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# Coexistence of IEEE 802.11n and Licensed-Assisted Access devices using Listen-before-Talk techniques

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# Introduction: LTE in unlicensed spectrum

- Development of LTE radio communications technology in unlicensed spectrum motivated by superior:
  - link performance
  - medium access control
  - mobility management
  - coverage
  - spectrum availability (> 400MHz)
- LTE Small Cells need to coexist with the Wi-Fi ecosystem

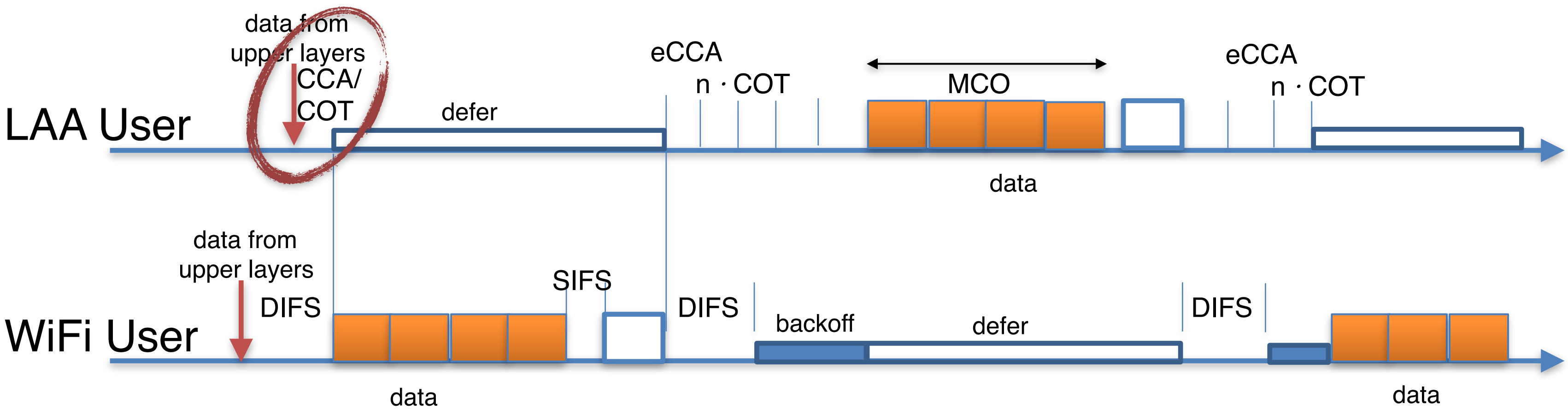
# LTE and WiFi Coexistence

- Several proposals:
  - LTE-U
    - Supplemental downlink (SDL), paired with a licensed LTE carrier, used in carrier-aggregation mode (*LTE-U Forum*) - does not require LBT (Listen Before Talk)
  - LTE-LAA
    - LBT MAC-layer operations based on Clear Channel Assessment (*3GPP-ETSI*) in 5GHz band
      - Frame-based Equipment (FBE)
      - <u>Load-based Equipment (LBE)</u>

# Regulations for FBE/LBE devices

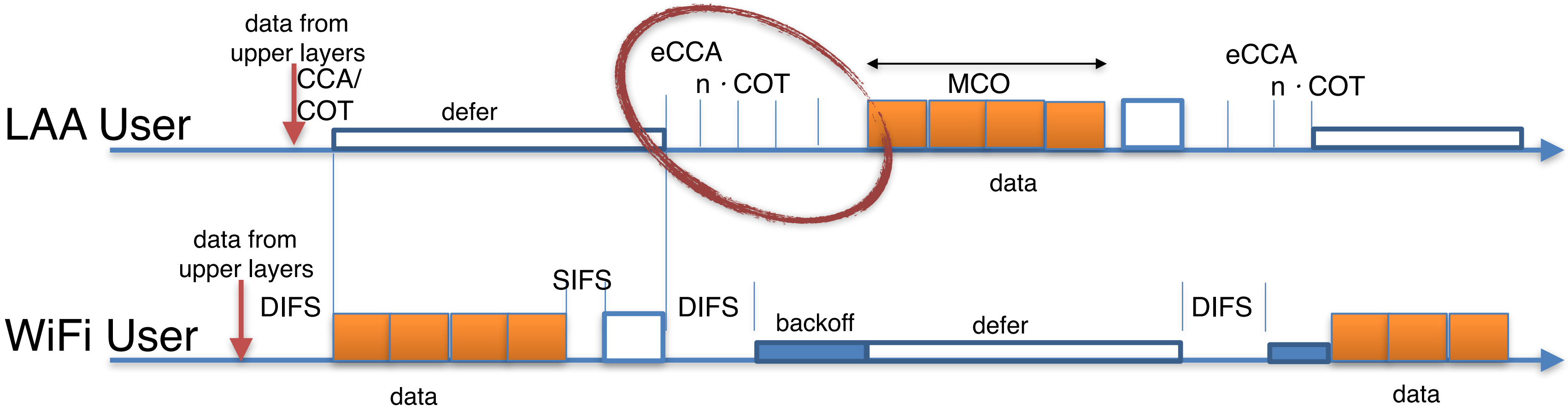
- Limitations on transmission power (23 dBm in Europe and 24 dBm in the U.S. for indoor usage)
- Interference-avoidance mechanisms toward incumbent systems by using Dynamic Frequency Selection (DFS)
- <u>Listen Before Talk (LBT) MAC-layer operations for graceful coexistence with the contention-based WiFi DCF protocol</u>

