# Low-Latency TXOP Sharing

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# Introduction

- **TXOP sharing significantly improves the timeliness (and throughput) of exchanging LL traffic**

- **The following four cases justify the importance of enhancing TXOP sharing**
  1. **AP is the TXOP holder, and a non-AP STA informs the AP about its TXOP sharing needs (e.g., via M-BA frame)**
     - The AP shares TXOP with the STA (e.g., TXOP Mode 1/2)
     - **How can we eliminate the overhead of control frame for TXOP sharing?**
  2. **Non-AP STA is the TXOP holder**
     - How can the AP inform the non-AP STA about its TXOP sharing needs? (e.g., M-BA?)
     - How can a non-AP STA share its TXOP with the AP? (we can use RD; however, the AP is limited to communicating with the TXOP holder only; see item 2 below)
  3. **Relaying: two non-AP STAs communicate via the AP (e.g., AR/VR applications)**
     - How can a non-AP STA share its TXOP with the AP to forward frames to the other non-AP STA?
  4. **Non-AP STAs are involved in P2P communication**
     - Channel access contention imposes a high load
     - How can a node share its TXOP with other nodes in a P2P group?

## ❑ Introduction

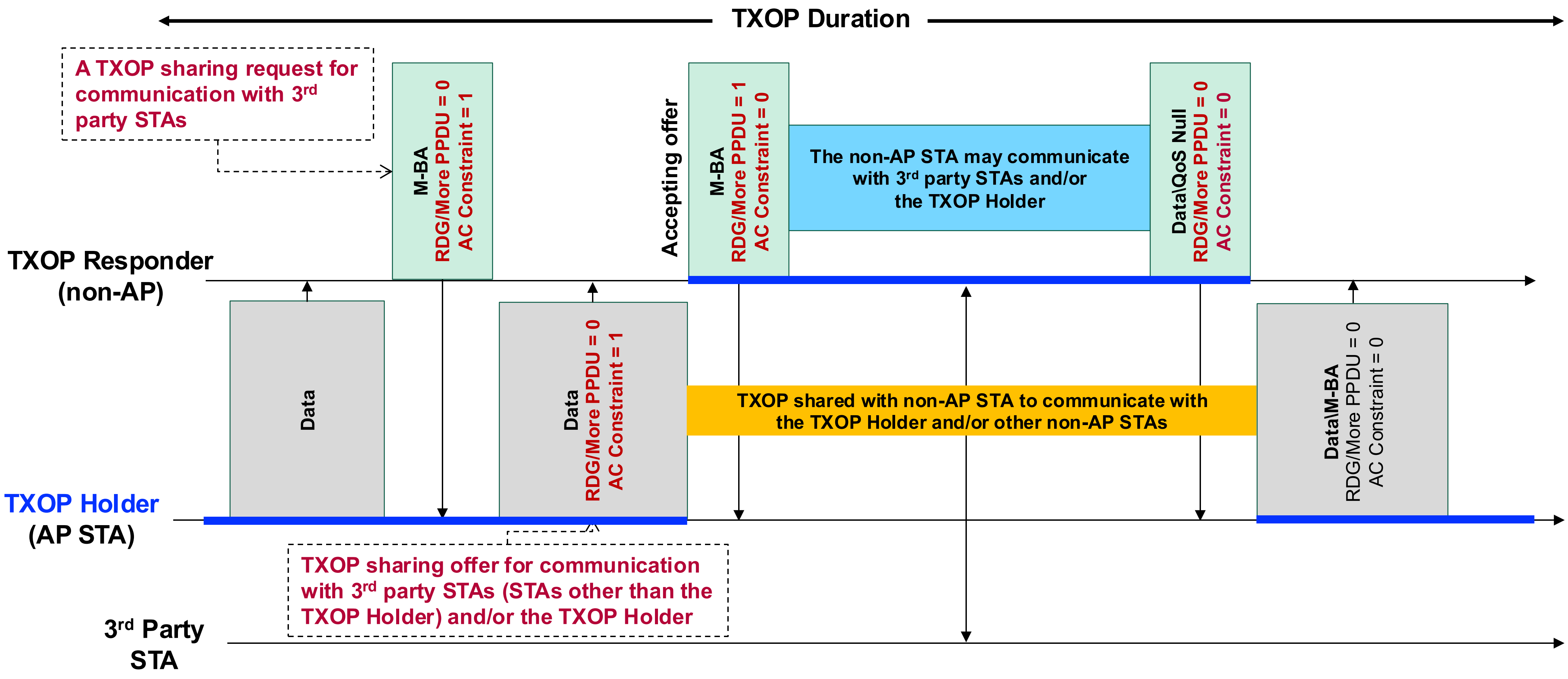
- The Reverse Direction (RD) protocol is specified in Section 10.29 of IEEE Std 802.11-2020
- Some contributions show the **effectiveness of using RD** for **interactive** and **Low-Latency (LL) traffic exchanges** [11-23/1387r0] [11-23/1874r0] [11-24/0668r1]
  - Bidirectional traffic exchange during TXOPs is highly desired
    - e.g., efficient TCP/QUIC communication requires the exchange of both data and ACK frames
    - e.g., interactive request-response transactions
- We need to support more operational modes for **bidirectional low-latency data exchange**, P2P communication and relaying operation [11-24/0073r0] [11-23/1958r0][11-23/1885r1] [11-23/1874r0] [11-23/1387r0] [11-24/0668r1] [11-24/392r1] [11-24/0105r0]

# Low-Latency TXOP Sharing (LLS)

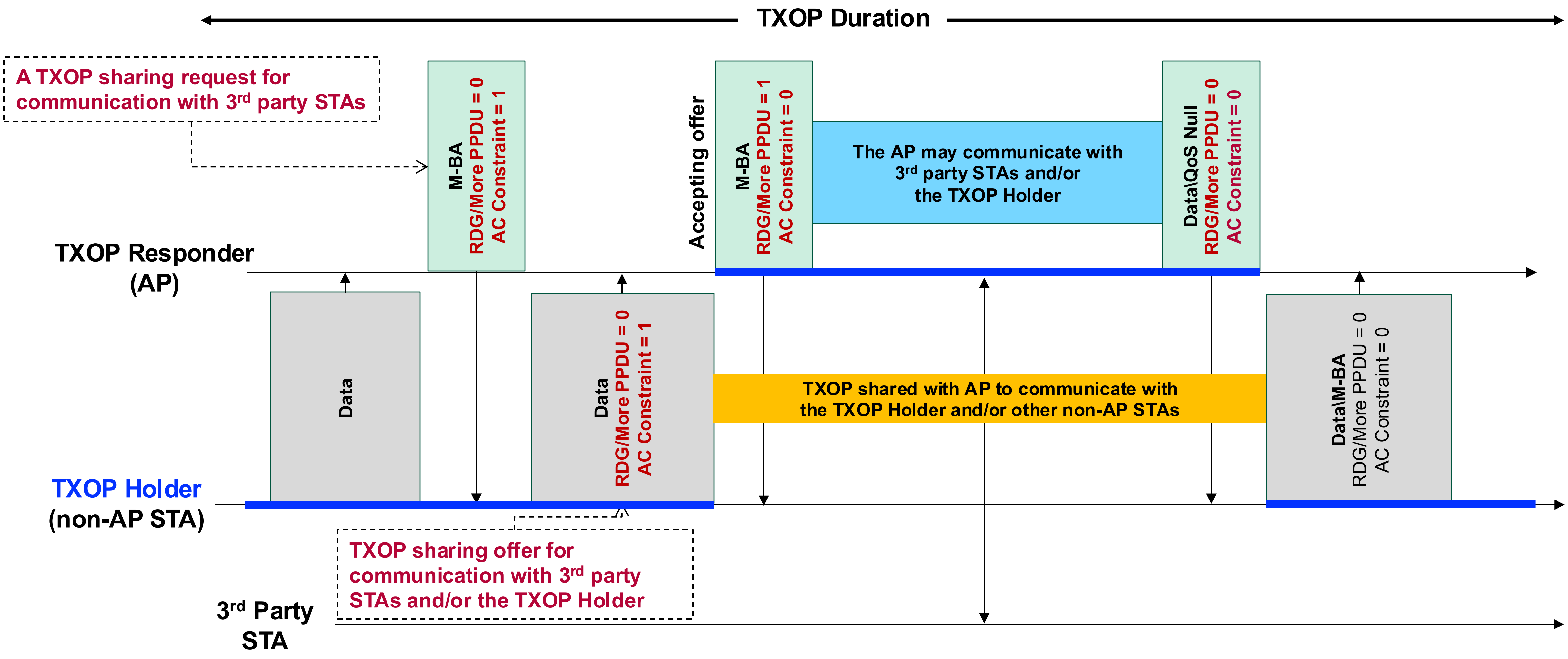
- The original RD protocol utilizes two bits/flags
  1. **`Reverse Direction Grant (RDG)/More PPDU`**
  2. **`AC Constraint`**
- Both **fields** are in the A-control subfield of data frames
- For **M-BA frames**, we propose to add these two flags as a new Feedback Info field or as a part of a LL indication field

- We use these two flags **to facilitate additional operational modes for LL traffic exchange [11-24/1871]**
  - A TXOP Responder (AP or non-AP) can indicate to the TXOP Holder that **it needs to send LL traffic to the TXOP Holder**
  - A TXOP Responder (AP or non-AP) can indicate to the TXOP Holder that **it needs to send LL traffic to other STAs (i.e., other than the TXOP Holder)**
  - A TXOP Holder (AP or non-AP) can share its TXOP and allow the TXOP Responder to communicate with the TXOP Holder only
  - A TXOP Holder (AP or non-AP) can share its TXOP and allow the TXOP Responder to communicate with the TXOP Holder and/or 3rd party STAs

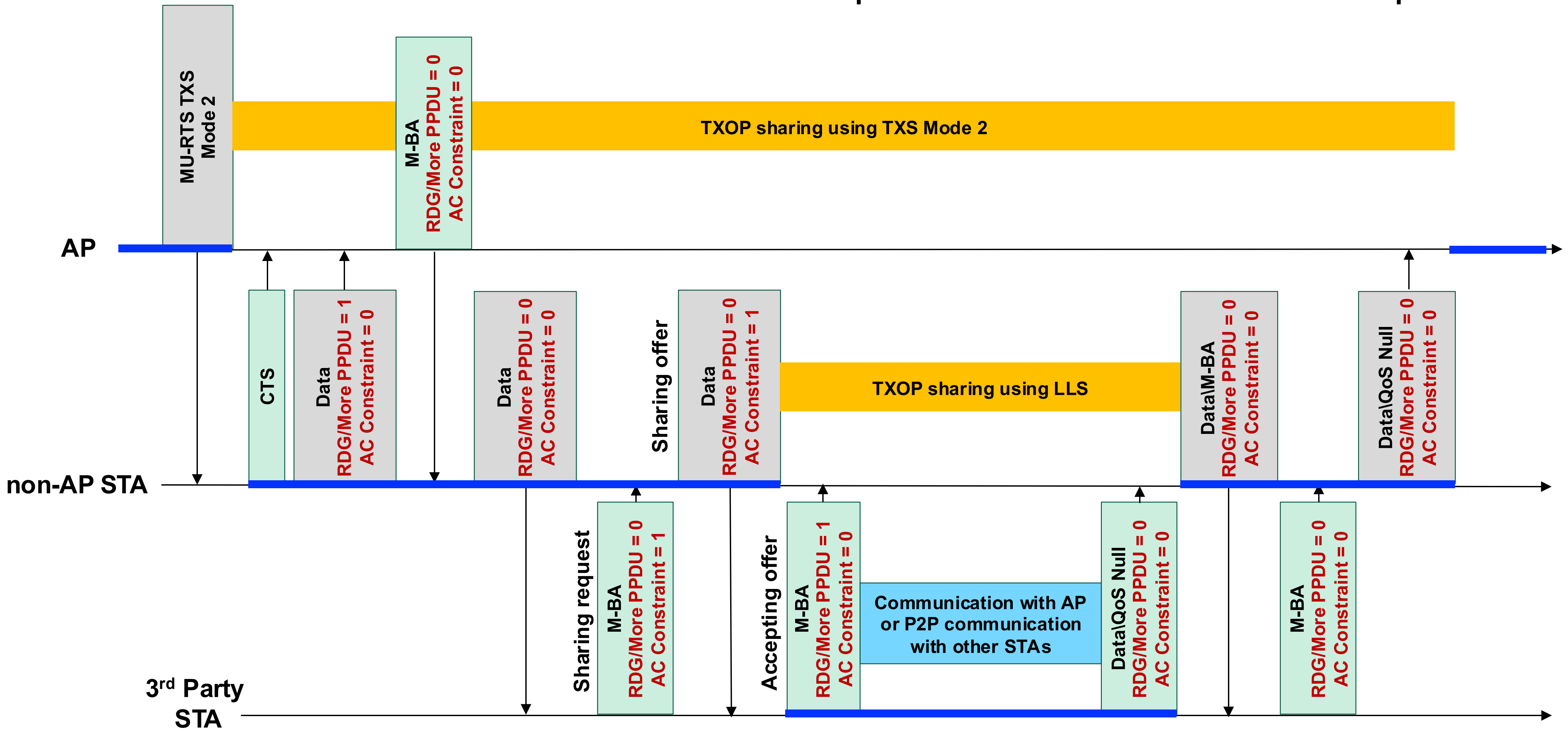
## AP shares its TXOP with the non-AP STA to communicate with other non-AP STAs or the TXOP holder



