Universitat Pompeu Fabra Barcelona
Wireless Networking Research Group

Machine Learning for Throughput Prediction in Coordinated Wi-Fi Networks .

An introduction to two problem statements for the ITU AI Challenge

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2021 Edition

- Explores the feasibility of applying ML in next-generation wireless local area networks, specifically through the use of federated learning.
- Focused on spatial reuse (SR) in the 802.11ax context [1].

FEDERATED SPATIAL REUSE OPTIMIZATION IN NEXT-GENERATION DECENTRALIZED IEEE 802.11 WLANS

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Abstract – *As wireless standards evolve, more complex functionalities are introduced to address the increasing requirements in terms of throughput, latency, security, and efficiency. To unleash the potential of such new features, artificial intelligence (AI) and machine learning (ML) are currently being exploited for deriving models and protocols from data, rather than by hand-programming. In this paper, we explore the feasibility of applying ML in next-generation wireless local area networks (WLANs). More specifically, we focus on the IEEE 802.11ax spatial reuse (SR) problem and predict its performance through federated learning (FL) models. The set of FL solutions overviewed in this work is part of the 2021 International Telecommunication Union (ITU) AI for 5G Challenge.*

***** This edition pretends to extend the work of previous years about SR, but now in the context of coordinated Wi-Fi networks *****.

[1] F. Wilhelmi, J. Hribar, S. F. Yilmaz, E. Ozfatura, K. Ozfatura, O. Yildiz, D. Gündüz, H. Chen, X. Ye, L. You, Y. Shao, P. Dini, and B. Bellalta, "Federated spatial reuse optimization in next-generation decentralized IEEE 802.11 WLANs," 2022. [Online]. Available: https://arxiv.org/abs/2203.10472

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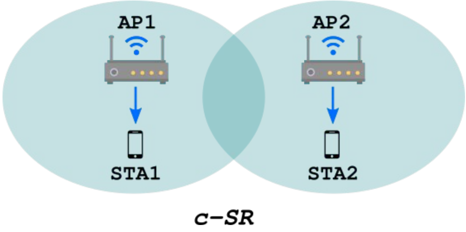
MAPC. Coordinated spatial reuse

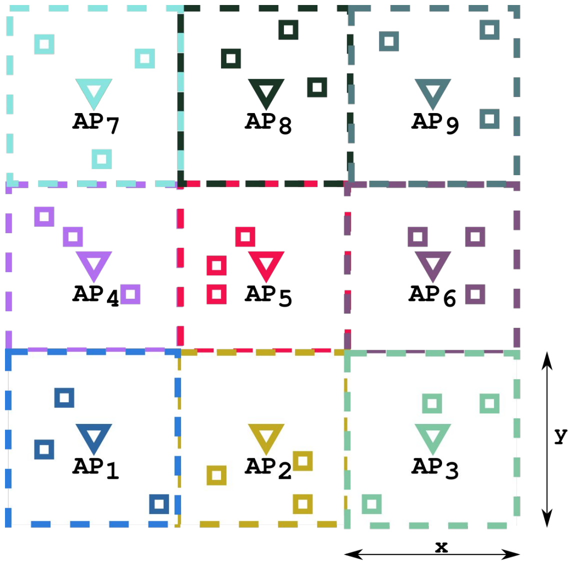
- Access points exchange information to coordinate simultaneous transmissions [2].
- Simultaneous transmissions are succeeded only if APs are suitable to transmit at the same time, i.e., if the signal-to-interference-plus-noise ratio (SINR) at the receivers is high enough. The higher the SINR at receivers, the higher the modulation and coding scheme (MCS) index and thus the data rates.
- To sum up, c-SR aims to find the best combinations that includes AP-STA pairs and maximize a given metric, in our case the aggregate throughput.



[2] D. Nunez, F. Wilhelmi, S. Avallone, M. Smith, and B. Bellalta, "TXOP sharing with Coordinated Spatial Reuse in Multi-AP Cooperative IEEE 802.11be WLANs," in *2022 IEEE 19th Annual Consumer Communications Networking Conference (CCNC)*, 2022, pp. 864–870.

Setup

- 9 APs, each of them centered in a subarea of 10x10 meters.
- The number of stations associated to each AP is randomly selected per deployment, *N*, 1≤N≤5, and stations are also uniformly deployed at random in each subarea.
- Downlink traffic in saturation conditions
- We consider the pathloss model for IEEE 802.11ax.