# MAC guidelines for LBE-LAA



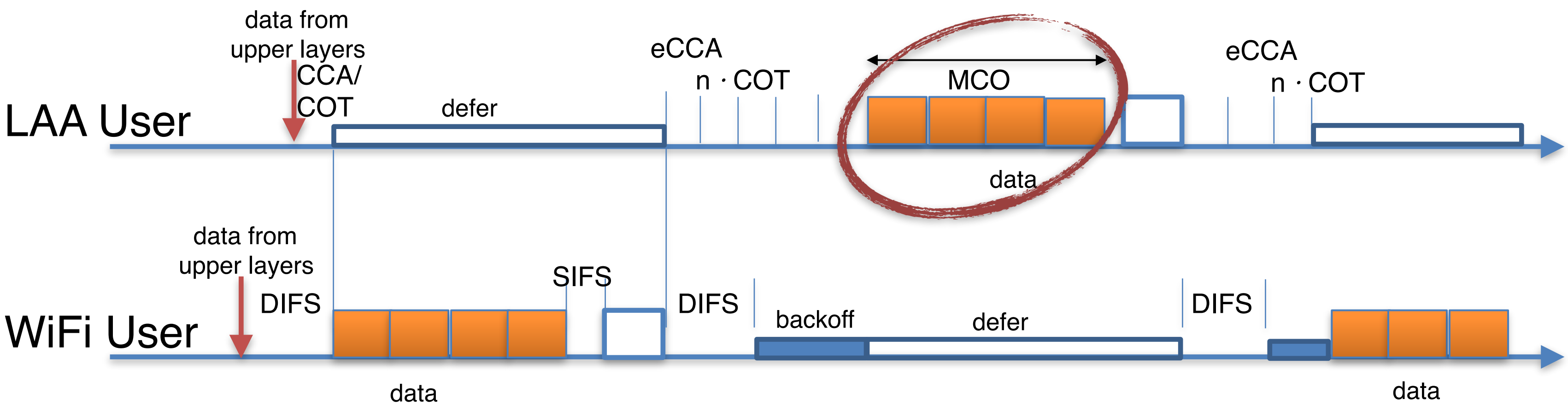

- Any transmission by LBE must be preceded by a Clear Channel Assessment (CCA)
  - The channel is observed for at least 20 μs (Channel Observation Time, COT)

# MAC guidelines for LBE-LAA




- If the channel is found occupied, an Extended CCA (eCCA) check is performed
  - the channel is monitored for a time $n \cdot COT$, $n \in [1,q]$, $q \in [4,32]$

# MAC guidelines for LBE-LAA




- Transmission by an LBE must not last for more than a Maximum Channel Occupancy (MCO) time
  - MCO determined as *13/32·q* ms