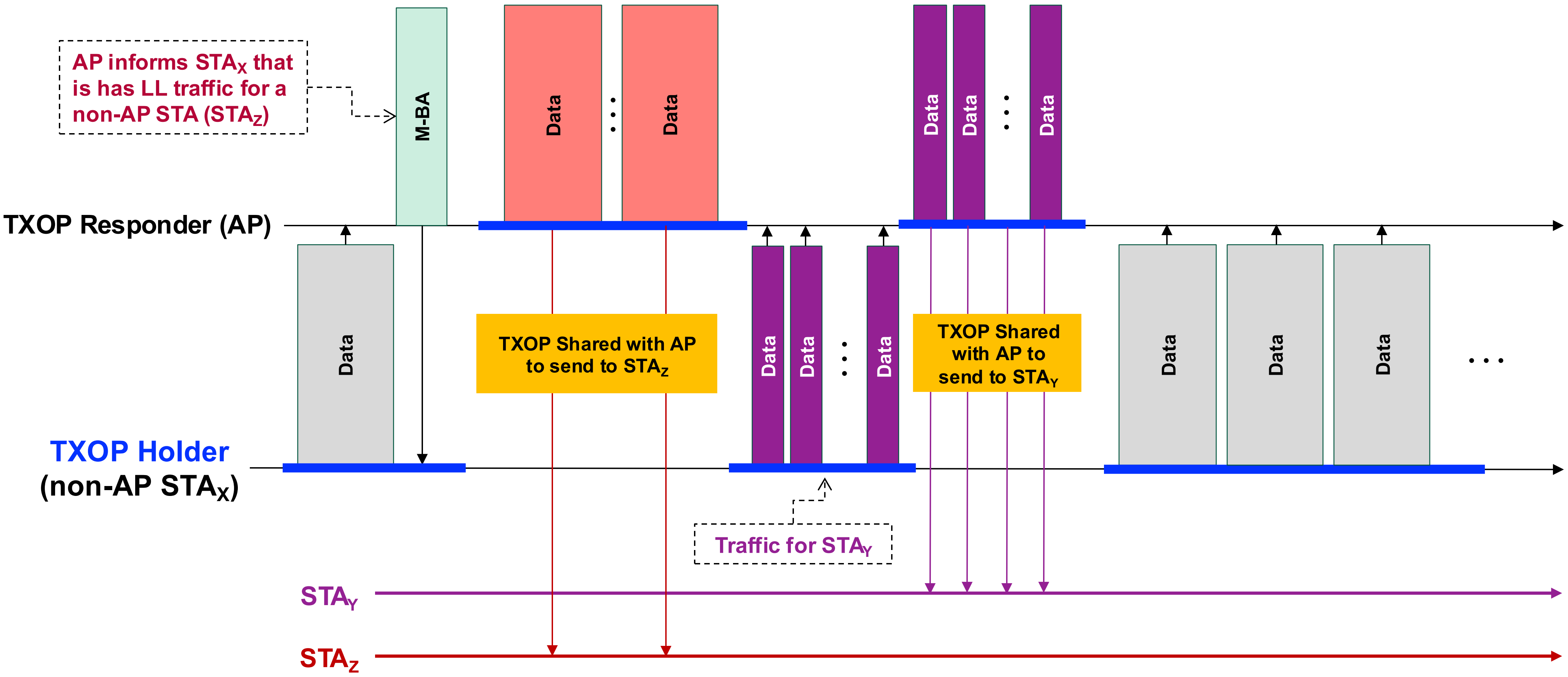
## Non-AP STA shares its TXOP with the AP to communicate with other non-AP STAs or the TXOP holder



## AP shares its TXOP with a non-AP STA (TXS Mode 2), and the non-AP STA performs P2P communication with multiple STAs



## Non-AP STA shares its TXOP with the AP to communicate with non-AP STAs



# Simulation Results

- We have implemented LLS in ns-3 and compared its performance versus:
  - **EDCA**
  - **HiP EDCA + LLS**

- Results are shown for the following metrics:
  - **Application delay**: Measured as the time interval between the generation of a 1024B **VO** message in the application layer of the sender until it is received by the application layer of the receiver
    - **In these results, legends show the difference of the 99th percentile compared to EDCA**
  - **MAC delay**: Measured as the time interval between the arrival of a **VO** frame in the MAC of the sender until it is received by the MAC layer of the receiver
    - **In these results, legends show the difference of the 99th percentile compared to EDCA**

  - **Throughput**: Measured as the Mbps of transmitted data **VO and BE** frames and their MAC headers (PHY headers excluded) for all STAs in the network
  - **Time spent contending**: Measured as the percentage of time (per second) that all STAs compete for channel access

## ❑ Simulation Results

- **PHY**
  - One BSS
  - MCS 6, NSS 2, BW 40 MHz, GI 800 ns
  - AP TX Power: 23 dBm, non-AP STAs: 17 dBm

- **MAC**
  - AC_BE: 80% of STAs, AC_VO: 20% of STAs
  - TXOP limits: AC_BE: 2.5 ms, AC_VO: 2 ms (Table 9-155 of IEEE Std 802.11-2020)
  - AC_VO AIFSN for AP = 1, for non-AP STAs = 2
  - AP AC_BE CW: [0, 63], non-AP STAs: [0, 1023]
  - MTU: 2296 bytes
  - AP MAC queue size: AC_BE: $(2000 \times numBE\_STAs)$ frames, AC_VO: $(2000 \times numVO\_STAs)$
  - non-AP STA MAC queue size: 2000 frames
  - qDisc: FQ-CoDel (on AP and non-AP STAs)

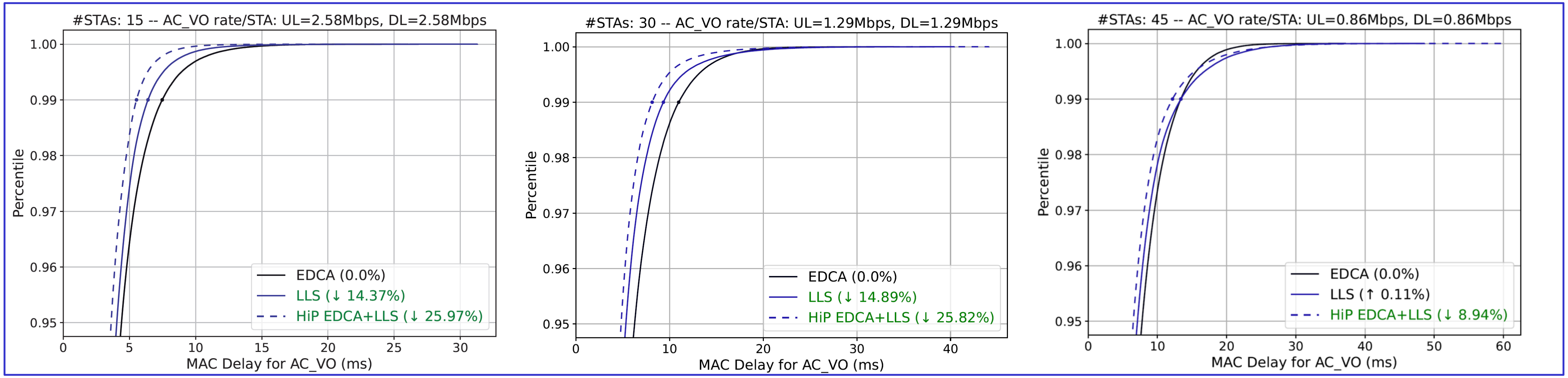
- **HiP EDCA**
  - Defer signal’s CW = 0
  - Short contention period CW: [0, 7]
  - AP is not allowed to send defer signals

## ❑ Simulation Results

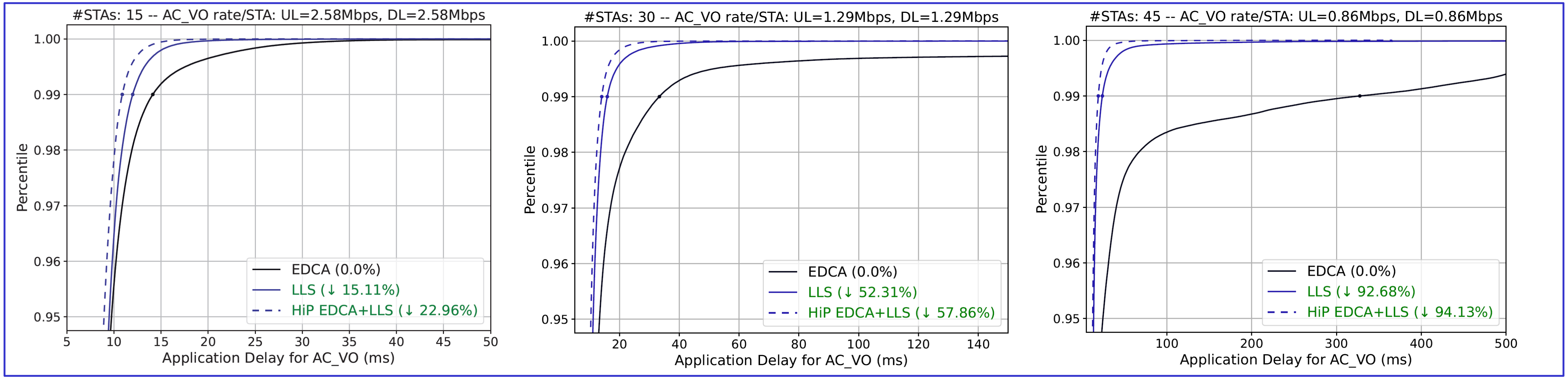
- **Traffic Generation**
  - STAs upload and download TCP traffic from a cloud server (connected to the AP) with 10 ms RTT
  - BE stations constantly upload and download as much TCP data as they are able, with no data rate limit
  - VO stations periodically upload and download TCP data each at a rate of $C \times \frac{Channel\ Capacity}{nStations \times 2}$, where the value of *C* depends on the simulation scenario
    - The duration of every sending period is randomly picked using an exponential distribution with a mean value of 50 ms; The duration between each sending period is picked with the same distribution
      - On average, VO STAs send for 50ms, then pause for 50ms
    - We divide by $(nStations \times 2)$ to account for each STA having 2 flows: one uplink and one downlink
- **Deployment**
  - Area: 20 x 20 $m^2$
  - AP in the middle
  - STAs placed randomly in a grid pattern
- **Simulation**
  - Total simulation time: 120 seconds (45 seconds warmup + 75 seconds data collection)
  - 15 iterations per configuration

- **Scenario 1 – Equal UL and DL** (Uplink *C* = 0.5, Downlink *C* = 0.5)
  - **Legend shows the difference of the 99th percentile compared to EDCA**

