Validation of the ns-3 802.11ax OFDMA Implementation

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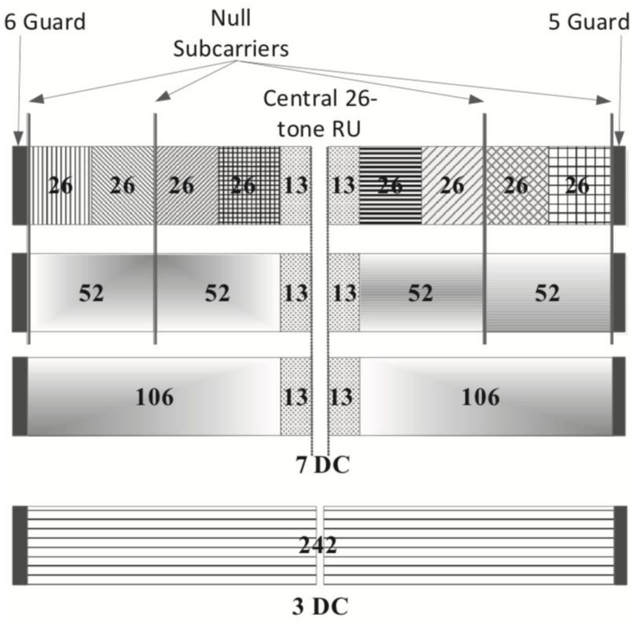
802.11ax

- Previous iterations of WiFi aimed at increasing throughput
- 802.11ax focuses on efficiency
  - Accommodating more devices
  - Increasing area throughput
- How it’s done
  - Spatial Reuse
  - UL MU-MIMO
  - Support for 6 GHz (WiFi 6E)
  - OFDMA

Orthogonal Frequency-Division Multiple Access

With OFDMA the APs can now:

- Serve multiple STAs in the DL
- Coordinate simultaneous UL transmissions from multiple STAs, using Trigger Frames



Support for 802.11ax OFDMA in ns-3

- DL and UL OFDMA at the MAC and PHY layers is supported since ns-3.34
- Refactoring of the MAC and PHY layers
- Effort by Stefano Avallone, Sébastien Deronne, and Rediet Getachew

The Mathematical Model

[4] Boris Bellalta and Katarzyna Kosek-Szott. 2019. AP-Initiated Multi-User Transmissions in IEEE 802.11ax WLANs. *Ad Hoc Networks* 85 (2019), 145–159.

The validation workflow

1. Find a suitable model from the literature
2. Strip it down to just what we need
3. Add some features
4. Implement it
5. Check if its output matches simulation results
6. If no match, diagnose, correct, and go back to 4

$$S_d^{\mathrm{HE}} = \frac{a_1 n_a^{\mathrm{SU}} L_D + a_3 V_u n_a^{\mathrm{MU,DL}} L_D}{\phi}$$

How the model works

- Based on the Bianchi 802.11 model
- Compute channel access probabilities
- Compute duration of events
- Get throughput!

$$\phi = \underbrace{b \cdot T_e}_{\text{Empty slot}} + \underbrace{\sum_{i=1}^{4} \left[a_i \cdot (T_{a_i} + T_e)\right]}_{\text{Successful transmissions}} + \underbrace{\sum_{i=1}^{4} \left[c_i \cdot (T_{c_i} + T_e)\right]}_{\text{Failed transmissions}}$$

Validation Scenario

Metrics:

- Throughput
- Head-of-Line Delay
  - Time between two consecutive transmissions to the same STA

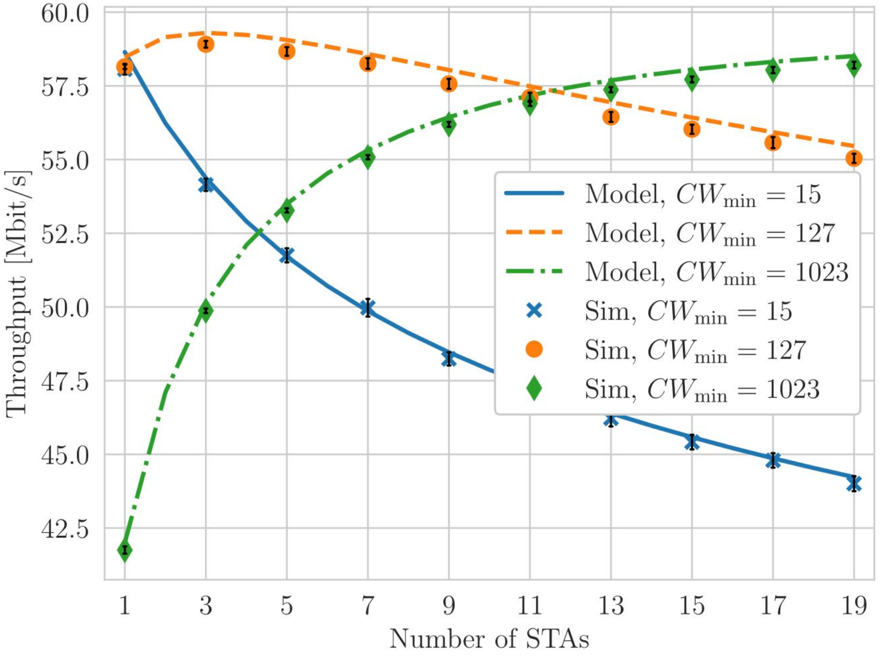
Variables:

