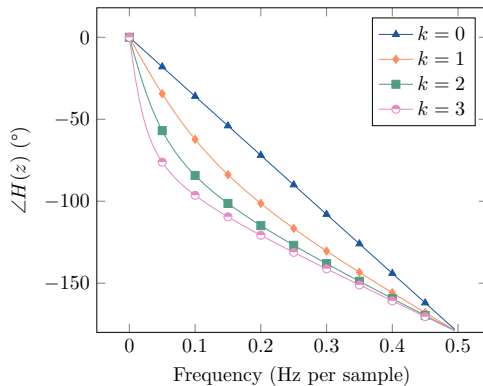
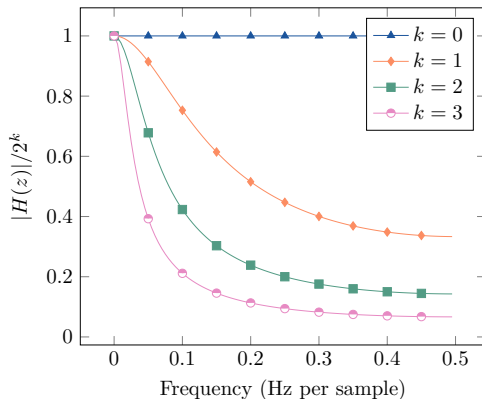
## Filtering - the filter

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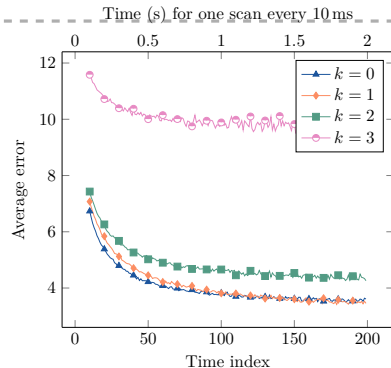
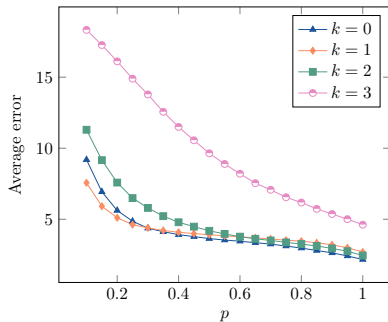


$$u[n+1] = \left(1 - \frac{1}{2^k}\right) u[n] + x[n]$$

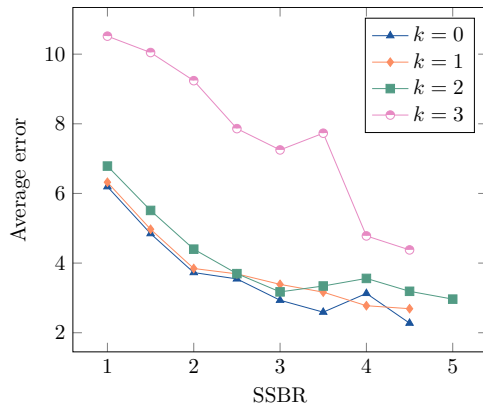
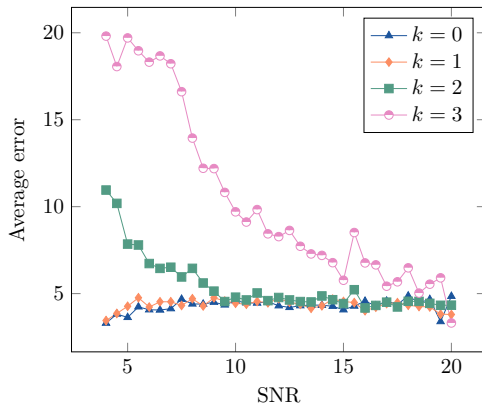
# Filtering - frequency response