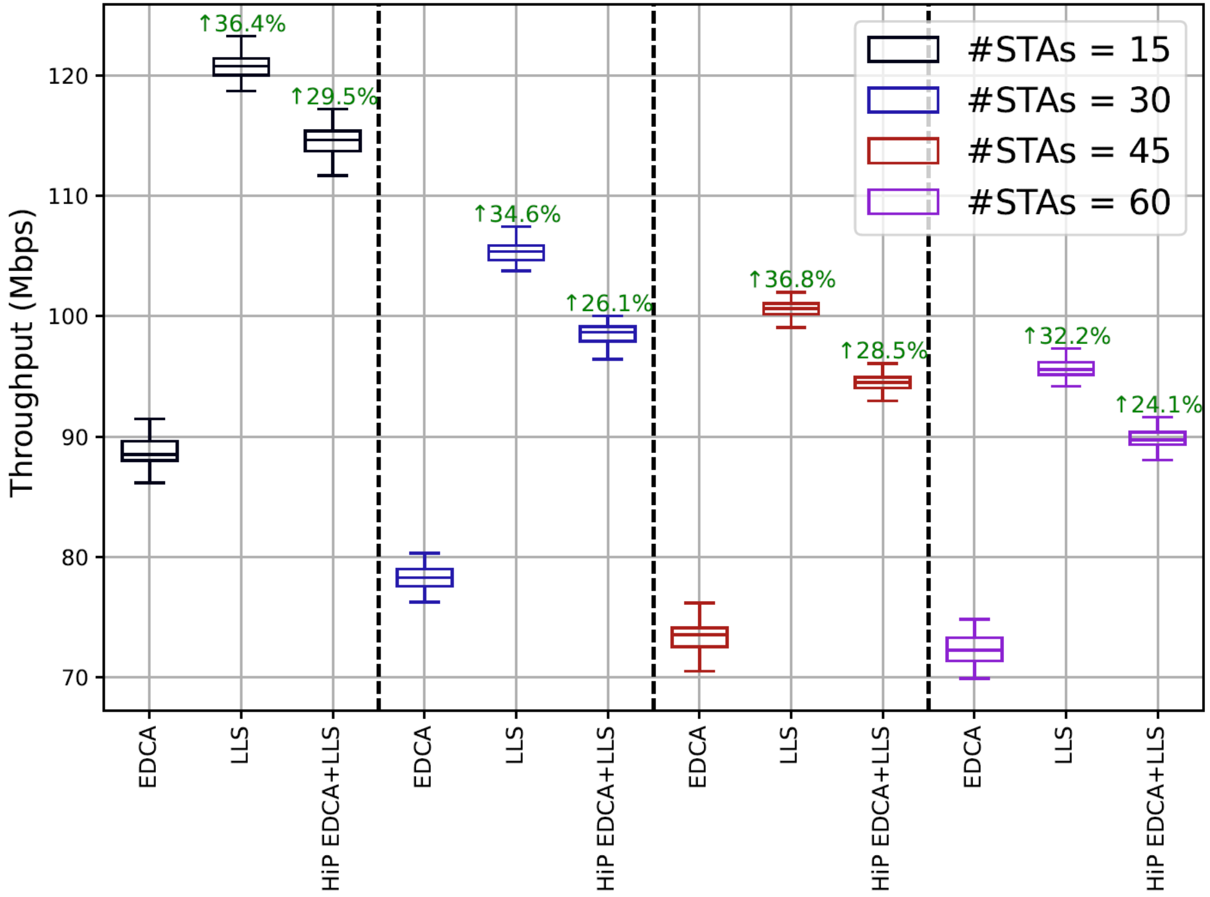
MAC Delay

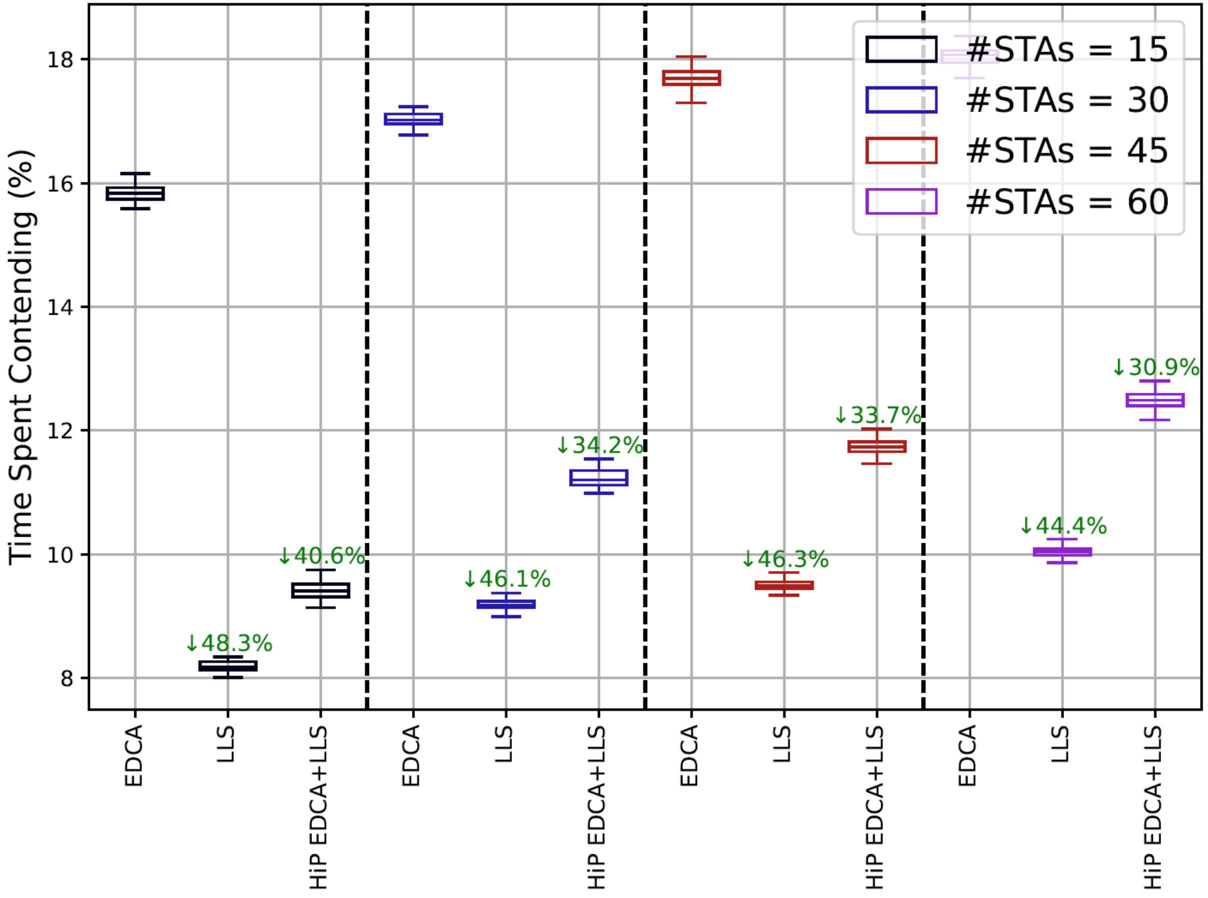



Application Delay



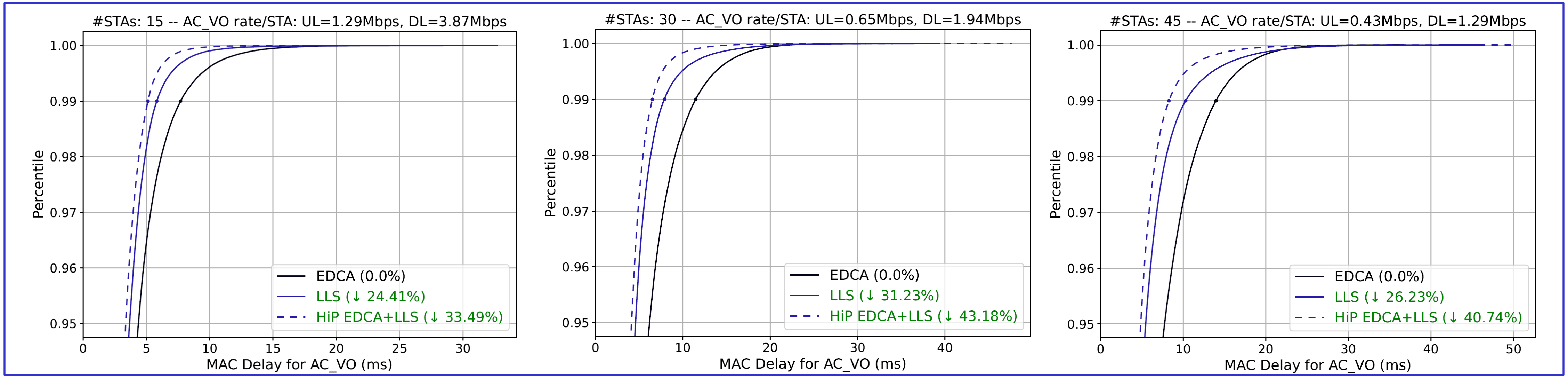
- **Scenario 1 – Equal UL and DL** (Uplink *C* = 0.5, Downlink *C* = 0.5)
  - **The percentage values show the improvement of the median compared to EDCA**



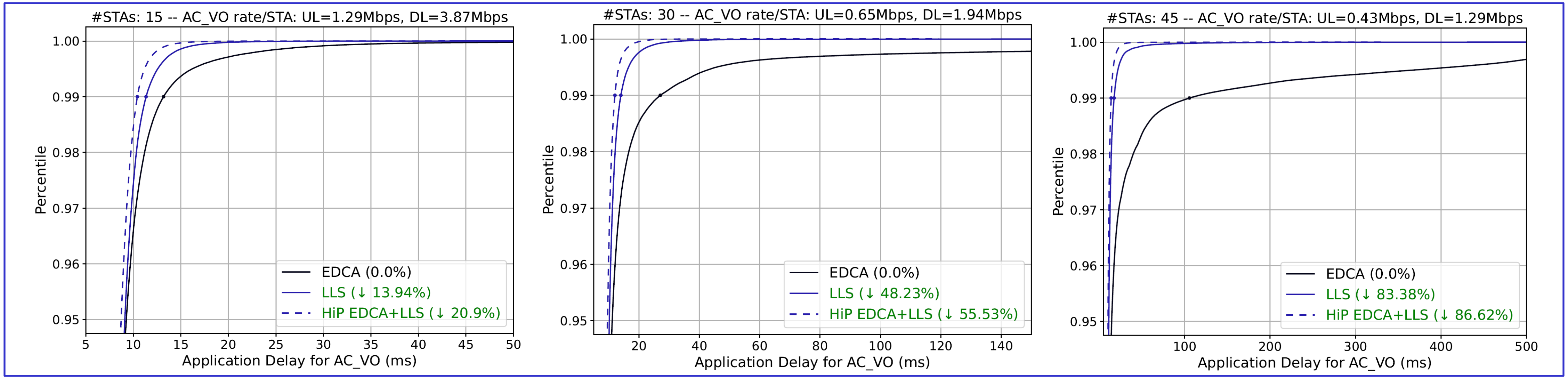



- **Scenario 2 – DL Dominant** (Uplink *C* = 0.25, Downlink *C* = 0.75)
  - **Legend shows the difference of the 99th percentile compared to EDCA**