- Number of STAs
- Type of employed scheduler
- Channel access parameters
- ACK Sequence
- Intensity of DL and UL traffic

Quantity	Value
Network radius	10 m
AP Transmission Power	17 dBm
STA Transmission Power	17 dBm
MCS	5
Application Layer Traffic Rate	100 Mbit/s
Traffic type	UDP
Access Category	BE
Beacon Period	20480 ms
MSDU Lifetime	20000 ms
Simulation Time	5 s
Propagation Loss Model	Friis

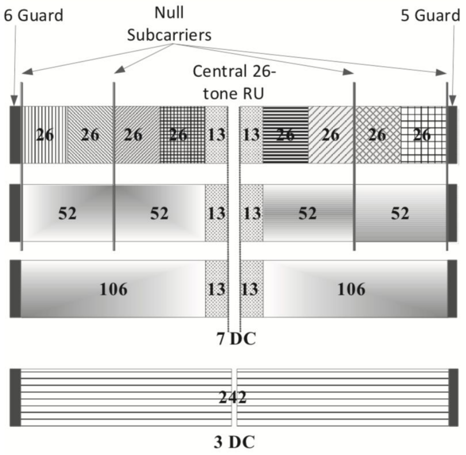
Single User Transmissions Only

Lines: Model
Markers: Simulation



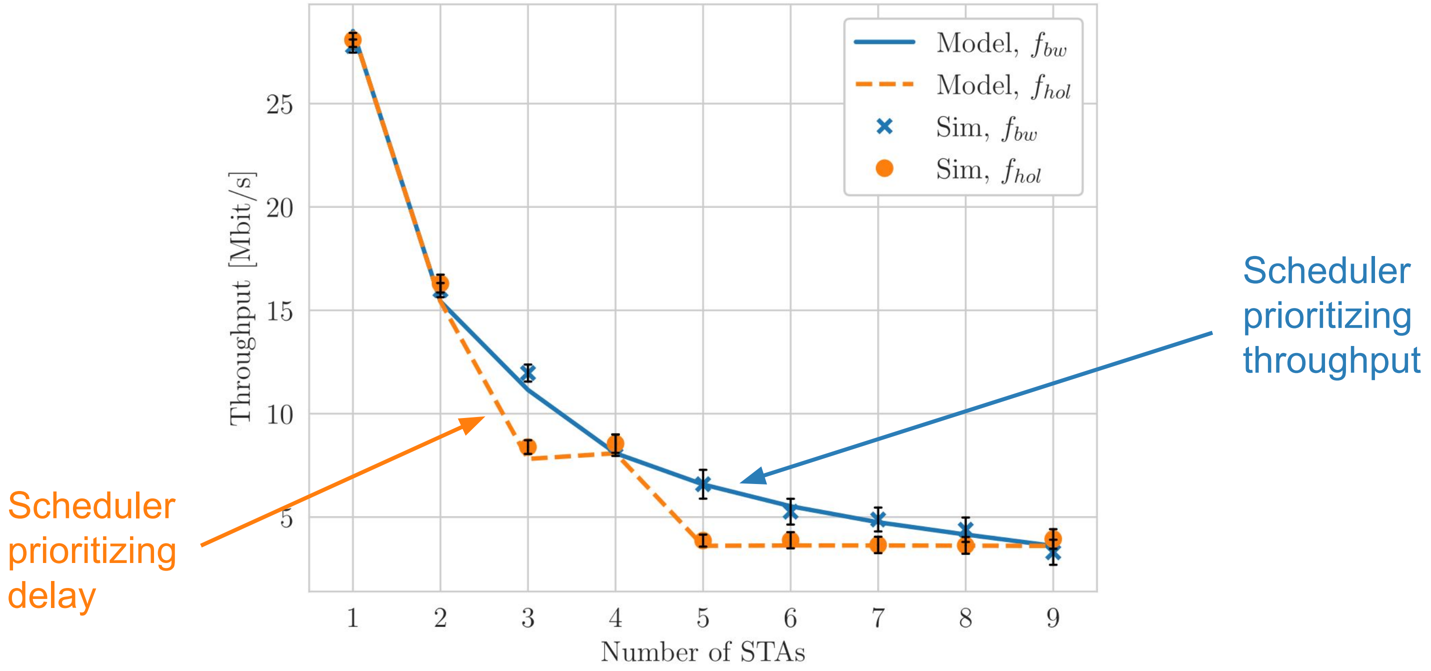
Scheduling

- How do we assign Resource Units to STAs?
- Scheduling is typically left to the implementation
