Towards a Fast and Efficient Strategy to Assign Channels in WLANs with Channel Bonding

Amel CHADDA Marija STOJANOVA Thomas BEGIN

Anthony BUSSON Isabelle GUÉRIN LASSOUS

Univ Lyon, ENS de Lyon, Université Claude Bernard Lyon 1, Inria, CNRS, LIP F-69342
Contact: firstname.lastname@ens-lyon.fr

20.11.2020

WLAN performance

Today's WLANs reuse and modify old protocols to become more efficient, but are also larger and more complex:

- data rates
- frame aggregation
- **channel bonding**
- coexistence of different standard amendments

WLANs become hard to predict, resulting in poor resource usage and unfair sharing. Taking into account all parameters is unmanageable.

Channel Bonding (CB) compromise:

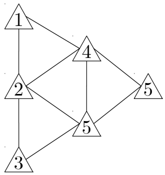
Potential outcomes

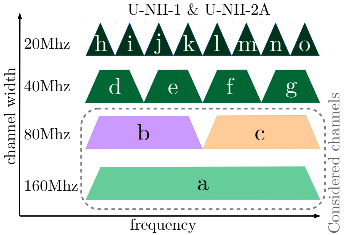
- higher data rates
- lower spatial reutilization
- lower fairness

Large set of channel assignments

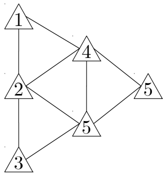
- Up to 4 different channel widths (20, 40, 80, 160 MHz)
- For a network of N nodes, 4^N possible combinations of channel widths
- 2 to 25 channels per channel width...