Inputs

RSSI matrix

- Contains the Received Signal Strength Indicator (RSSI) in dBm seen from each station when every AP transmits.
- E.g.:

  $RSSI_{21}$ = -70 dBm means that **STA_2** receives -70 dBm of power when **AP_1** transmits.

	AP_1	AP_2	AP_3
STA_1	$RSSI_{11}$	$RSSI_{12}$	$RSSI_{13}$
STA_2	$RSSI_{21}$	$RSSI_{22}$	$RSSI_{23}$
STA_3	$RSSI_{31}$	$RSSI_{32}$	$RSSI_{33}$

Inputs

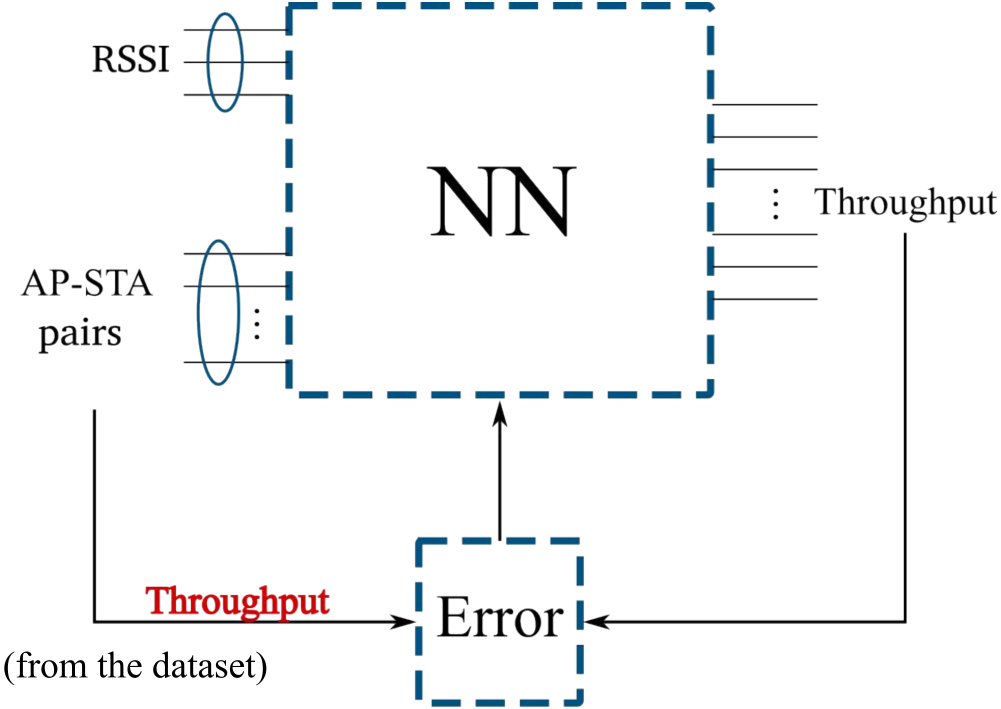
Scheduled AP-STA pairs

- Contains the list of AP-STA pairs for a given TXOP. These APs will be selected to transmit simultaneously to their corresponding STA, using the c-SR scheme.
- The maximum number of APs transmitting simultaneously is constrained to 4 i.e., 1-4 APs transmitting in c-SR mode at every transmit opportunity (TXOP)

E.g.:

{3,4,0,0,0,0,0,0,25} means **AP_1**, **AP_2** and **AP_9** transmit to **STA_3**, **STA_4** and **STA_{25}**, respectively.

Model


RSSI
AP-STA pairs
NN
Throughput
Throughput
(from the dataset)
Error

Dataset

- Different deployments (10 000) are provided and in each of them the number of stations as well as their positions are randomly generated.
    - Number of stations: 1-5
    - Position: if the number of stations is set to e.g., 3, means that 3 stations are associated to each AP. They are randomly placed in each subarea.
- For every deployment 100 different TXOPs are simulated. In each of them, the AP-STA pairs are randomly generated.

