[LAA/Wi-Fi Coexistence Issues: Wi-Fi Client Association and Data Transmission]

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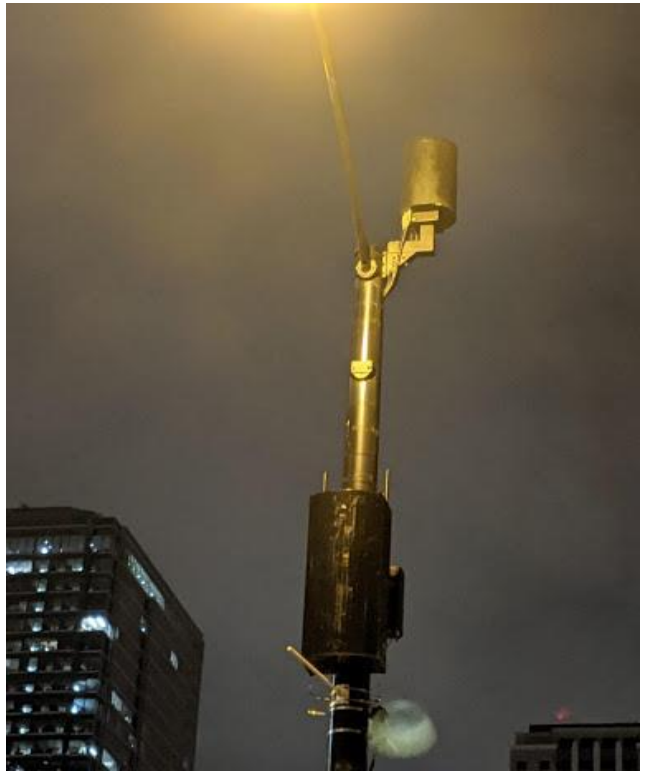
Abstract

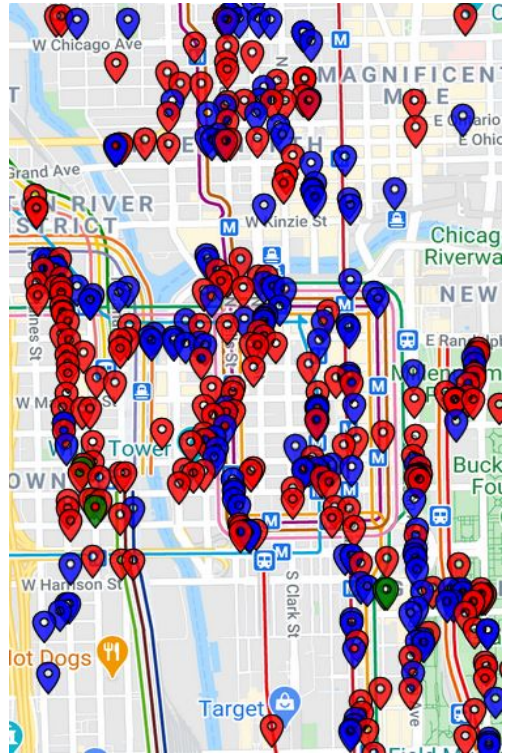
The hidden-node problem has been well studied in the context of overlapping Wi-Fi APs. However, when Wi-Fi coexists with LAA, the hidden node problem is exacerbated since the well known RTS/CTS mechanism cannot be used to resolve contentions, resulting in throughput degradation for Wi-Fi. We have made careful measurements of this phenomenon in deployed LAA networks in the Chicago area and we present our measurement results in two locations: one in the IIT campus and one in the UChicago campus.