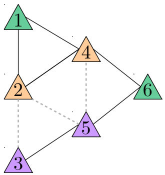
Channel width and assignment

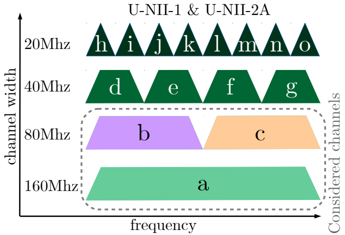




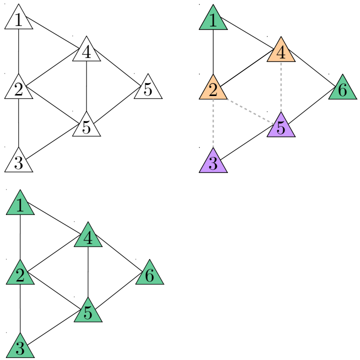
Channel width and assignment

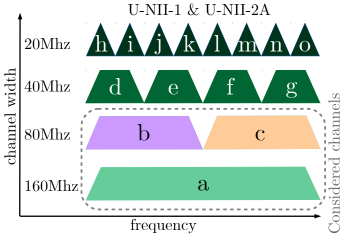




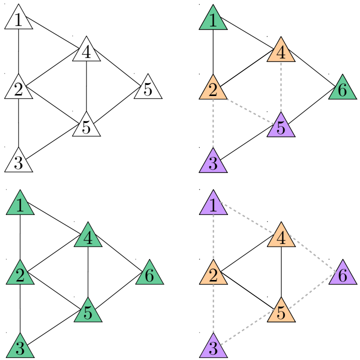


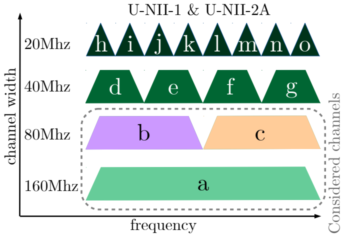
Channel width and assignment



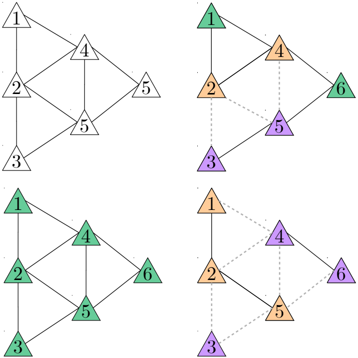


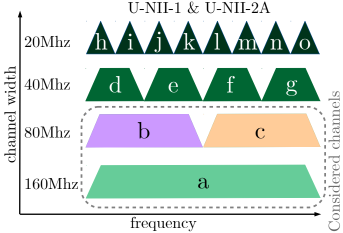
Channel width and assignment



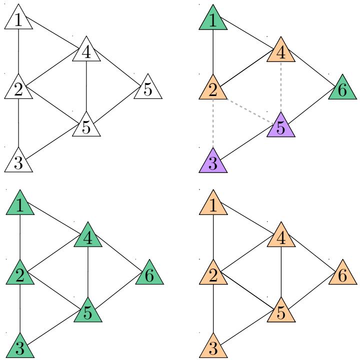


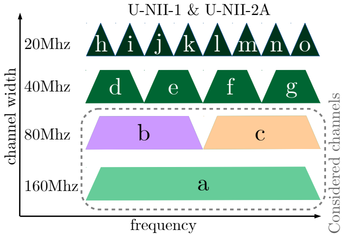
Channel width and assignment





Channel width and assignment





What we propose:

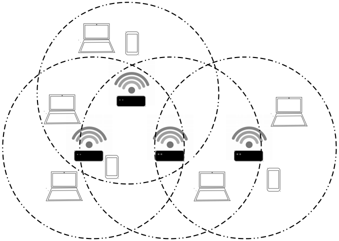
A data-driven and graph-centric solution that:

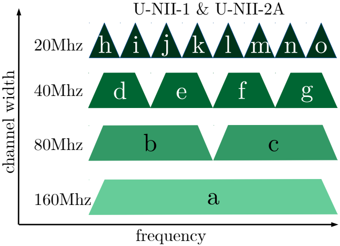
- Separate channel width selection and channel assignment
- Handles saturated networks with arbitrary topologies (e.g. not fully connected)
- Chooses the best-suited channel width for the entire network
- Fast and efficient
- Input:
  - Network's conflict graph
- Output:
  - Channel width
  - Channel assignment

Terminology

WLAN devices and available channels

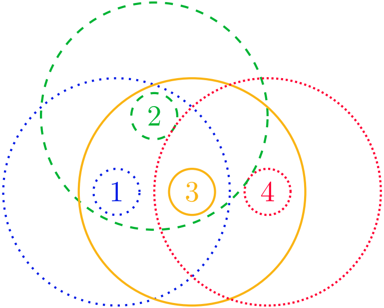
- A collection of Access Points (APs) and stations
- A set of available channels





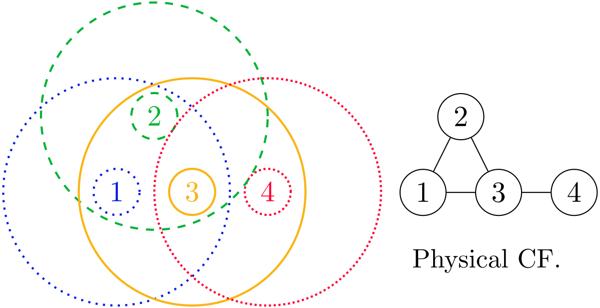
Conflict graph: Physical and logical neighbors

- WLAN of N APs with symmetrical detection zones
- Static Channel Bonding (SCB)



Conflict graph: Physical and logical neighbors

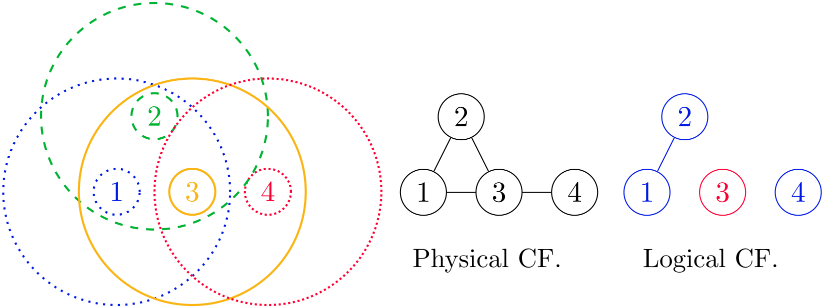
- Topology is represented by a Conflict Graph (CF)
- APs that detect each other are *physical* neighbors



Physical CF.