Dataset

Deployment's number

RSSI matrix

TXOPs

```
Deployment 8
-66.62,-80.99,-88.80,-70.31,-81.68,-89.05,-82.89,-86.75,-91.38
-75.94,-60.31,-75.94,-78.31,-69.86,-78.31,-85.61,-83.35,-85.61
-84.31,-72.35,-59.80,-85.59,-77.16,-72.35,-89.48,-85.59,-84.31
-81.44,-84.24,-89.21,-64.75,-76.98,-86.28,-64.75,-76.98,-86.28
-76.21,-70.46,-80.28,-72.89,-61.91,-78.51,-81.71,-79.45,-83.95
-88.71,-82.69,-78.11,-86.63,-76.98,-57.76,-87.59,-79.96,-72.01
-86.71,-89.02,-92.55,-77.28,-83.37,-89.51,-60.77,-79.31,-87.96
-86.85,-83.58,-84.54,-81.20,-71.14,-75.13,-79.66,-63.32,-71.14
-92.55,-89.02,-86.71,-89.51,-83.37,-77.28,-87.96,-79.31,-60.77
0,0,0,0,0,6,0,0,0,0,0,0,0,0,432,0,0,0
0,0,0,0,0,6,7,8,9,0,0,0,0,0,78,108,30,78
1,0,3,0,5,6,0,0,0,78,0,54,0,54,108,0,0,0
1,2,3,0,0,0,7,0,0,54,78,78,0,0,0,156,0,0
0,0,0,0,5,0,0,0,0,0,0,0,0,348,0,0,0,0
0,0,0,4,0,0,0,8,0,0,0,0,78,0,0,0,108,0
0,0,3,0,5,0,0,0,9,0,0,108,0,108,0,0,0,156
0,2,0,0,0,0,0,0,0,0,348,0,0,0,0,0,0,0
```

RSSI matrix:

- Each row contains the RSSI values seen from a station.
  E.g., row 2, column 3, i.e., **$RSSI_{23}$ = -75.94 dBm**, means that **STA_2** receives **-75.94 dBm** when **AP_3** transmits.

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Dataset

Deployment's number

RSSI matrix

TXOPs

```
Deployment 8
-66.62,-80.99,-88.80,-70.31,-81.68,-89.05,-82.89,-86.75,-91.38
-75.94,-60.31,-75.94,-78.31,-69.86,-78.31,-85.61,-83.35,-85.61
-84.31,-72.35,-59.80,-85.59,-77.16,-72.35,-89.48,-85.59,-84.31
-81.44,-84.24,-89.21,-64.75,-76.98,-86.28,-64.75,-76.98,-86.28
-76.21,-70.46,-80.28,-72.89,-61.91,-78.51,-81.71,-79.45,-83.95
-88.71,-82.69,-78.11,-86.63,-76.98,-57.76,-87.59,-79.96,-72.01
-86.71,-89.02,-92.55,-77.28,-83.37,-89.51,-60.77,-79.31,-87.96
-86.85,-83.58,-84.54,-81.20,-71.14,-75.13,-79.66,-63.32,-71.14
-92.55,-89.02,-86.71,-89.51,-83.37,-77.28,-87.96,-79.31,-60.77
0,0,0,0,0,6,0,0,0,0,0,0,0,0,432,0,0,0
0,0,0,0,0,6,7,8,9,0,0,0,0,0,78,108,30,78
1,0,3,0,5,6,0,0,0,78,0,54,0,54,108,0,0,0
1,2,3,0,0,0,7,0,0,54,78,78,0,0,0,156,0,0
0,0,0,0,5,0,0,0,0,0,0,0,0,348,0,0,0,0
0,0,0,4,0,0,0,8,0,0,0,0,78,0,0,0,108,0
0,0,3,0,5,0,0,0,9,0,0,108,0,108,0,0,0,156
0,2,0,0,0,0,0,0,0,0,348,0,0,0,0,0,0,0
```

TXOPs:

- Each row represents some simultaneous transmissions at a given TXOP. The first 9 columns of each row show the AP-STA pairs selected for this TXOP and the remaining 9 exhibit the throughput achieved by these devices.