# Differences between DCF/EDCA and LAA MAC

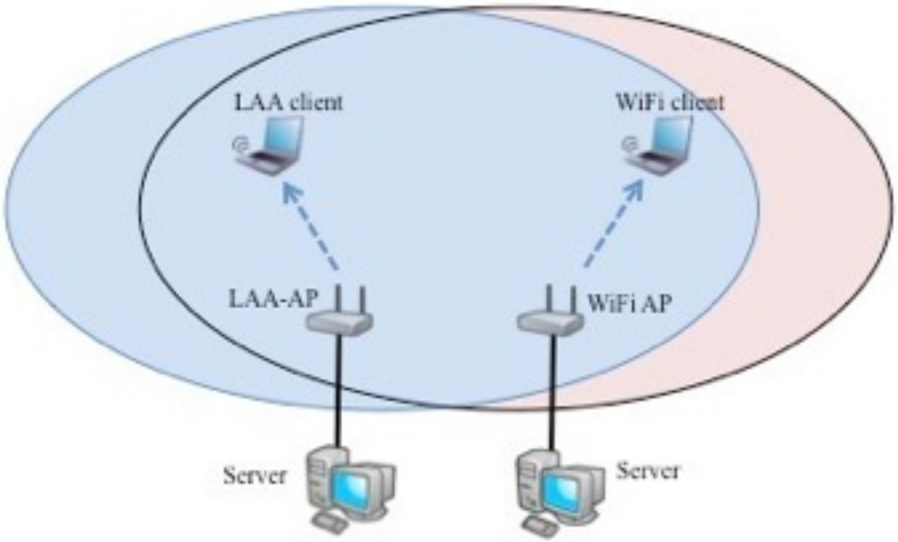
- EDCA backoff and eCCA ranges differ depending on the implementation, the version of 802.11 and the choice of Access Category
- eCCA does not increase exponentially
- The random values in LAA eCCA do not include 0

- The choice of the *q* parameter is critical:
  - small *q* shortens the wait before channel capture by LAA
  - small *q* shortens the maximum channel occupancy by LAA
  - …and viceversa

# Simulation Scenario

- LAA and 802.11n MAC implemented in OMNET++ for frame-level simulation
- Topology: single-cell heterogeneous residential network
  - overlapping LAA and WiFi APs coverages, contending for the channel
  - LAA and WiFi clients, exchanging traffic with outside server
- Traffic: two flow types sent in different 802.11n Access Categories
  - downlink UDP with exponentially-distributed intergeneration time
  - On-Off VoIP traffic

| PHY/MAC Parameters | Value |
|---|---|
| PHY data bitrate | 135 Mb/s |
| PHY basic bitrate | 13 Mb/s |
| PHY control bitrate | 135 Mb/s |
| 802.11 MAC Slot Time | 9 $\mu$s |
| LAA MAC COT | 20 $\mu$s |
| 802.11/LAA MAC retry limit | 7 $\mu$s |
| LAA $q$ parameter | 8, 32 $\mu$s |
| 802.11 MAC A-MPDU max size | 65535 B |
| 802.11 MAC MPDU spacing | 8 $\mu$s |