- Assumption: we only split the available bandwidth evenly
  - 9 RUs composed of 26 tones, or
  - 4 RUs composed of 52 tones, or
  - 2 RUs composed of 106 tones, or
  - 1 RU composed of 242 tones
- We implemented two extremely simple “schedulers”:
  - One prioritizing bandwidth utilization
  - One trying to serve as many STAs as possible

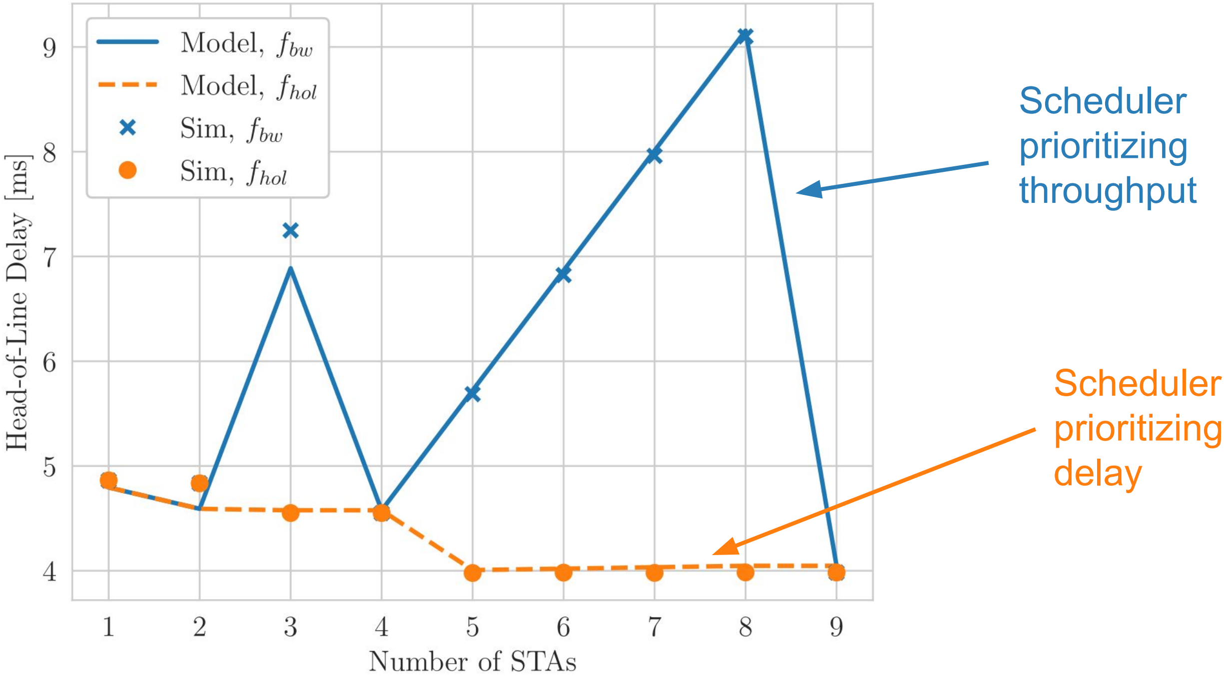


# of STAs	N	1	2	3	4	5	6	7	8	9	≥ 10
# of RUs to split the BW in	f_{bw}	1	2	2	4	4	4	4	4	9	9
	f_{hol}	1	2	4	4	9	9	9	9	9	9

DL Throughput for Our Schedulers



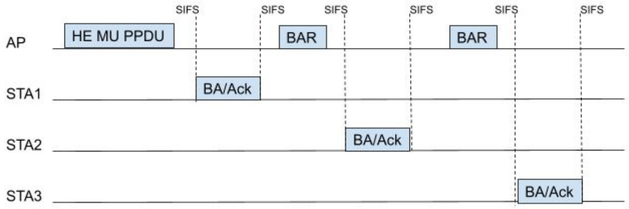
Head-of-Line Delay for Different Schedulers