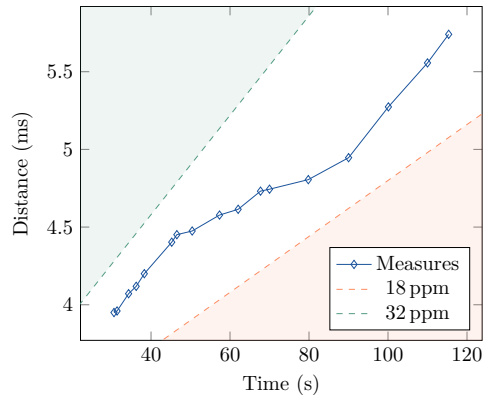
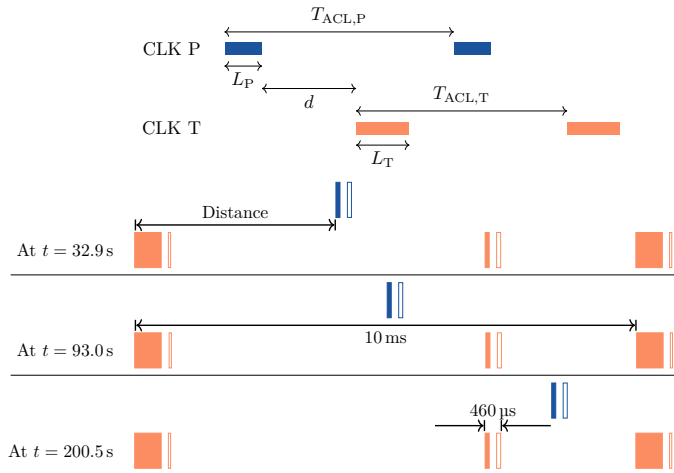
# Wi-Fi detection - activity results



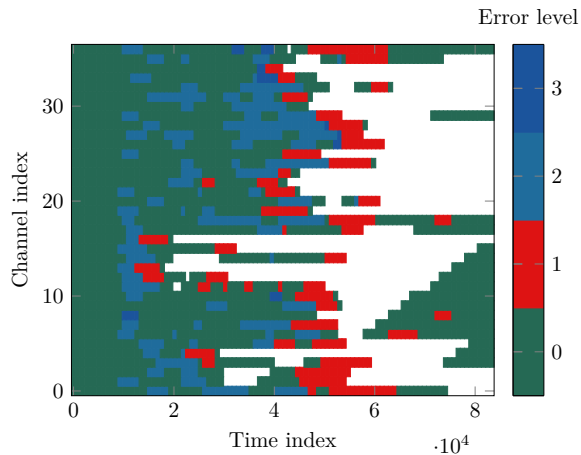
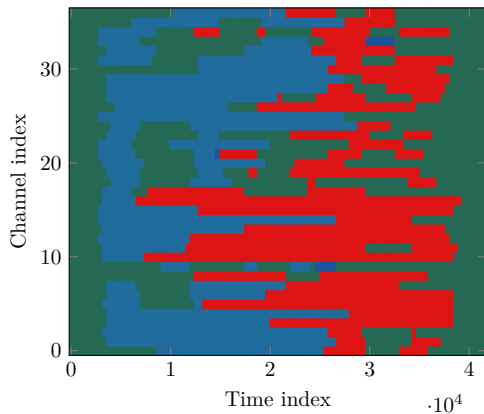
# Wi-Fi detection - energy results



# Clock drift



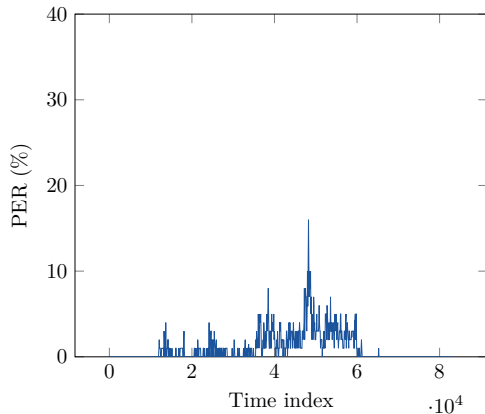
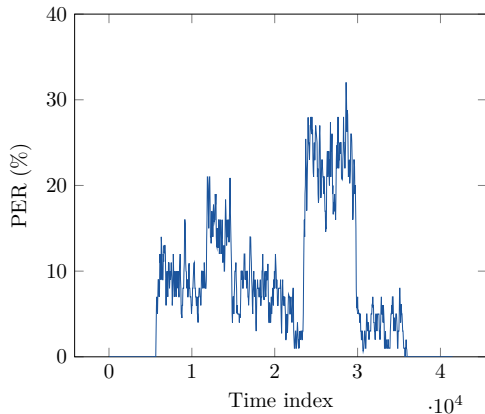
## CA vs NOCA - status