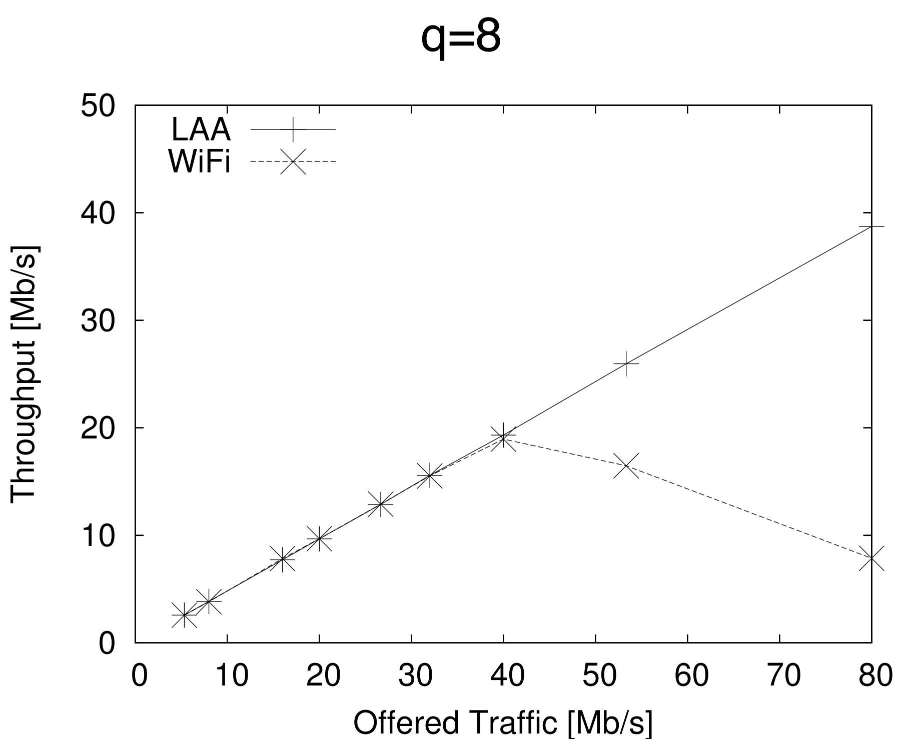


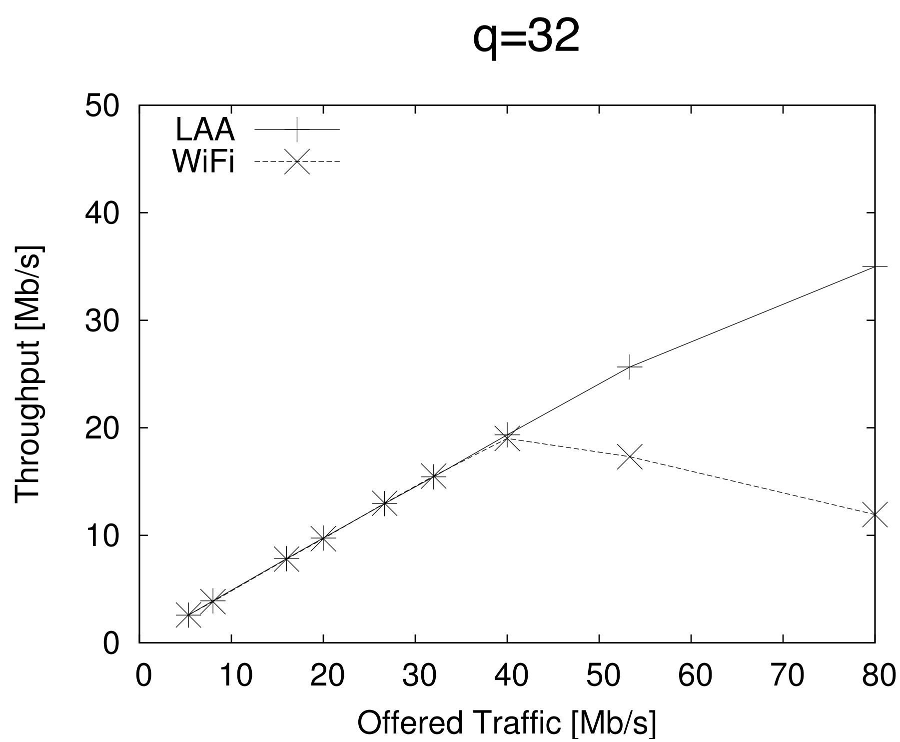
# Metrics of interest

- *Throughput*: the average of the number of packets correctly received, divided by the simulated interval
- *Frames per MCO*: average number of frames transmitted by the LAA-AP during the MCO
- *Subframes per A-MDPU*: average number of subframes aggregated into an A-MPDU by the WiFi AP
- *End-to-end delay and jitter*: average packet delivery delay and jitter measured at the application layer