Example LAA deployments in Chicago

LAA @ UChicago



LAA @ Downtown Chicago



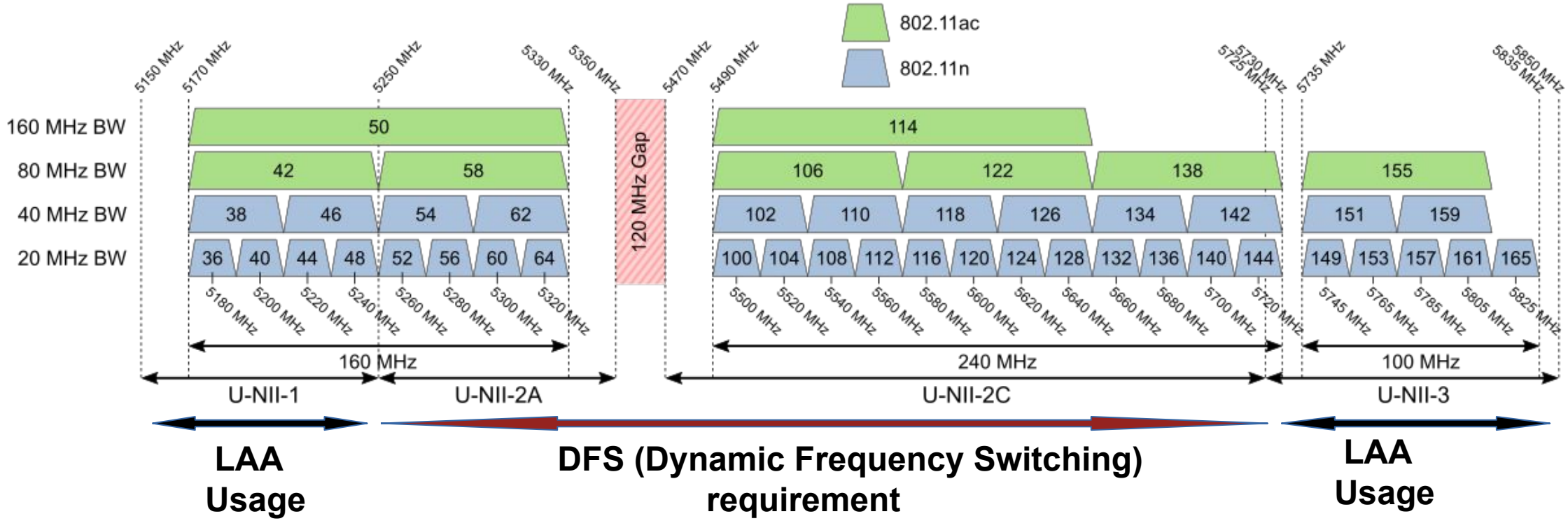
Approximation of LAA BS @ Downtown in Jan 2020 AT&T (blue), T-Mobile (green), Verizon (red)

Hidden Node Experiments

- **Experiment 1, IIT:** A hidden node scenario with a deployed T-Mobile LAA small cell coexisting with 5 Wi-Fi APs that we deployed to study performance in a controlled manner. We observe that the Wi-Fi clients experience association problems when they try to connect to their corresponding Wi-Fi APs. This is due to the LAA BS being unaware of the Wi-Fi AP's transmission, and transmitting with the maximum transmission opportunity time (TXOP) of 8 ms.

- **Experiment 2, UChicago:** A hidden node scenario with a deployed AT&T LAA small cell coexisting with the 3 Wi-Fi APs that we deployed inside the UChicago bookstore in close proximity to the outdoor LAA. We present one set of results where 5 Wi-Fi clients are associated with one AP, which operates with a 80 MHz bandwidth and primary channel 157. We performed three different kinds of experiments: (i) clients midway between LAA & Wi-Fi, (ii) clients close to the Wi-Fi AP, and (iii) clients close to the LAA BS.

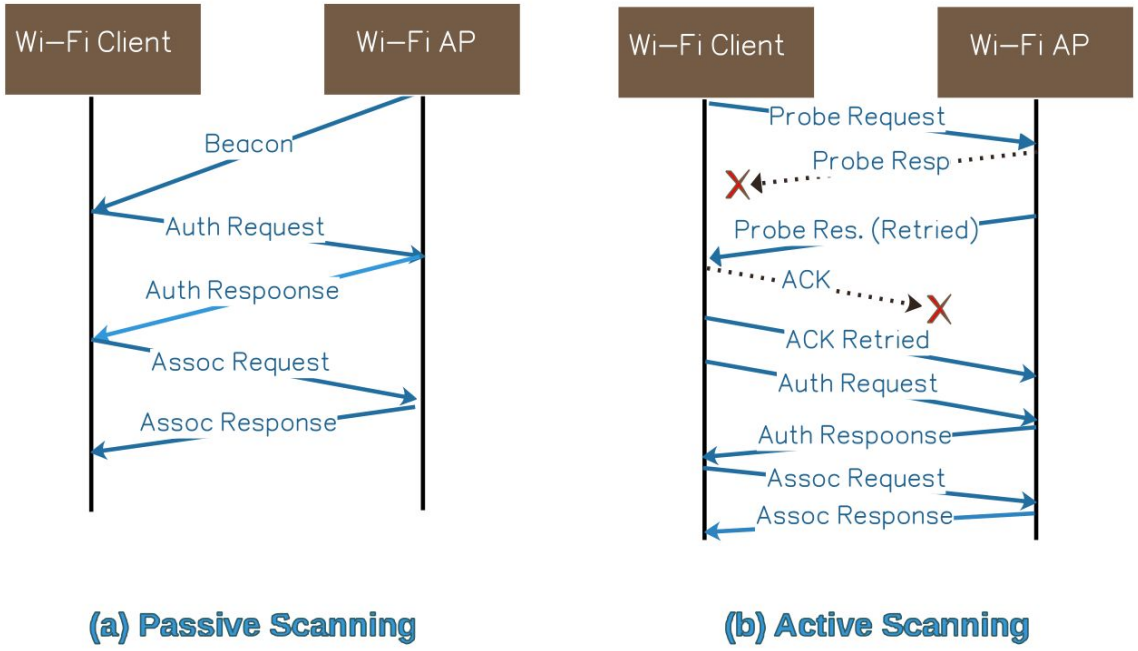
Wi-Fi & LAA Channelization for the experiments