Conflict graph: Physical and logical neighbors

- APs are assigned channels
- APs that still detect each other are *logical* neighbors



Performance metrics: Starvation

Starvation

- AP n is starving when its throughput is smaller than some pre-set limit p_{starve}
- p_{starve} is the starvation threshold
- ST = number of APs in starvation

Proposed solution

Core principles

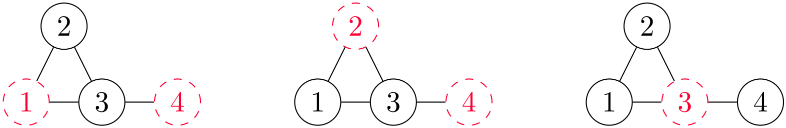
Goals?

Find a channel width and assignment that, based on the obtained logical conflict graph, maximize throughput while minimizing starvation.

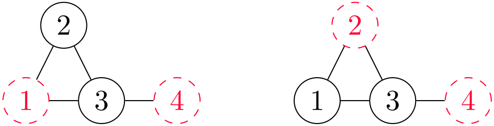
- Decouple the channel width selection and channel assignment problems
  - separate channel assignment for each channel width
- Consider worst-case scenarios
  - all APs are saturated
- Fully graph-centric
  - only conflict graph on input

Graph theory: Maximal and maximum independent set

Maximal independent sets:

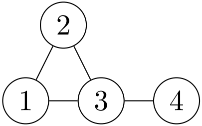


Maximum independent sets:



Maximum Independent set Ratio (MIR) (1)

- CSMA/CA tends to maximize the number of simultaneous transmissions [1]
- The highest number of simultaneous transmissions → APs of the same maximum independent set(s) (MIS)
- Starving nodes are rarely in any MIS

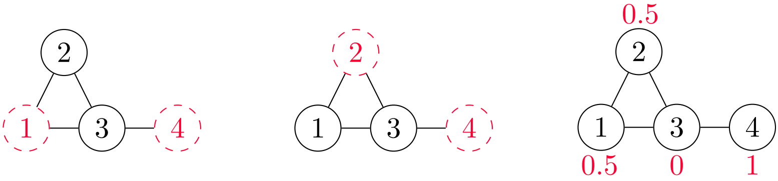


[1] Durvy et al., Self-organization prop. of CSMA/CA.

Maximum Independent set Ratio (MIR) (2)

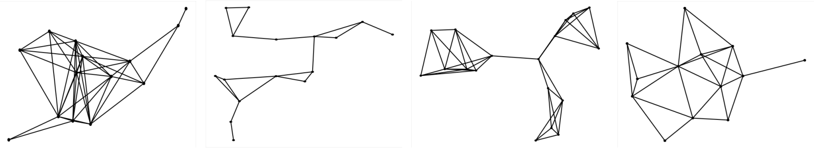
The MIR of node n is the proportion of maximum independent sets that include n:

$$MIR(n) = \frac{|MIS \text{ including } n|}{|\text{total } MIS|} \quad (1)$$

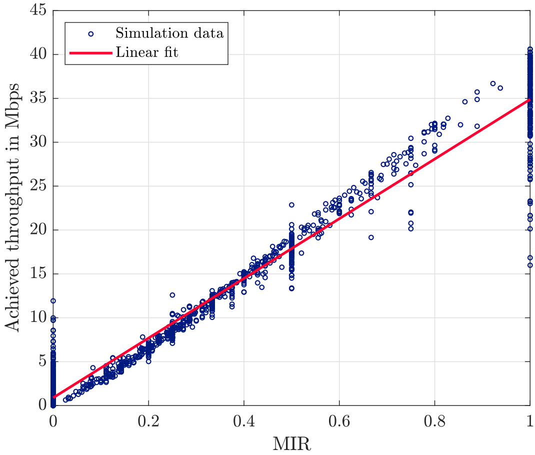


MIR's impact on WLAN performance

- Randomly generate a collection of 60 graphs
- Calculate the MIR for every node in every graph
- Run ns-3 simulations to obtain the achieved throughput of every node
- Study the relationship of throughput and MIR