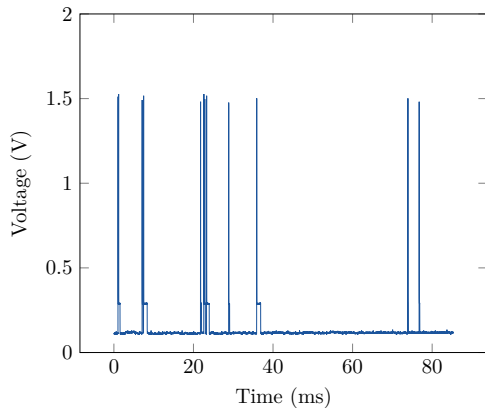
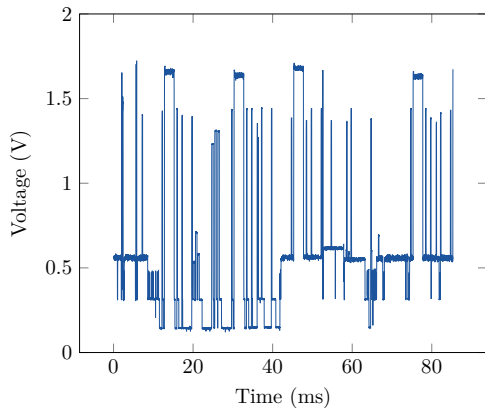
## CA vs NOCA - PER

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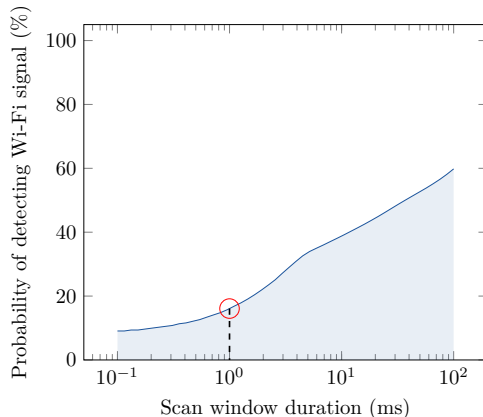
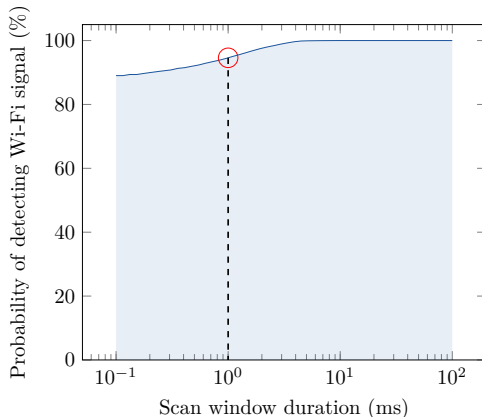


## Wi-Fi activity - office vs basement

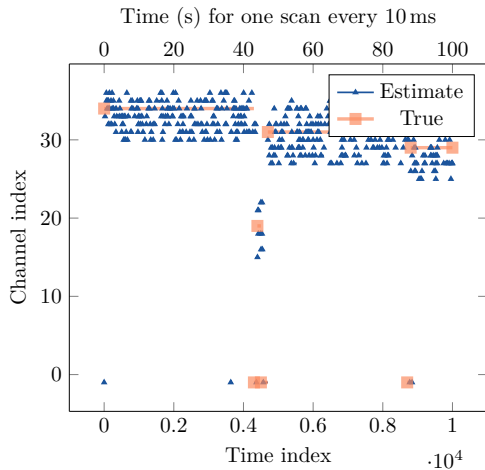
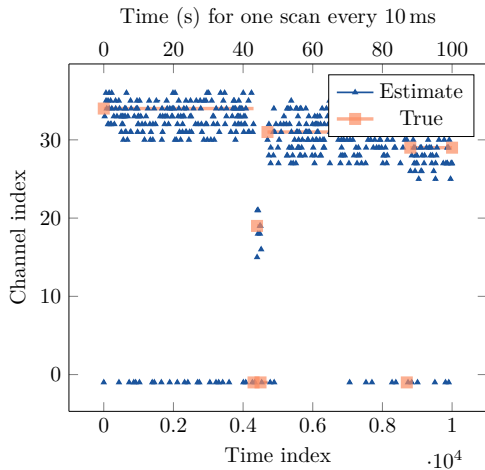
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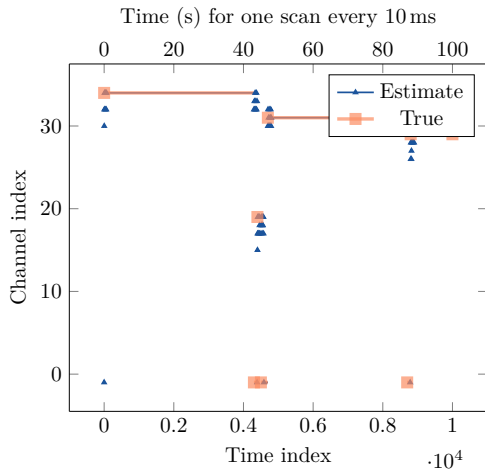
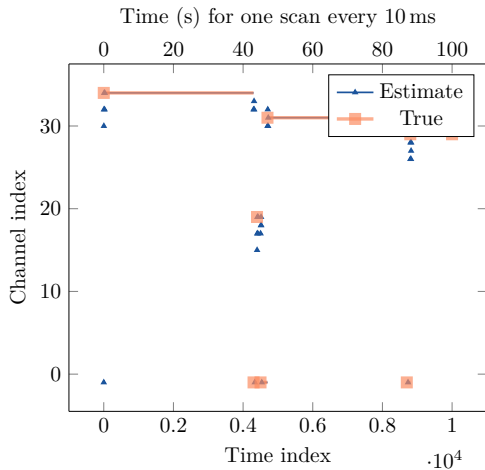
## Wi-Fi detection probability - office vs basement