Dataset

Deployment's number

RSSI matrix

TXOPs

```
Deployment 8
-66.62,-80.99,-88.80,-70.31,-81.68,-89.05,-82.89,-86.75,-91.38
-75.94,-60.31,-75.94,-78.31,-69.86,-78.31,-85.61,-83.35,-85.61
-84.31,-72.35,-59.80,-85.59,-77.16,-72.35,-89.48,-85.59,-84.31
-81.44,-84.24,-89.21,-64.75,-76.98,-86.28,-64.75,-76.98,-86.28
-76.21,-70.46,-80.28,-72.89,-61.91,-78.51,-81.71,-79.45,-83.95
-88.71,-82.69,-78.11,-86.63,-76.98,-57.76,-87.59,-79.96,-72.01
-86.71,-89.02,-92.55,-77.28,-83.37,-89.51,-60.77,-79.31,-87.96
-86.85,-83.58,-84.54,-81.20,-71.14,-75.13,-79.66,-63.32,-71.14
-92.55,-89.02,-86.71,-89.51,-83.37,-77.28,-87.96,-79.31,-60.77
0,0,0,0,0,6,0,0,0,0,0,0,0,0,432,0,0,0
0,0,0,0,0,6,7,8,9,0,0,0,0,0,78,108,30,78
1,0,3,0,5,6,0,0,0,78,0,54,0,54,108,0,0,0
1,2,3,0,0,0,7,0,0,54,78,78,0,0,0,156,0,0
0,0,0,0,5,0,0,0,0,0,0,0,0,348,0,0,0,0
0,0,0,4,0,0,0,8,0,0,0,0,78,0,0,0,108,0
0,0,3,0,5,0,0,0,9,0,0,108,0,108,0,0,0,156
0,2,0,0,0,0,0,0,0,0,348,0,0,0,0,0,0,0
```

TXOPs:

- E.g., TXOP 6 —> **0,0,0,4,0,0,0,8,0,0,0,0,78,0,0,0,108,0** means **AP_4** (column 4) and **AP_8** (column 8) transmit to **STA_4** (there is a "4" in column 4) and **STA_8**, respectively. Then the throughput achieved by **STA_4** and **STA_8** are 78 and 108 Mbps, respectively.

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Dataset

Deployment's number

RSSI matrix

TXOPs

```
Deployment 8
-66.62,-80.99,-88.80,-70.31,-81.68,-89.05,-82.89,-86.75,-91.38
-75.94,-60.31,-75.94,-78.31,-69.86,-78.31,-85.61,-83.35,-85.61
-84.31,-72.35,-59.80,-85.59,-77.16,-72.35,-89.48,-85.59,-84.31
-81.44,-84.24,-89.21,-64.75,-76.98,-86.28,-64.75,-76.98,-86.28
-76.21,-70.46,-80.28,-72.89,-61.91,-78.51,-81.71,-79.45,-83.95
-88.71,-82.69,-78.11,-86.63,-76.98,-57.76,-87.59,-79.96,-72.01
-86.71,-89.02,-92.55,-77.28,-83.37,-89.51,-60.77,-79.31,-87.96
-86.85,-83.58,-84.54,-81.20,-71.14,-75.13,-79.66,-63.32,-71.14
-92.55,-89.02,-86.71,-89.51,-83.37,-77.28,-87.96,-79.31,-60.77
0,0,0,0,0,6,0,0,0,0,0,0,0,0,432,0,0,0
0,0,0,0,0,6,7,8,9,0,0,0,0,0,78,108,30,78
1,0,3,0,5,6,0,0,0,78,0,54,0,54,108,0,0,0
1,2,3,0,0,0,7,0,0,54,78,78,0,0,0,156,0,0
0,0,0,0,5,0,0,0,0,0,0,0,0,348,0,0,0,0
0,0,0,4,0,0,0,8,0,0,0,0,78,0,0,0,108,0
0,0,3,0,5,0,0,0,9,0,0,108,0,108,0,0,0,156
0,2,0,0,0,0,0,0,0,0,348,0,0,0,0,0,0,0
```

Note: If the SINR value falls under a certain threshold (around 5.7 dB) the throughput is set to zero.

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Problem Statements

1. **Throughput prediction:** To build a ML model able to predict the throughput that a subset of access points transmitting at the same time can achieve using coordinated spatial reuse scheme. Using a set of files for training, participants will be able to train a ML model that estimates the throughput for a given set of scenarios only with the information about the RSSI matrix and a subset of AP-STAs selected to transmit/receive at every TXOP.

Next steps:

- We will provide them the aforementioned dataset for training that includes throughput values for every TXOP.
- Participants need to (propose) train a ML model.
- The solution will be evaluated in a test dataset without throughput values.

Problem Statements

2. **Multi-AP group creation**: To build a ML solution able to build groups of compatible APs that include a particular AP. The objective here is to find the best subset of APs that include the target AP, and the 'best' subset of APs is the one that maximizes the aggregate throughput (the sum of the throughput for all APs in the group). This can be done using the throughput prediction model from previous point, or by exploring a different path.

Next steps:

- As a use-case to apply the trained model, participants have to estimate the combination around every AP that achieves the best aggregate throughput for every deployment, constraining the number of APs to at most 4 (they have to explicitly indicate the AP-STA pairs in each case)

Questions

?

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