**MAC Delay**




**Application Delay**



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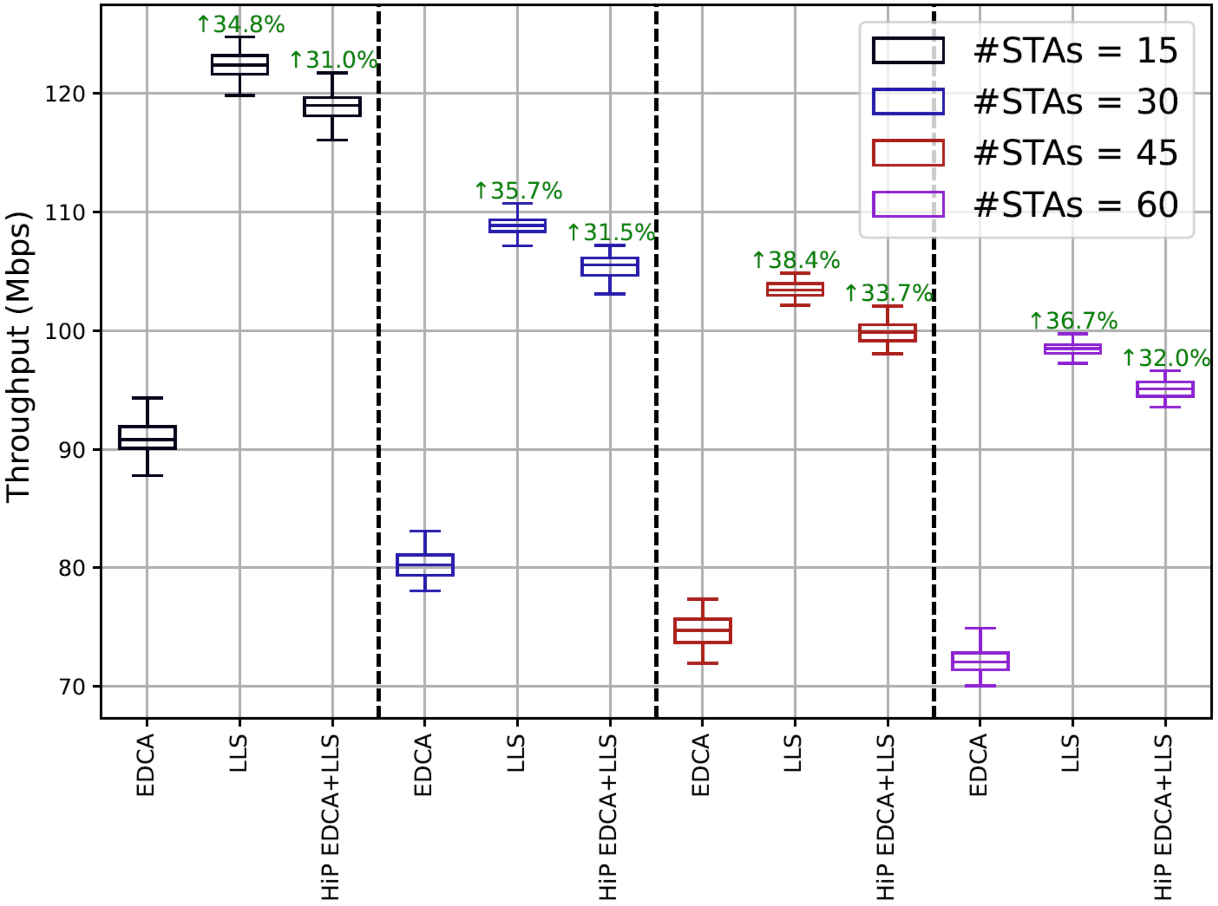
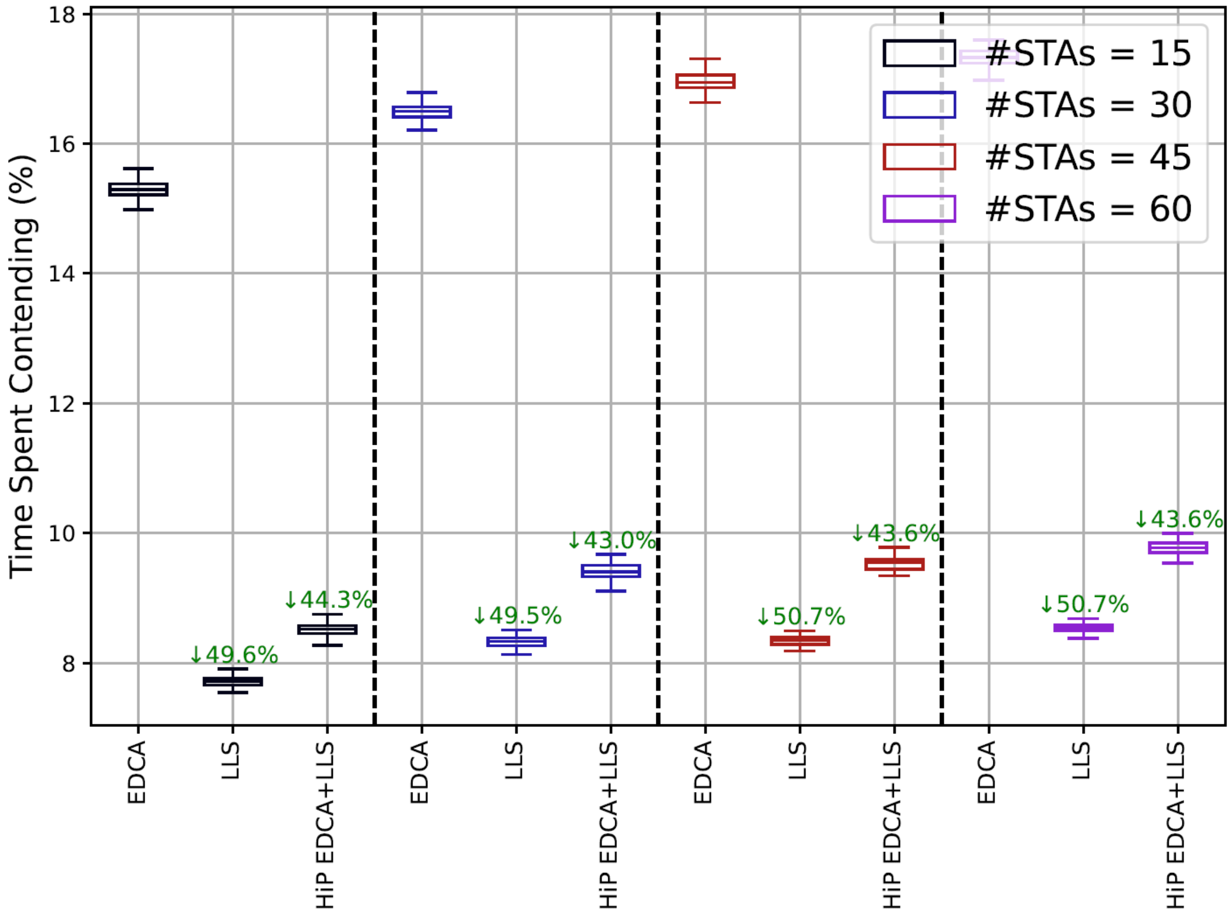
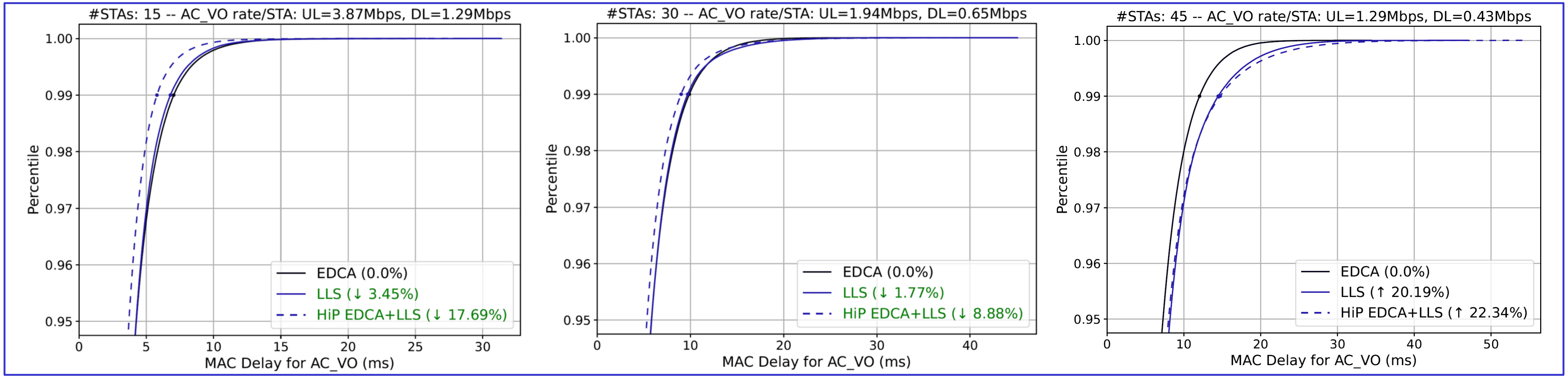


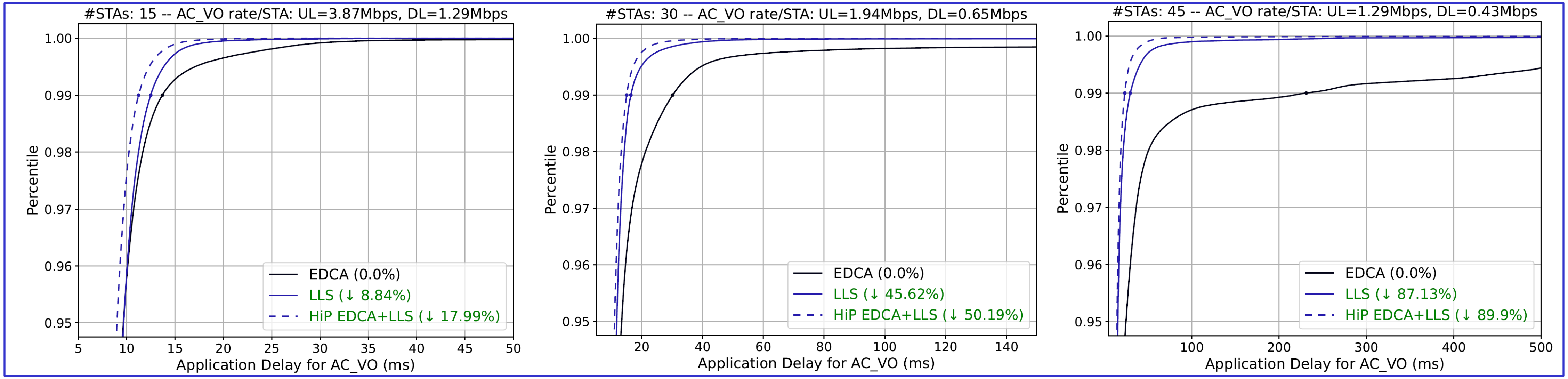



- **Scenario 3 – UL Dominant** (Uplink *C* = 0.75, Downlink *C* = 0.25)
  - **Legend shows the difference of the 99th percentile compared to EDCA**

MAC Delay




Application Delay



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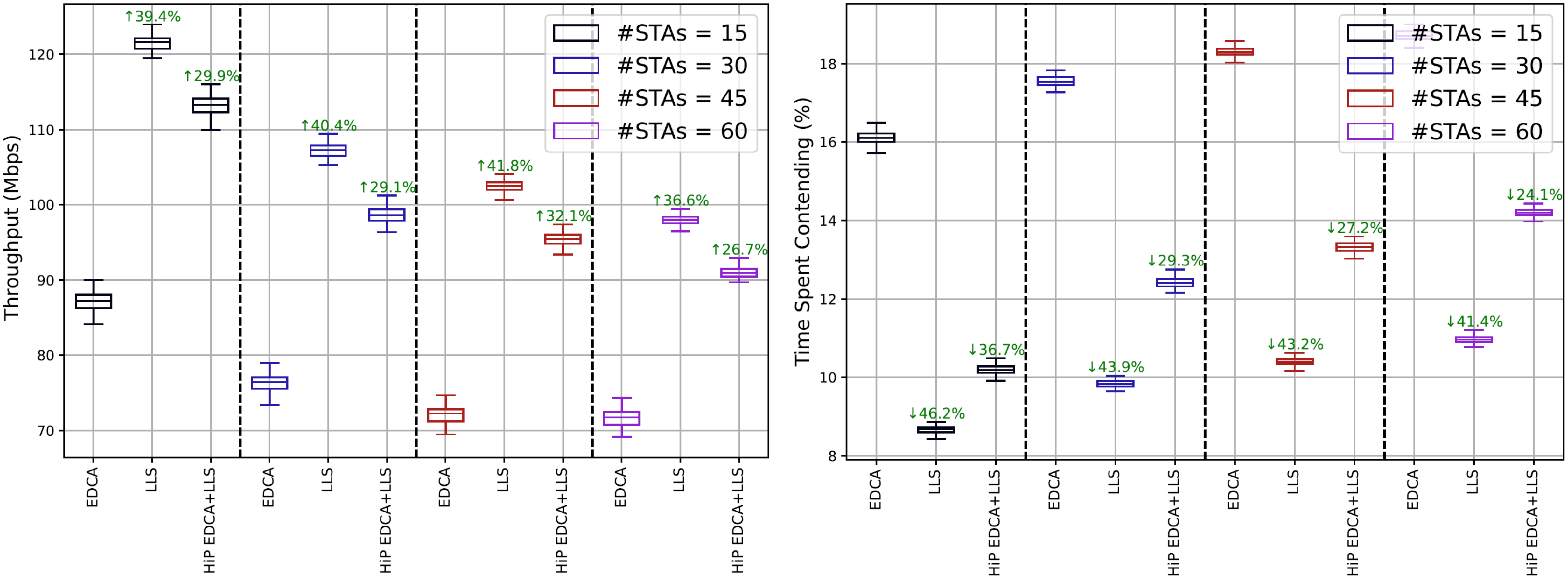


# Summary

- LLS
  - Allows a non-AP/AP STA to share its TXOP with a non-AP/AP STA
  - Allows a TXOP responder to communicate with the holder and other STAs
  - Enhances P2P and relay communication (with and without TXS Mode 2)
  - Works with 11be TXS sharing
  - Leverages enhancements of M-BA frames
  - No control frames are required to perform sharing

- **Simulation results show that**
  - **LLS outperforms EDCA** in all scenarios in terms of **application** tail time latency and **throughput**
  - **LLS outperforms EDCA** in most scenarios in terms of **MAC** tail time latency
  - **LLS may be used alongside HiP EDCA** for further reduction of tail time latency

# Straw Polls

- **Do you agree to use the two Reverse Direction (RD) flags for both <u>LL indication</u> and <u>TXOP sharing</u>?**

YES/NO/ABSTAIN

- **Do you agree that 11bn should include Reverse Direction (RD) flags in the M-BA frame?**