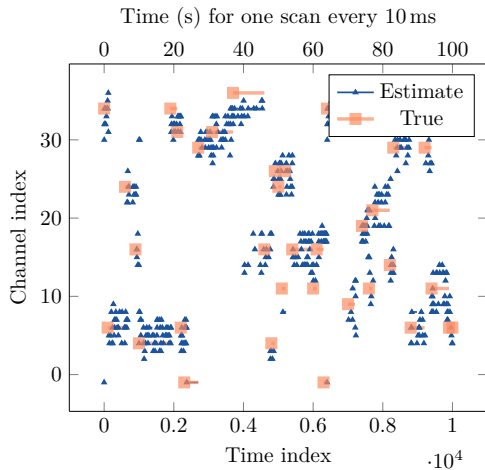
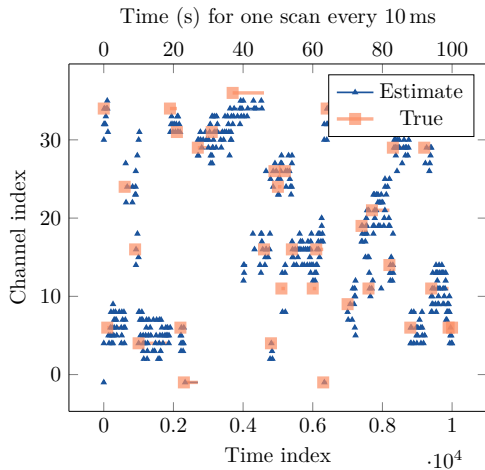
# Wi-Fi detection - any Wi-Fi - $p = 30\%$ - $k = 0$ vs $k = 1$



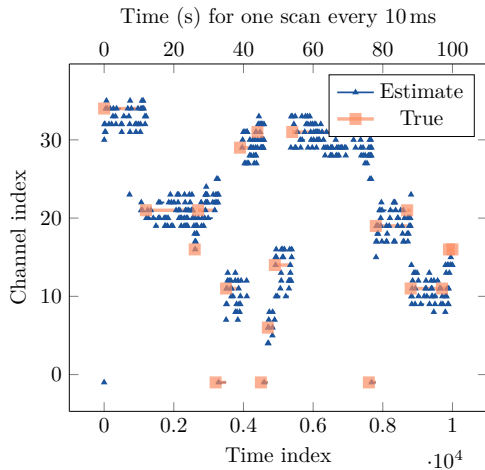
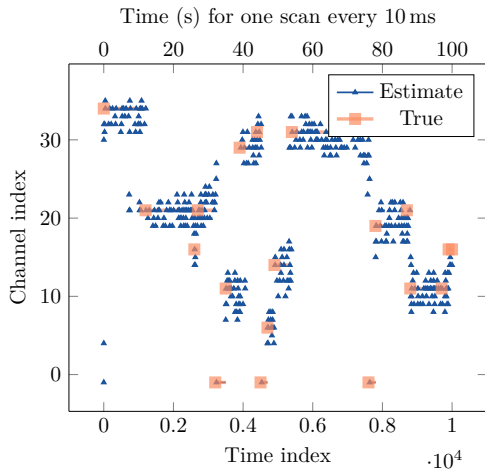
## Wi-Fi detection - one Wi-Fi - $p = 100\%$ - $k = 0$ vs $k = 1$



# Wi-Fi detection - any Wi-Fi - $p = 80\%$ - $k = 0$ vs $k = 1$



# Wi-Fi detection - two Wi-Fi - $p = 80\%$ - $k = 0$ vs $k = 1$



# Wi-Fi detection - one Wi-Fi - $p = 80\%$ - $k = 0$ vs $k = 1$