MIR's impact on WLAN performance



Proposed algorithm

1. Start with the widest channel size
2. Use Taboo search to find a channel assignment
3. Calculate MIRs and estimate throughput
4. If there are starving nodes, divide channel width by 2 and go to step 2
5. If there are no starving nodes, accept this channel width and assignment

```
Input: physical conflict graph, number of vertices N, starvation threshold p_starve
Output: selected channel width w, channel assignment v
-------------------------------------------------------------
w ← 160
k ← |C_160|          //# of channels for the current width
while w ≥ 20 do
   v ← compute a k-coloring channel assignment (Tabu)
   compute MIR(n, G_w(v)), ∀n ∈ {1, ..., N}
   compute γ'(n), ∀n ∈ {1, ..., N}
   compute ST
   if ST > 0 then
      w ← w / 2
      k ← |C_w|
   else
      return (w, v)
   end if
end while
return (w, v)
```

Numerical results

Numerical results: Graph generation and simulation setup

- We randomly generate 105 graphs
- 8 to 30 APs and average densities of 2.5 to 8.3
- 60-second ns-3 simulation using the 802.11ac standard amendment
- All APs are saturated using MCS = 5 and aggregate 4 MPDUs in each transmission

Numerical results: Accuracy under different p_{starve}

Hits and misses: how many times the channel width chosen by our solution matched that of the simulator:

algo \ simu	80 MHz	40 MHz	20 MHz
80 MHz	17	0	0
40 MHz	0	79	0
20 MHz	0	0	9

$p_{\text{starve}} = 0.125$

algo \ simu	80 MHz	40 MHz	20 MHz
80 MHz	22	1	0
40 MHz	0	73	0
20 MHz	0	0	9

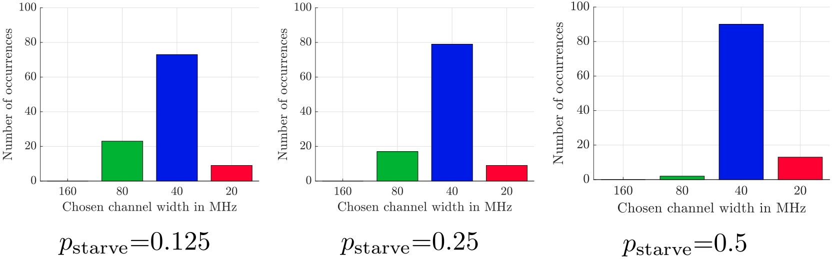
$p_{\text{starve}} = 0.25$

algo \ simu	80 MHz	40 MHz	20 MHz
80 MHz	0	2	0
40 MHz	0	18	72
20 MHz	0	0	13

$p_{\text{starve}} = 0.5$

When p_{starve} is properly set, the chosen channel width is (virtually) always the same for our proposed solution and the simulator.

Numerical results: Distribution of channel width



- 40 MHz is the prudent channel width
- 160 MHz always leads to starvation in some APs
- p_{starve} impacts the chosen channel frequency

Discussion

Conclusions

- A fast and efficient approach to select channel width and assignment
- Decoupled channel width selection and channel assignment
- Graph-centric and requiring little network information
- Focused on avoiding AP starvation
- Easily parameterized to fit different performance criteria

Future works

- Inclusion of more diverse traffic and network scenarios to test the solution's robustness
- Modifying performance criteria: considering proportional fairness instead of starvation

Q&A

Thank you for your attention!

Q&A

Achievable throughput exact equation:

$$\gamma_n = \frac{L \times a}{T_{DCF} + a \times \frac{L+H_{\text{MAC}}}{R} + T_{\text{ACK}}}\ , \qquad (2)$$

Q&A

Achievable throughput: best-case scenario of isolated AP

$$\gamma_n = \frac{\text{data size}}{\text{full transmission time}} \tag{2}$$

Achieved throughput: realistic scenario of competing APs

$\gamma\prime_n$ is the throughput AP n obtains as it competes for medium access with its logical neighbors

Starvation threshold

$\frac{\gamma\prime_n}{\gamma_n} \leq p_{\text{starve}}$

Q&A

- The Tabu Search algorithm for k-coloring has an $O(D_{max}N^4)$ complexity, where D_{max} is the maximum degree in the graph
- Bron-Kerbosch's algorithm that is used to find the MIR ratios has an $O(3^{\frac{N}{3}})$
- All other parts of our algorithm have a lower complexity, meaning that the overall complexity of the proposed solution is $O(3^N)$.