- Results are collected with and without 802.11n frame aggregation

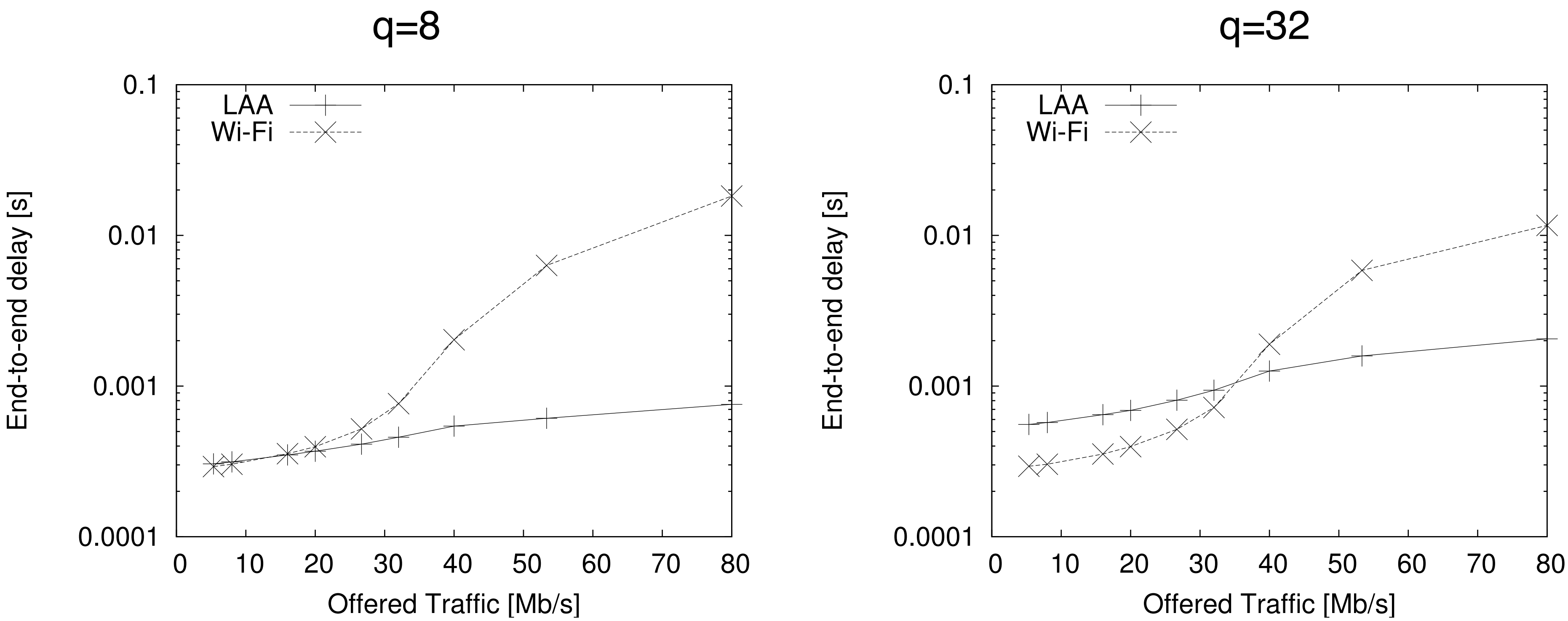
# No frame aggregation - UDP traffic




WiFi traffic sent as AC BE without MPDU aggregation

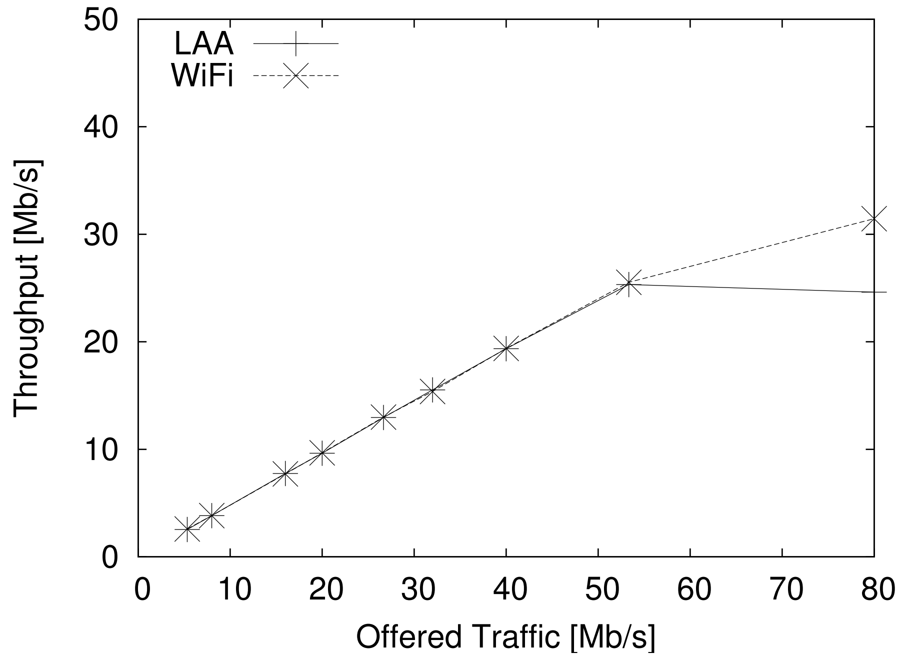
# No frame aggregation - UDP traffic



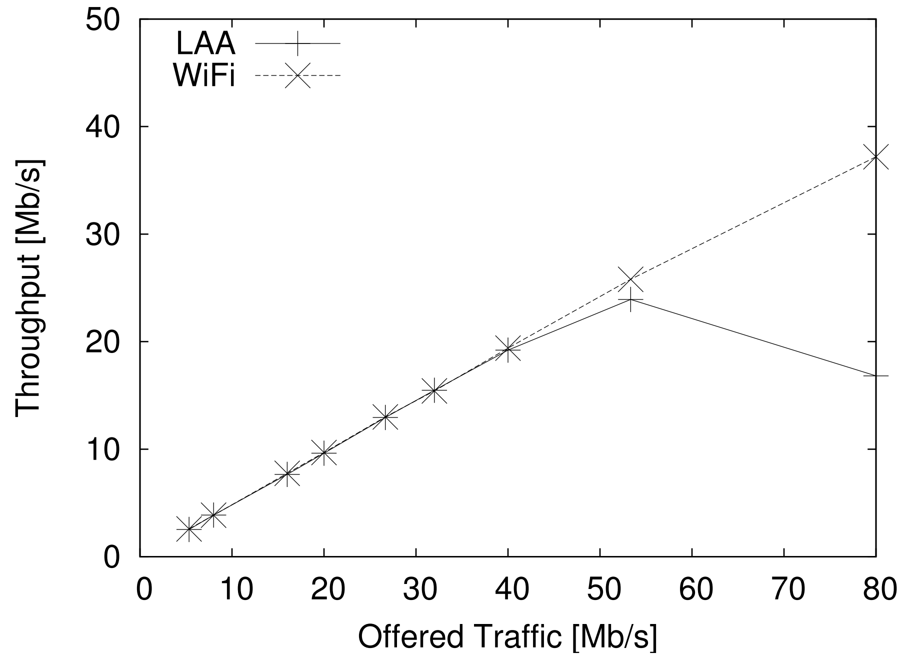

WiFi traffic sent as AC BE without MPDU aggregation