- Experiment 1: the T-Mobile LAA BS deployed at IIT uses channels 36, 40, and 44
- Experiment 2: the AT&T LAA BS deployed at UChicago uses channels 149, 153, and 157

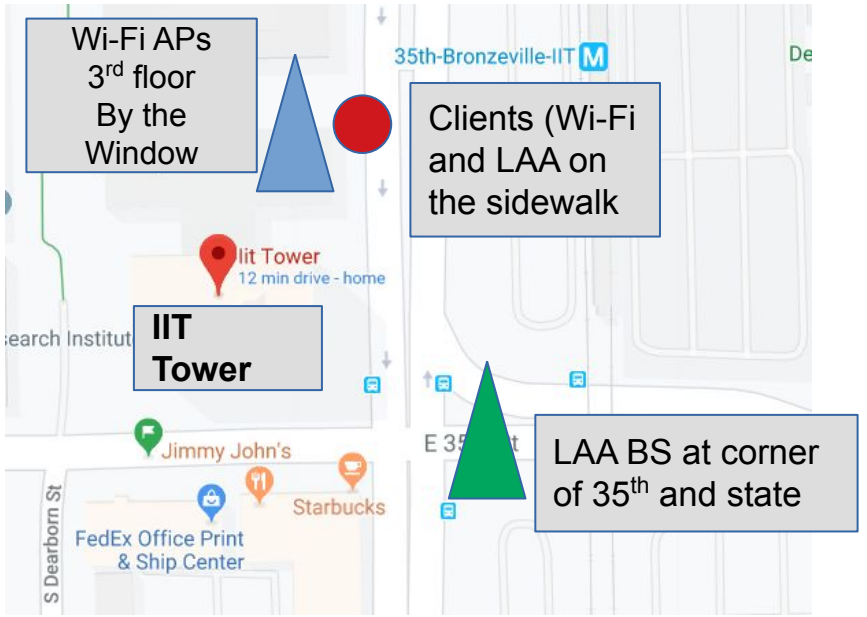
Wi-Fi Client Association Problem

- There are two ways Wi-Fi clients can discover APs: passive and active scanning
- All of transmission in this process are unicast, except beacon and probe request
- Due to hidden node problem or high interference, association process may be timed out