YES/NO/ABSTAIN

APPENDIX

# An Example Encoding of RD Flags

## Items marked with * are the newly proposed features

| Frames sent by TXOP Holder | RDG/More PPDU | AC Constraint | *TXS-TCI | *TXS-DU |
|---|---|---|---|---|
| None (Returns TXOP to AP in case of TXS Mode 2)<br>• *Time until next TXOP sharing | 0 | 0 | | *The minimum/exact amount of time before next TXOP sharing instance |
| *TXOP Sharing Offer (TSO): Sharing for communication with 3rd party STAs | *0 | *1 | *Permissible traffic types during the TXOP sharing period | *TXOP sharing duration |
| Frame (does not return TXOP to AP in case of using TXS Mode 2) | 1 | 0 | | *TXOP sharing duration |
| TXOP Sharing Offer (TSO): Sharing with AC constraint | 1 | 1 | *Permissible traffic types during the TXOP sharing period | *TXOP sharing duration |

| Frames sent by TXOP Responder | RDG/More PPDU | AC Constraint | *TXS-TCI | *TXS-DU |
|---|---|---|---|---|
| None/Offer Rejection | 0 | 0 | | |
| • *Offer Rejection<br>• *Requesting sharing for communication with 3rd party (communication with the TXOP Holder is allowed) | *0 | *1 | *Traffic type/amount report | *Requested TXOP sharing duration |
| • Accepting TXOP sharing offer<br>• While Responder is sending frames to the Holder | 1 | 0 | | |
| • *Offer Rejection<br>• *Requesting sharing for communication with TXOP Holder | *1 | *1 | *Traffic type/amount report | *Requested TXOP sharing duration |

**Items marked with * are the newly introduced subfields**

<table>
<tr><th colspan="8">A-Control (30 bits total)</th></tr>
<tr><td></td><th colspan="4">CAS (8 bits total)</th><td colspan="3"></td></tr>
<tr><td>4 bits</td><td>1 bit</td><td>1 bit</td><td>1 bit</td><td>5 bits (reserved)</td><td>4 bits</td><td>14 bits</td></tr>
<tr><td>CAS Control ID value: 6</td><td>AC Constraint (*extended encoding)</td><td>RDG/More PPDU (*extended encoding)</td><td>PSRT PPDU</td><td>*TXS-TCI<br>• TXOP Holder: Permissible traffic types<br>• TXOP Responder: Buffer report</td><td>*A new Control ID value (between 10 to 14)</td><td>*TXS-DU<br>• TXOP Holder: TXOP sharing duration<br>• TXOP Responder: Requested TXOP sharing duration</td></tr>
</table>

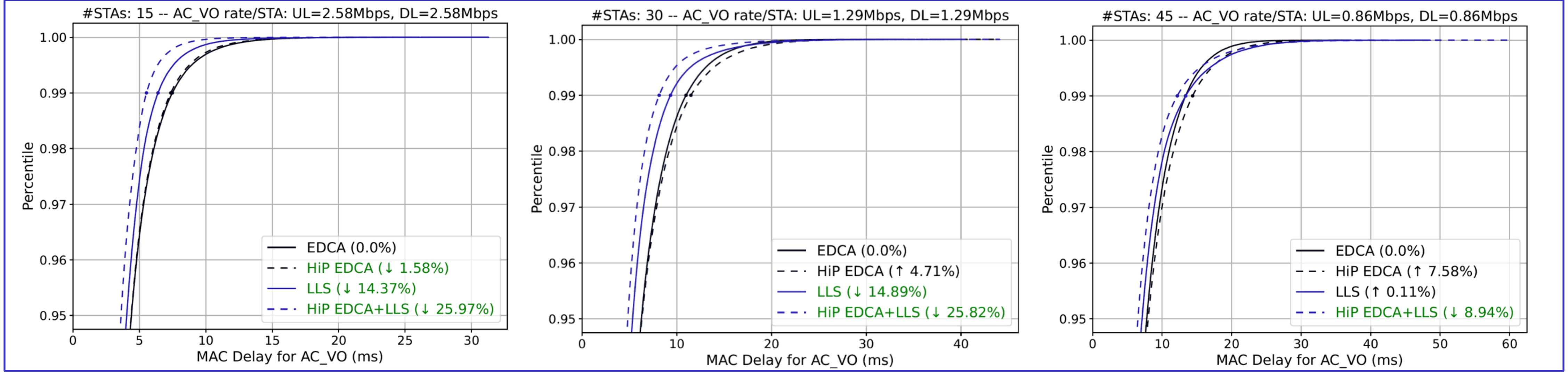
- **TXS-TCI: TXOP Sharing-Traffic Characteristics Indication**
- **TXS-DU: TXOP Sharing-Duration**
- For the AC Constraint and RDG/More PPDU fields, we propose extended bit encodings, in addition to those available in the existing RD protocol (in 802.11ax/be)

APPENDIX

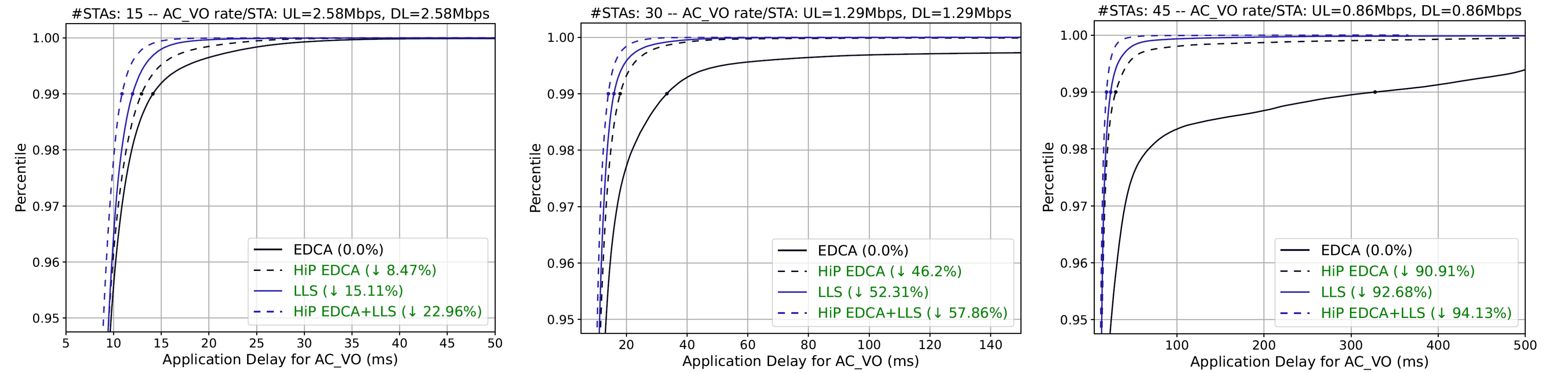
## Performance Comparison with HiP EDCA

- **Scenario 1 – Equal UL and DL** (Uplink *C* = 0.5, Downlink *C* = 0.5)
  - **Legend shows the difference of the 99th percentile compared to EDCA**

MAC Delay




Application Delay



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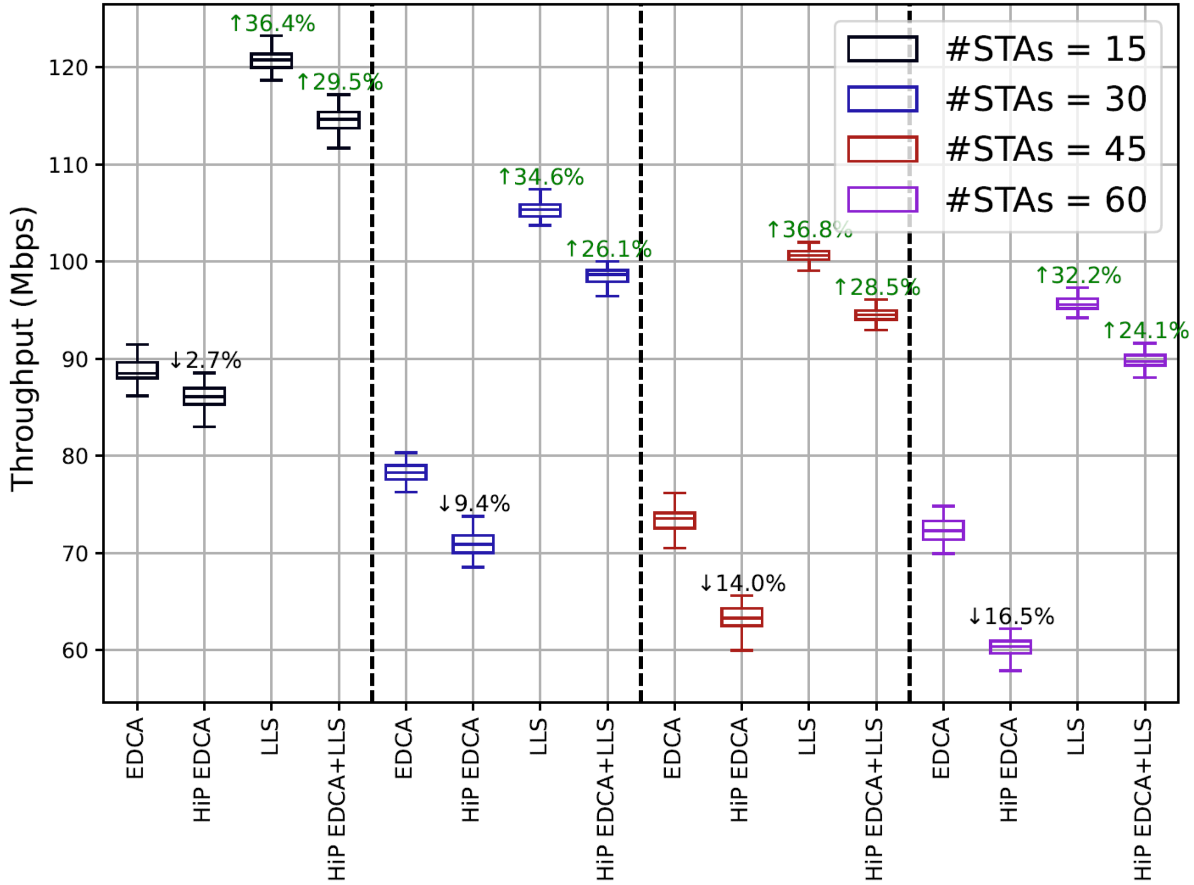
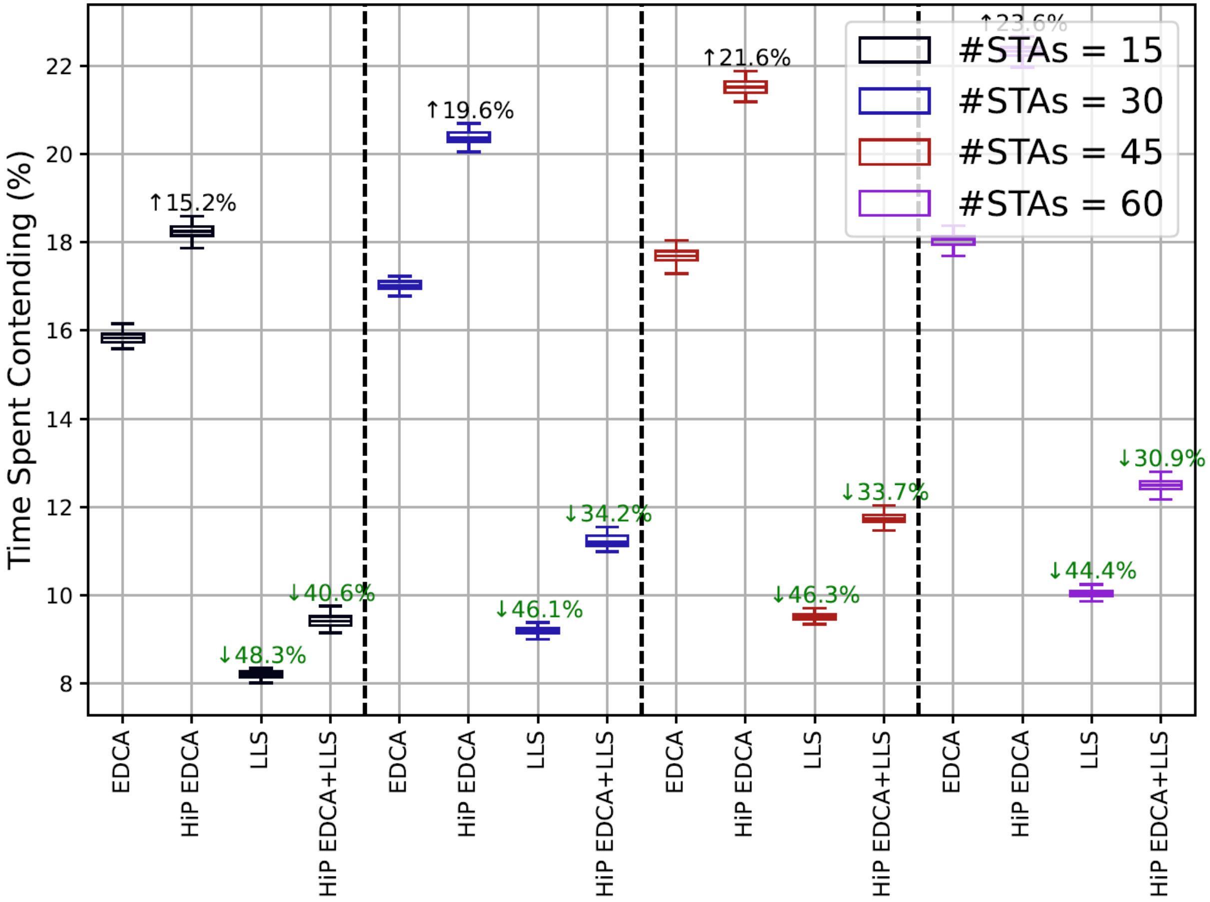
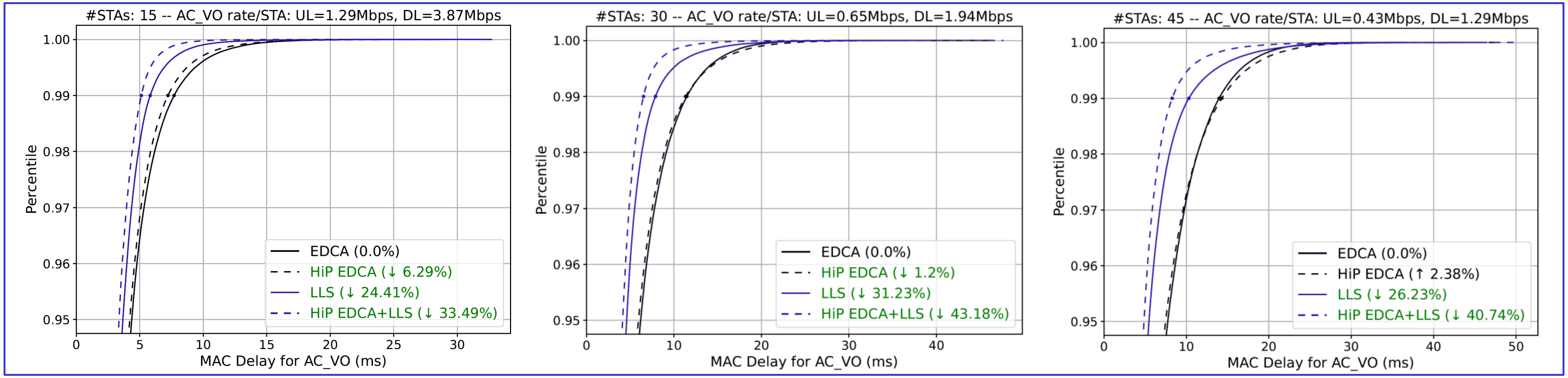