# No frame aggregation - UDP traffic

q=8

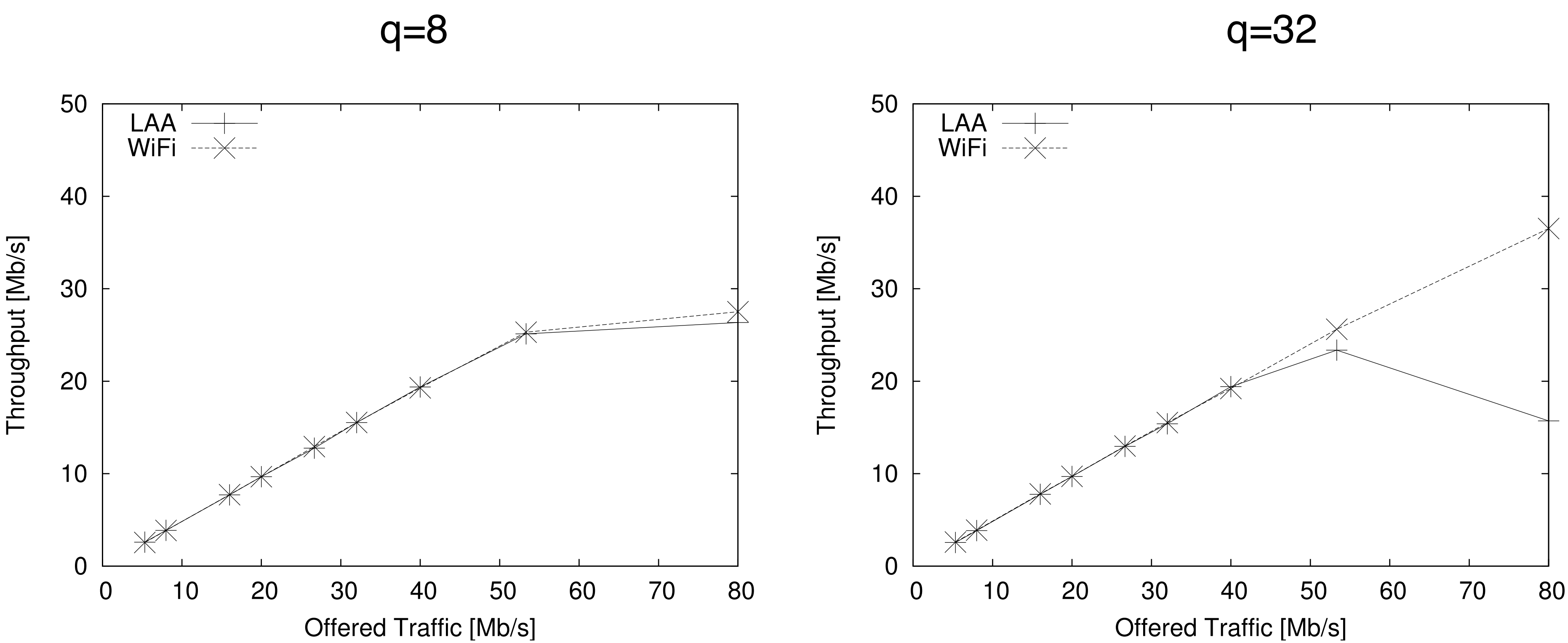



q=32




WiFi traffic sent as AC VI without MPDU aggregation

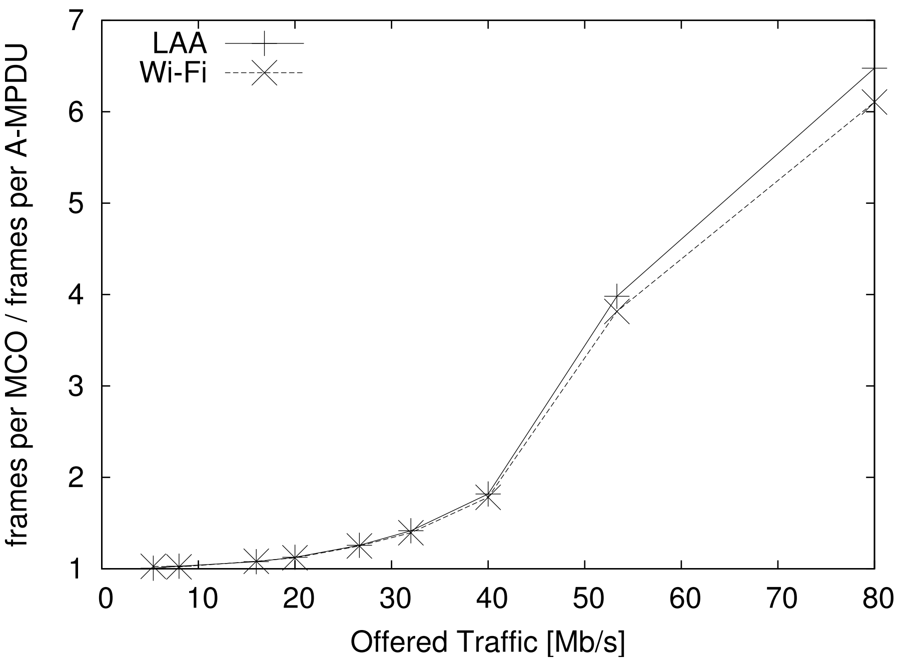
# Frame aggregation - UDP traffic



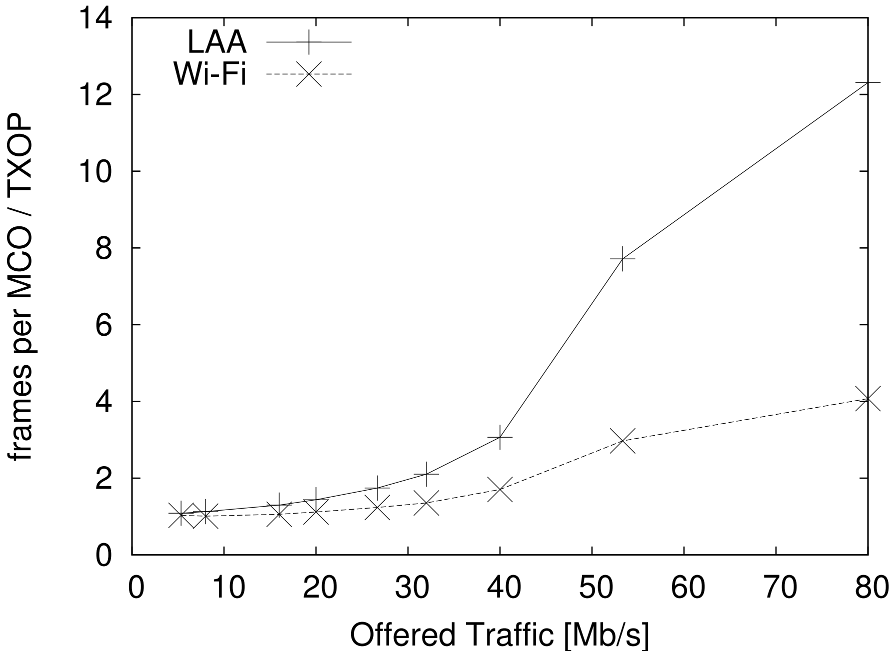

WiFi traffic sent as AC BE with MPDU aggregation

# Frame aggregation - UDP traffic

q=8



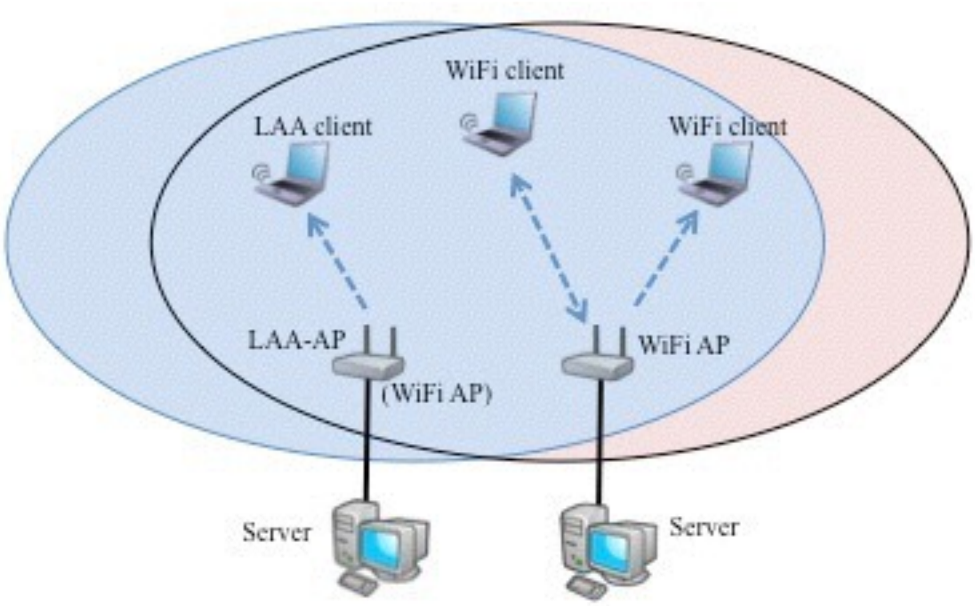