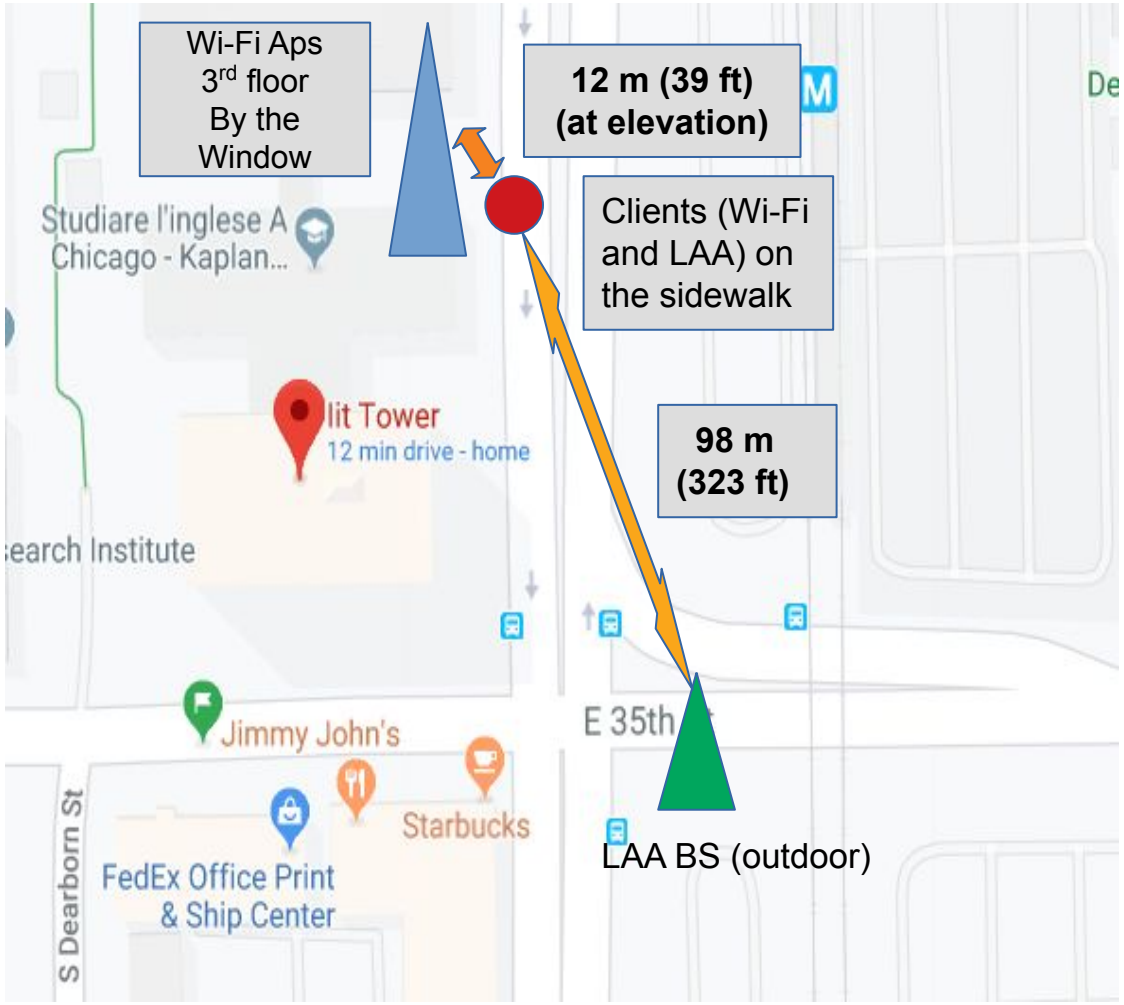
Experiment 1: IIT Campus

- **Wi-Fi Indoors:**
  - 5 Wi-Fi APs connected to the IIT network
  - 3 Laptops running Wireshark in monitor mode
- **LAA Outdoors:**
  - T-Mobile on a pole
  - 5 Wi-Fi clients (Google Pixel 3, Samsung S10, Xiaomi A2, OnePlus 6, Chuwi Hi9)
  - 1 LAA client (Google Pixel 3)