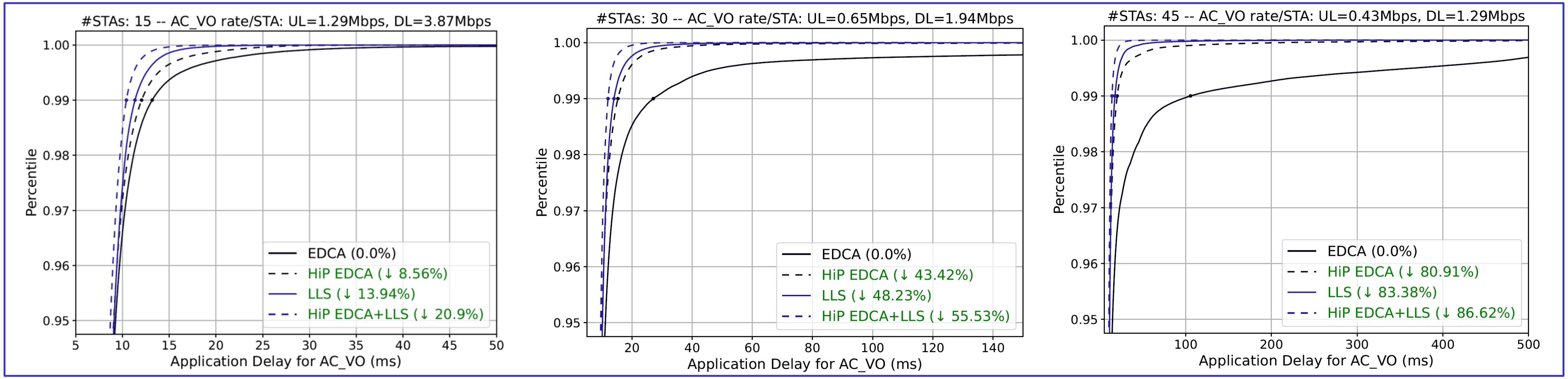



- **Scenario 2 – DL Dominant** (Uplink *C* = 0.25, Downlink *C* = 0.75)
  - **Legend shows the difference of the 99th percentile compared to EDCA**

**MAC Delay**




**Application Delay**



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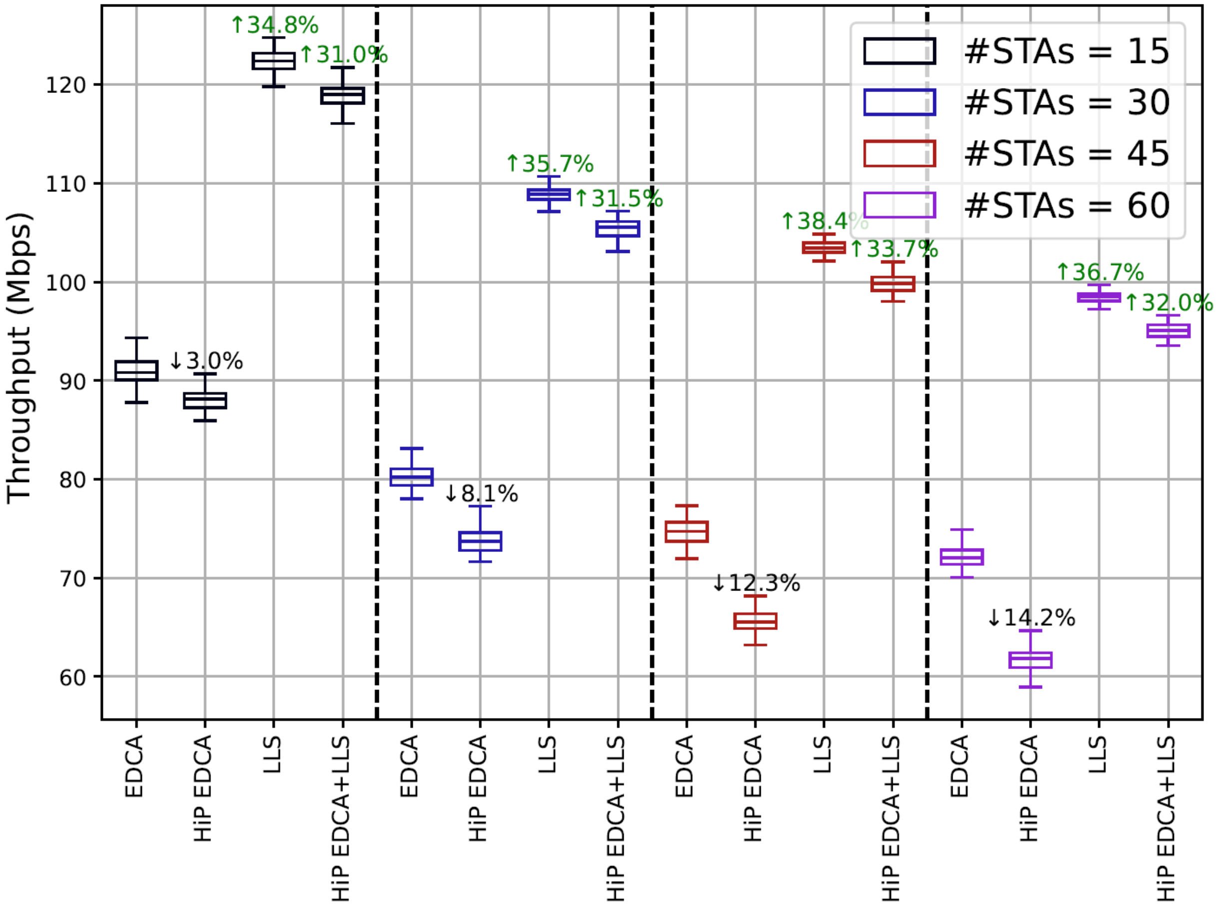