q=32



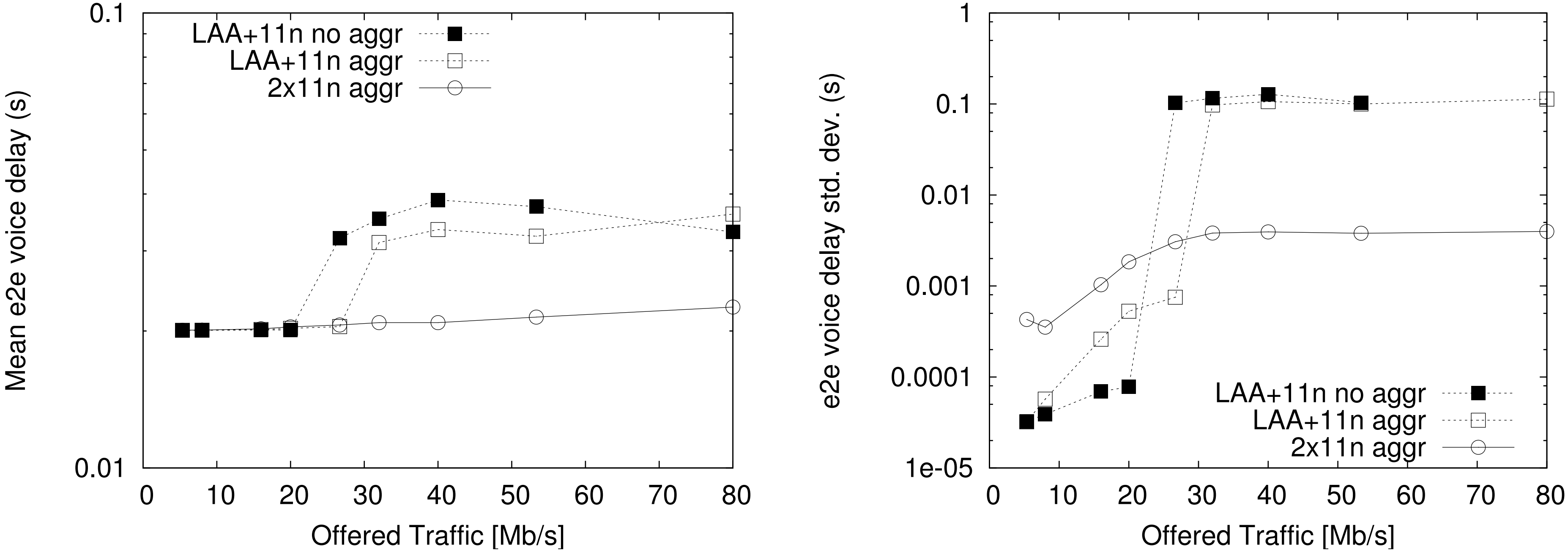

WiFi traffic sent as AC BE with MPDU aggregation

# VoIP traffic

- Additional WiFi Client sending uplink On-Off VoIP traffic in AC_VO category
- VoIP traffic competes with UDP downlink transmitted by:
  - 1 LAA-AP + 1 WiFi AP
  - 2 WiFi AP



# VoIP traffic




VoIP traffic sent as AC VO (LAA using q=8)

# Conclusions

- WiFi 802.11n fairly competes against LAA at high loads
  - if WiFi traffic is sent in higher Access Categories
  - if frame aggregation is enabled
- VoIP traffic
  - can be unaffected at low-medium loads if protected by the AC VO category
  - delay jitter increase for extended MCO interval by LAA traffic
- Behaviors at high loads depend on the choice of the *q* parameter