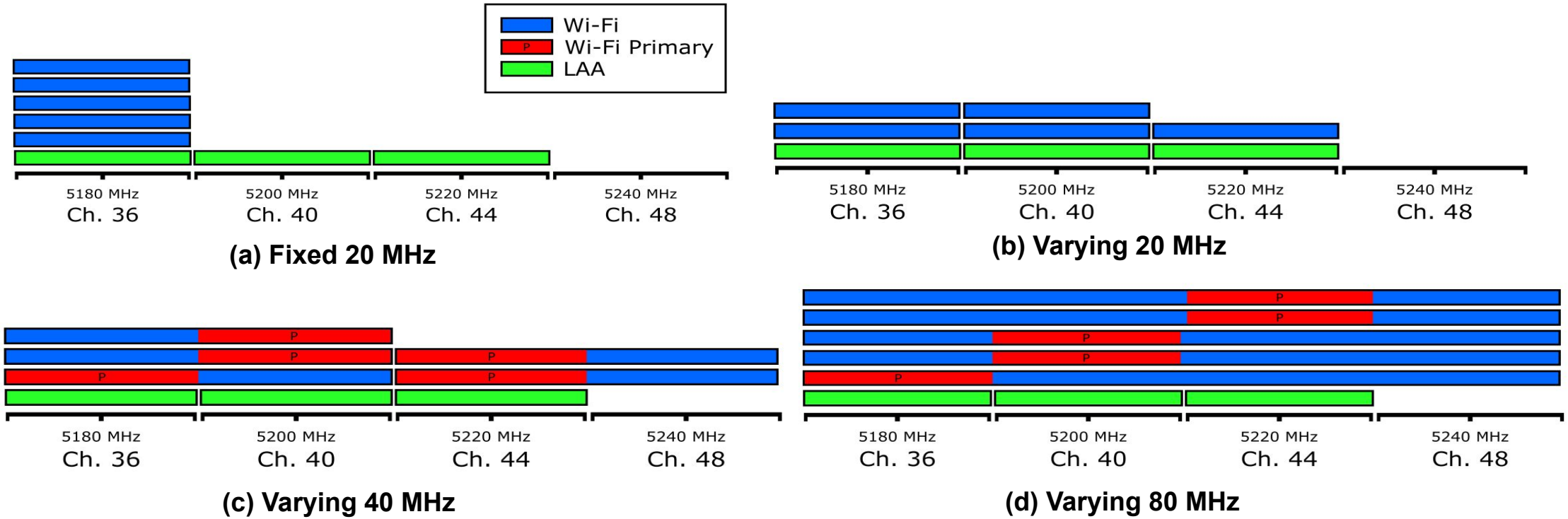


Experiment 1, contd.

- **Distances:**
  - 98 m (322 ft) between LAA BS and clients
  - 12 m (39 ft) between Wi-Fi APs and clients, due to elevation
- The clients have good signals to their corresponding AP/BS
  - RSSI at the Wi-Fi clients is around -35 dBm
  - SINR at the LAA client is around 18 dB
- The LAA signal is very weak at the APs, and vice versa
- Perfect condition for a hidden node