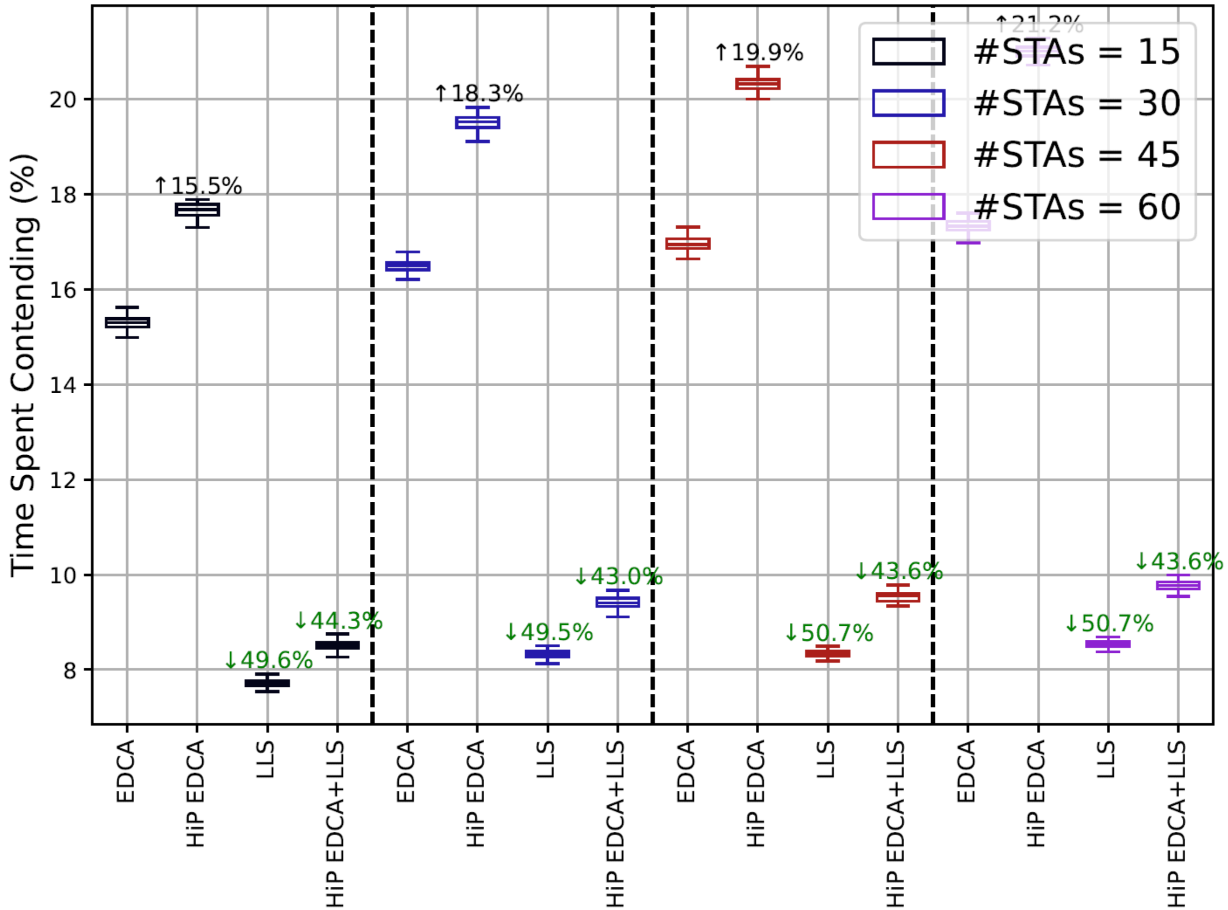

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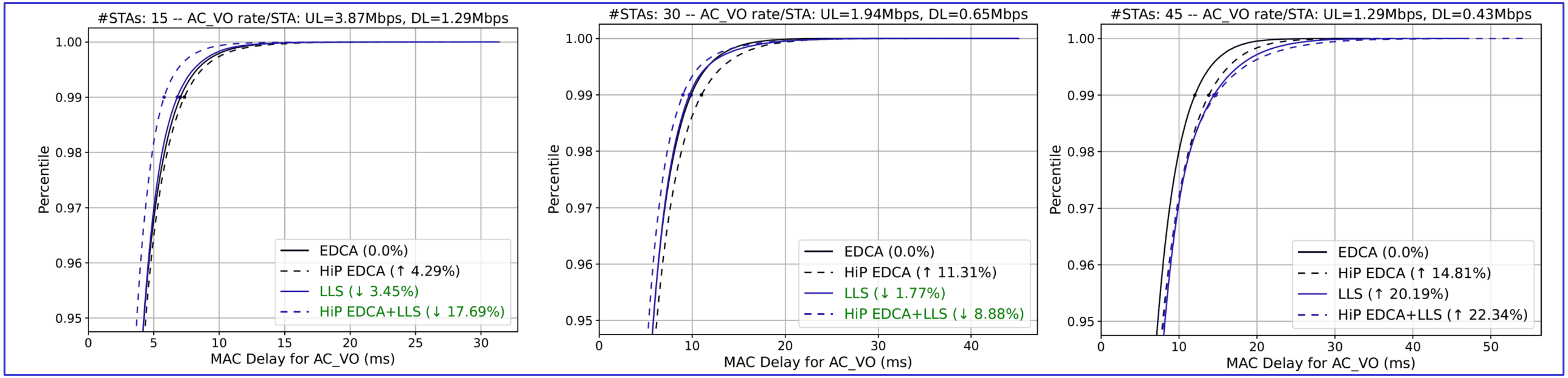
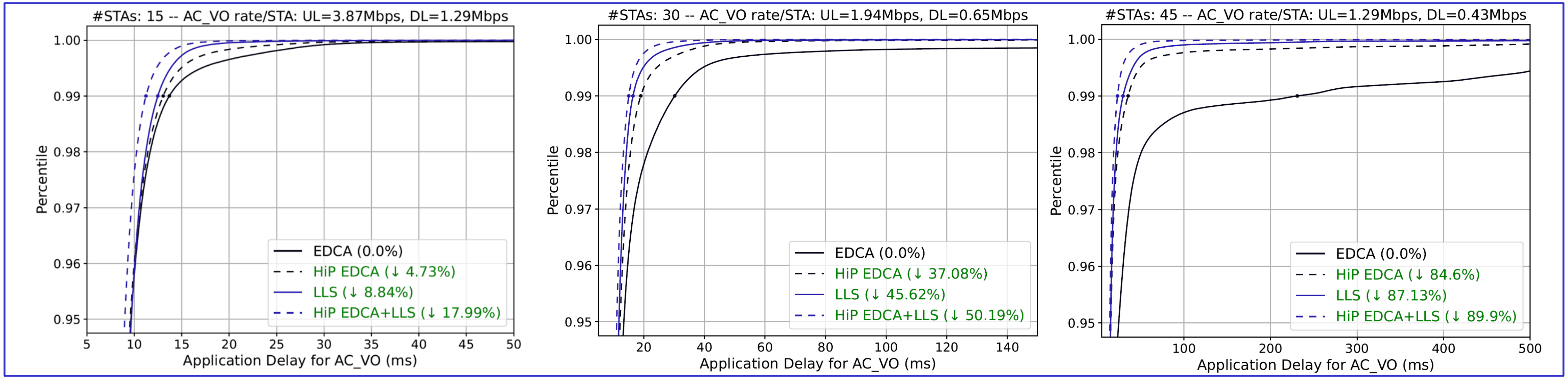
MAC Delay




Application Delay



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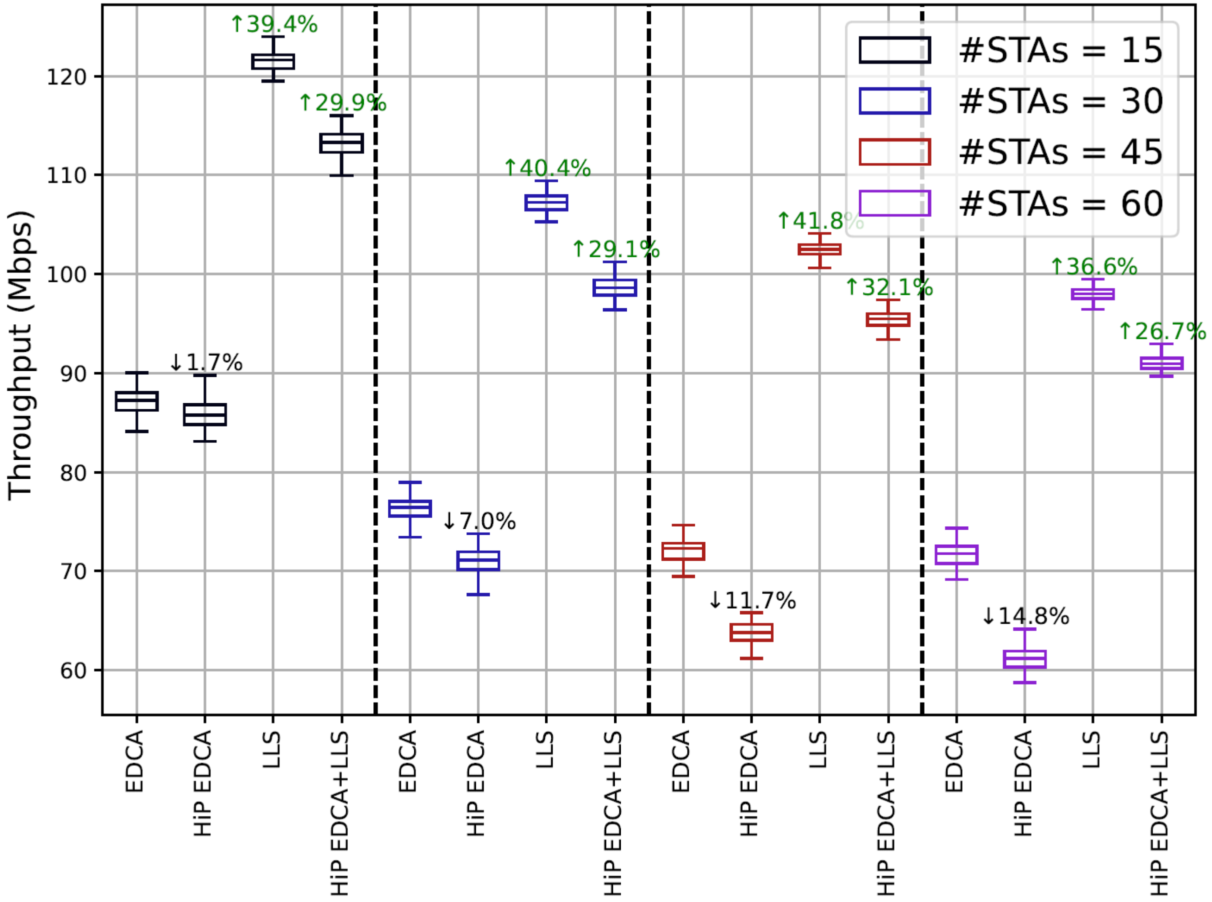
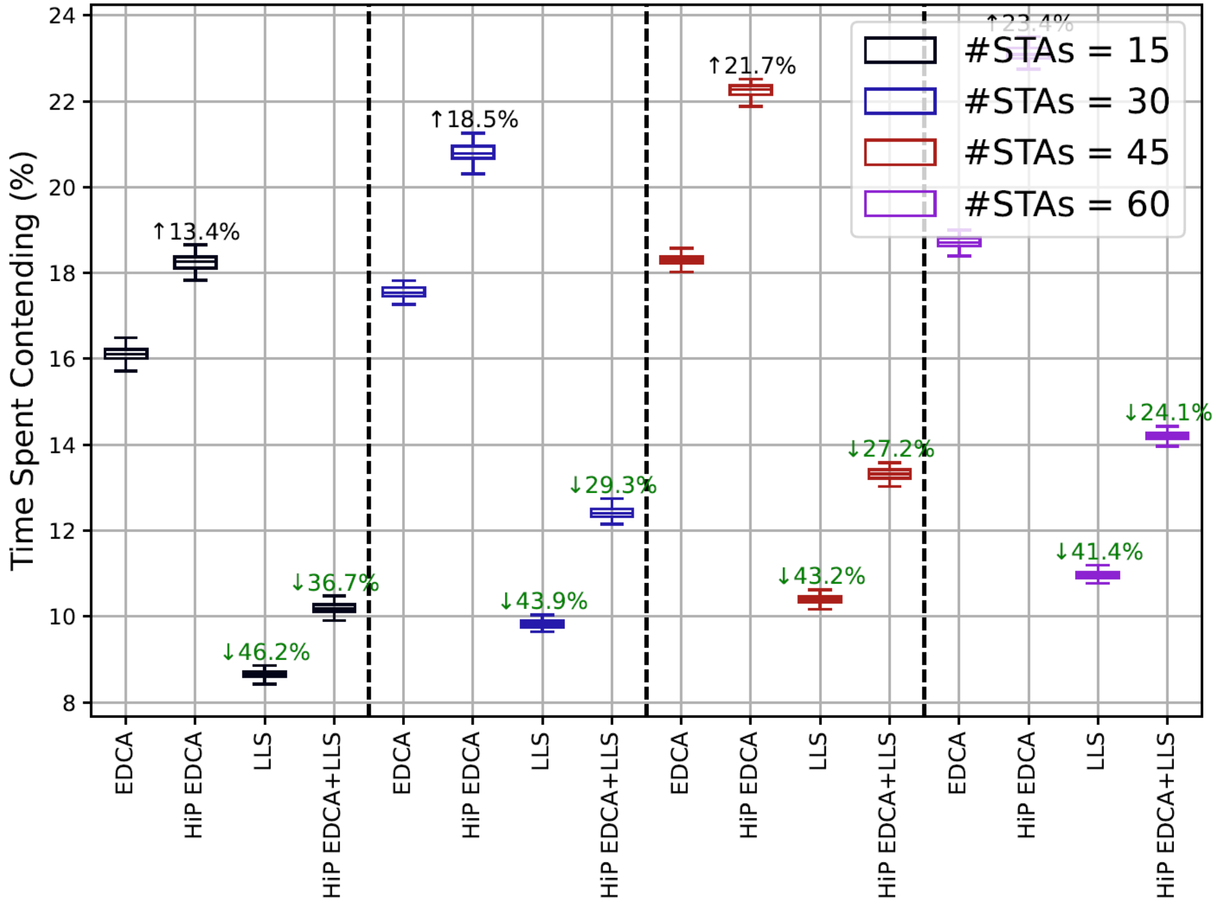
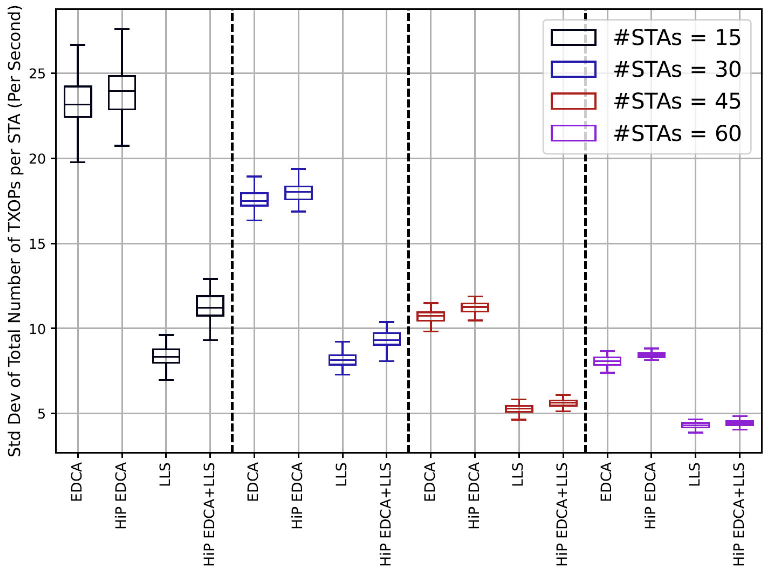