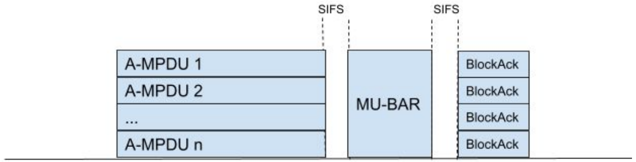


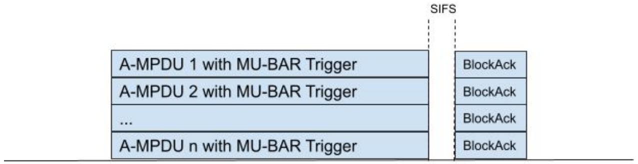
ACK Sequences

After a MU DL transmission, the AP can request ACKs in various ways

- **ACK-SU-FORMAT**: the AP sends a Single User Block Ack Request to each STA in sequence
- **MU-BAR**: a SIFS after the MU DL transmission, the AP sends an MU BAR to coordinate simultaneous transmission of ACKs by all STAs
- **AGGR-MU-BAR**: the MU BAR is aggregated directly to the DL MU transmission



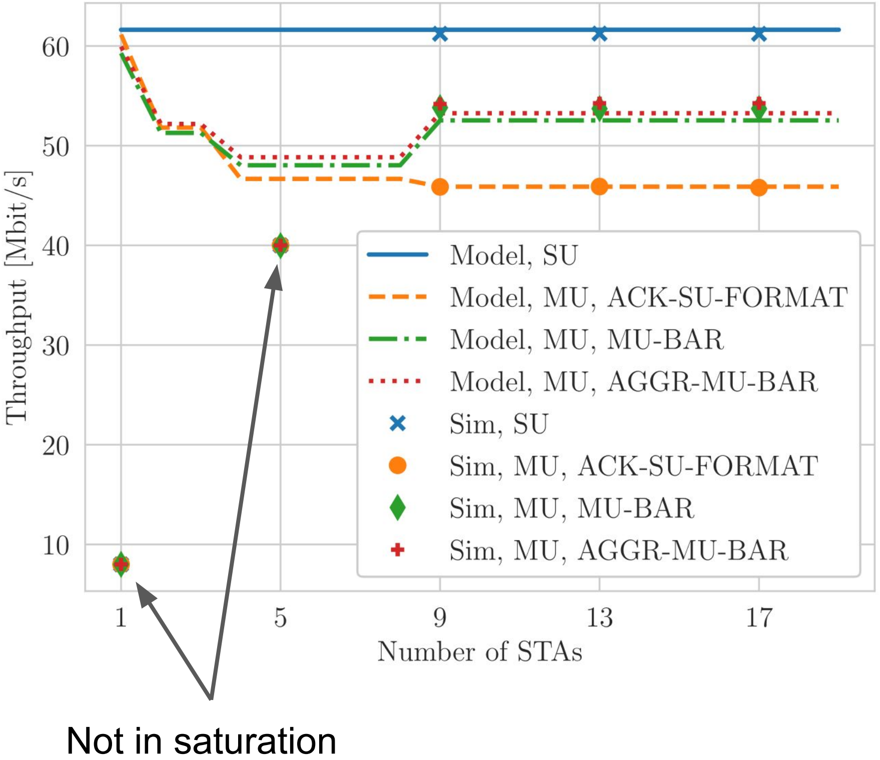




Different ACK Sequences

For this simulation, we have each STA generate a fixed amount of traffic

Few STAs: low traffic



Code is available!

Batteries included:

- Python-based implementation of the model
- ns-3 code updated to current ns-3-dev
- Jupyter Notebook to:
  - Run simulations
  - Run the model
  - Generate the plots you find in the paper

Get it at https://github.com/signetlabdei/ofdma-validation

Conclusions

- Things seem to work as expected
  - Throughput
  - Head-of-Line Delay
  - Frame durations
  - Channel access probabilities
- Fixed some bugs in the simulator along the way
- Future developments
  - Use this as a form of testing?
  - Validate other aspects of 802.11ax OFDMA
  - Coexistence with legacy devices

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