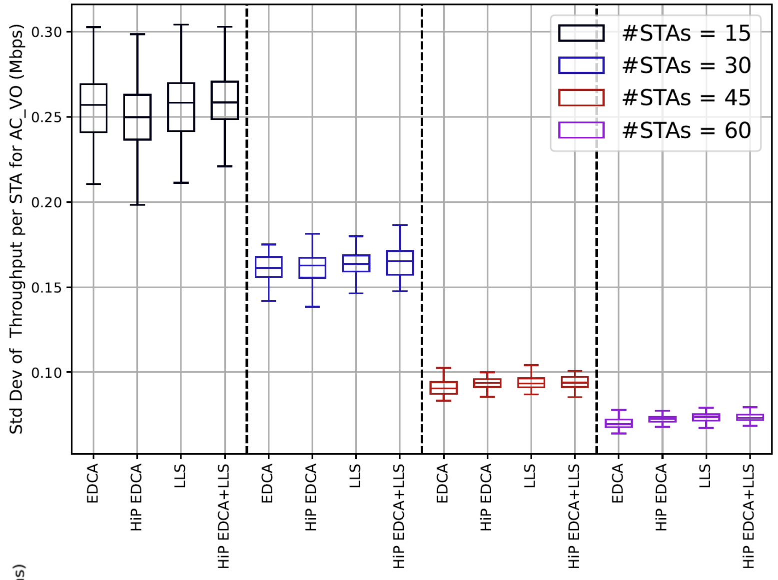



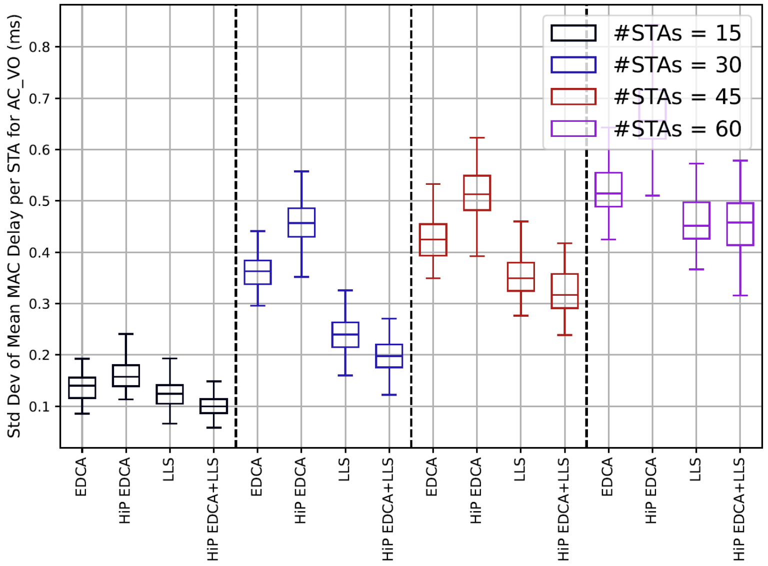
# Fairness among individual STAs

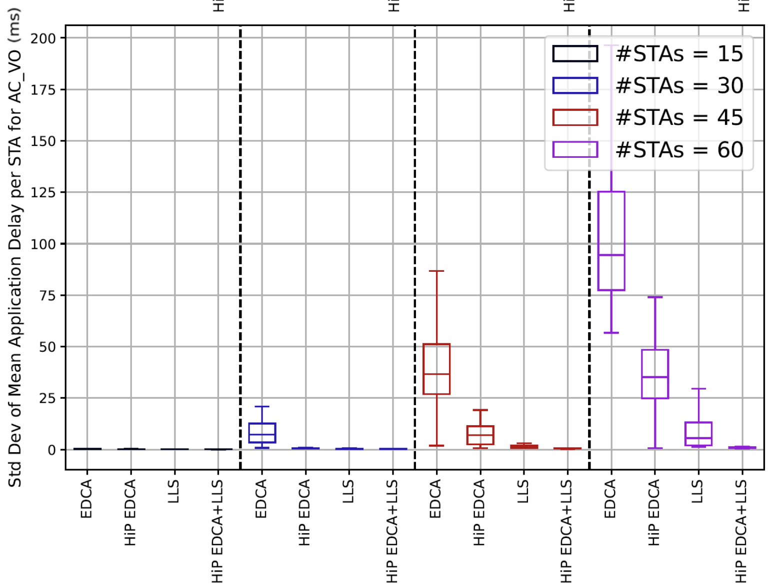
- To measure fairness, we consider the standard deviation of the following metrics per STA:
  - **Number of successful TXOPs** per second for AC_BE and AC_VO
  - **Throughput** for AC_VO
  - Mean **application delay** for AC_VO
  - Mean **MAC delay** for AC_VO

- Results shown are for scenario 1 (equal UL/DL)



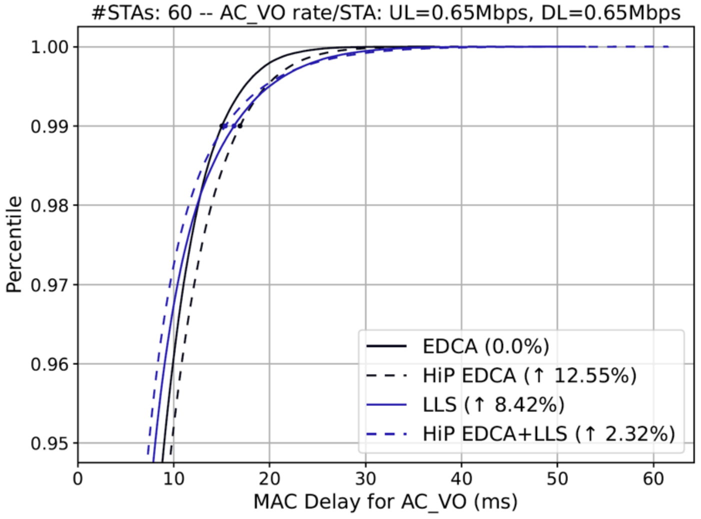



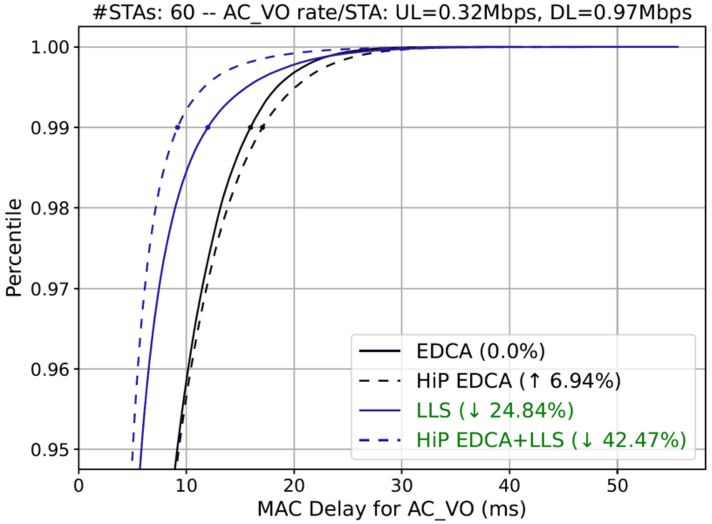



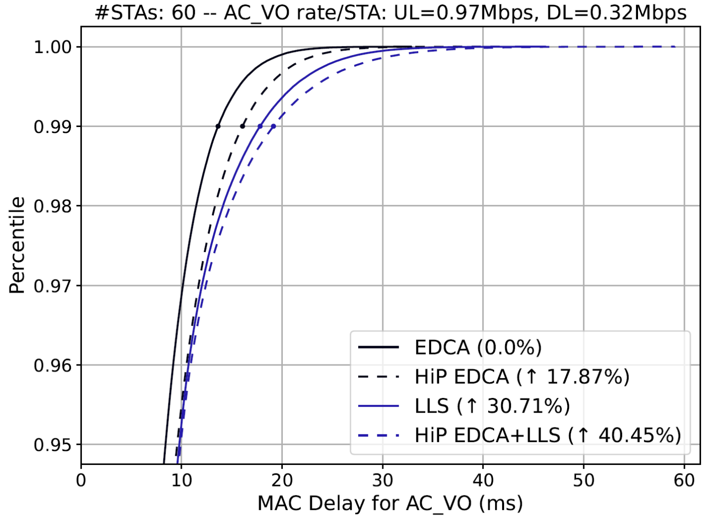
# Application and MAC Delay when #STAs = 60

Scenario 1 – Equal UL/DL | Scenario 2 – DL Dominant | Scenario 3 – UL Dominant

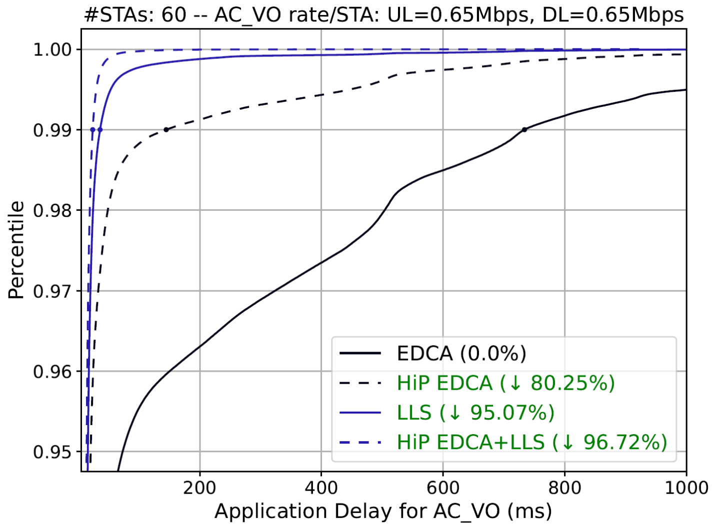
## MAC Delay

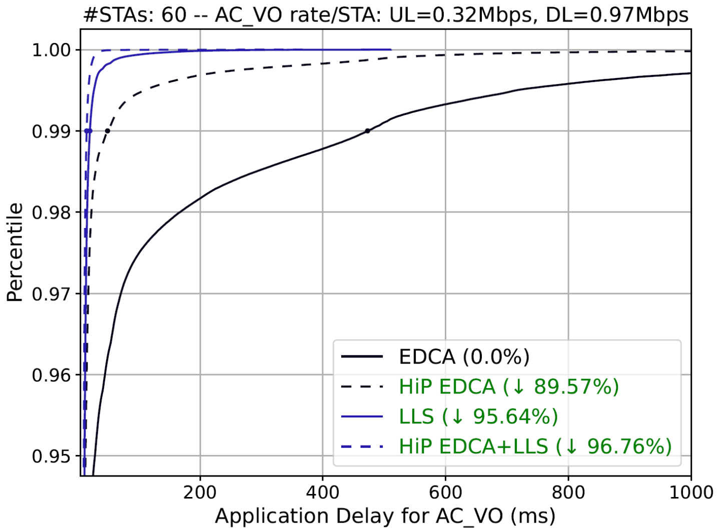


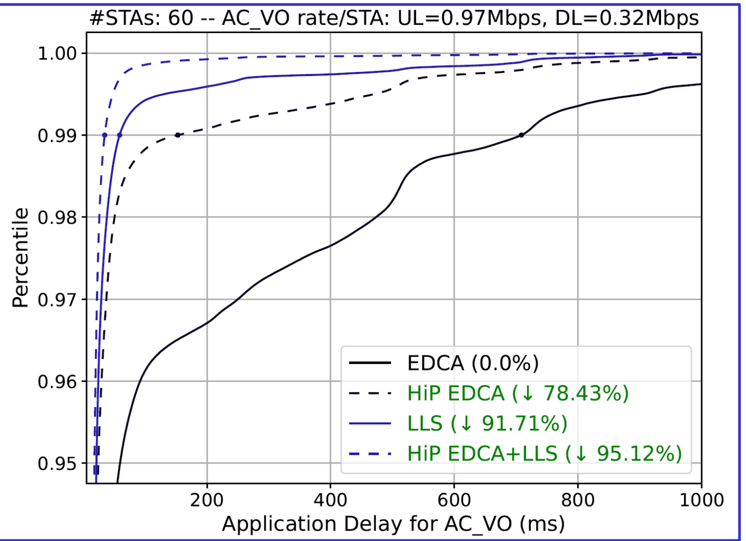




## Application Delay



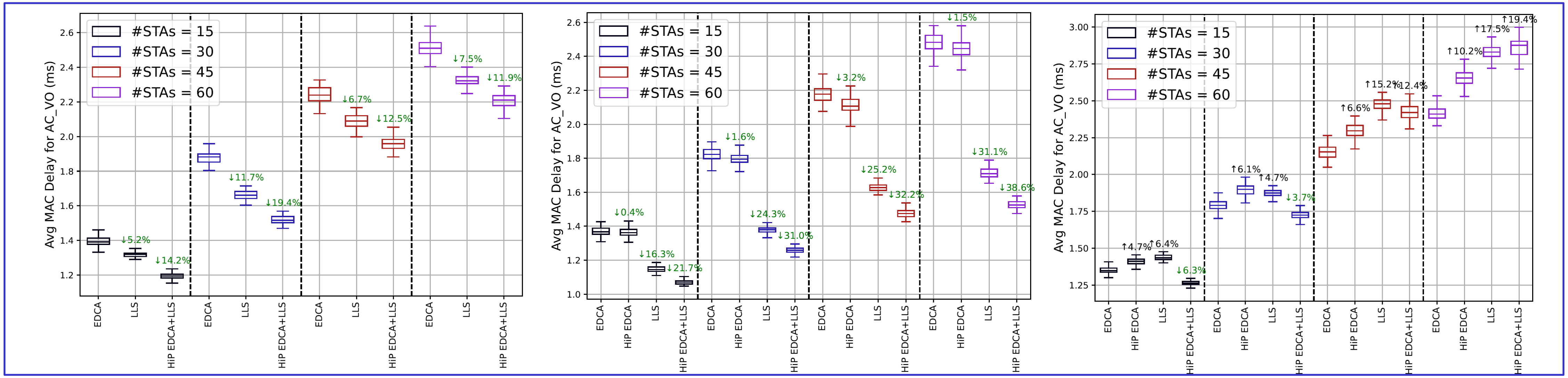



# Average application and MAC delay for AC_VO

Scenario 1 – Equal UL/DL | Scenario 2 – DL Dominant | Scenario 3 – UL Dominant

## MAC Delay




## Application Delay