Experiment 1: Wi-Fi AP Configurations



(a) Fixed 20 MHz

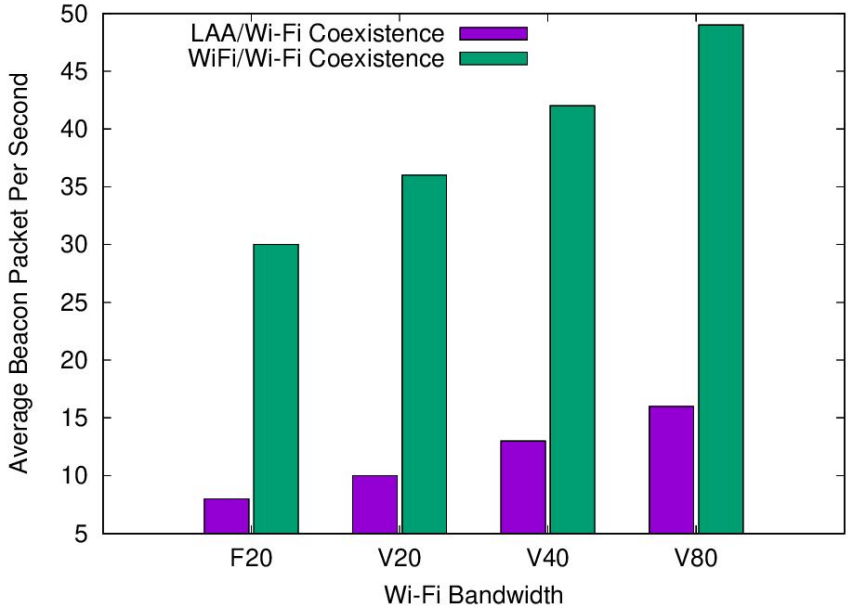
(b) Varying 20 MHz

(c) Varying 40 MHz

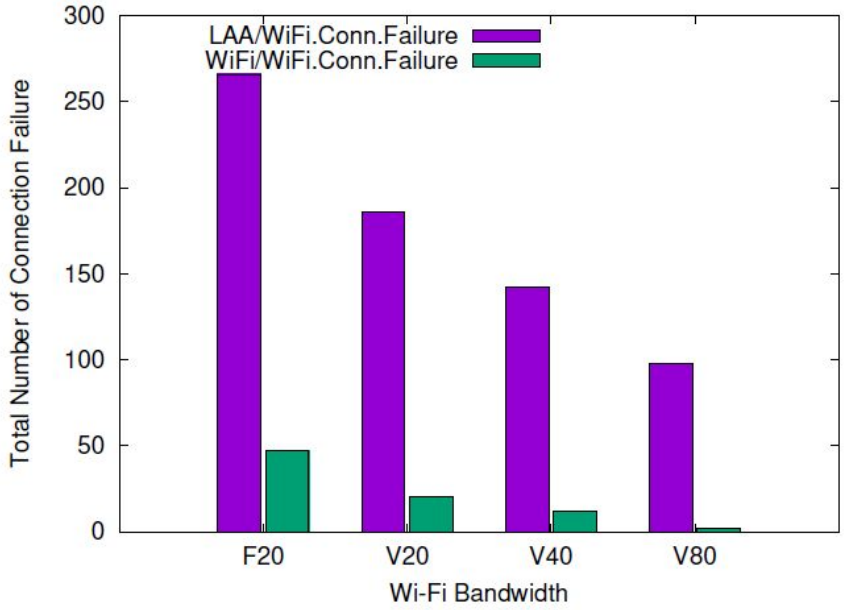
(d) Varying 80 MHz

- We vary the primary channel around Channels 36, 40, and 44 which are being used by LAA.
- Primary channel is important for backward compatibility and management packets (beacon)
- Only 20 MHz was captured by Wireshark, therefore we do not present the throughput performance of the “Varying 40” and “Varying 80” configurations above

Experiment 1: Wi-Fi Association Process and Beacon Transmissions



Successful beacon transmissions



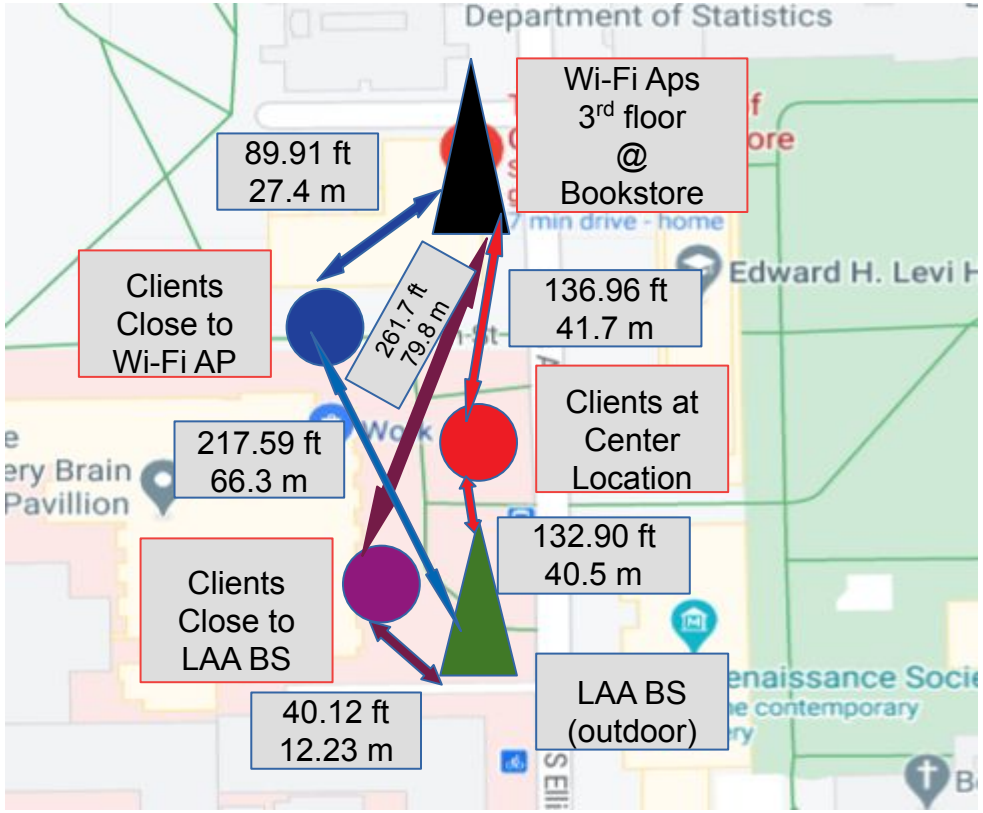
Number of Dis-association connections

- Successful beacon transmissions and reception are important for passive scanning
- We see a decrease in the number of successful beacon transmissions when LAA and Wi-Fi coexist
- With 5 APs and a beacon interval of 102.4 ms, we expected around 50 beacons per second: even without LAA, when 5 APS coexist on the same channel (F20), beacon transmissions are affected.

Experiment 2: UChicago Bookstore

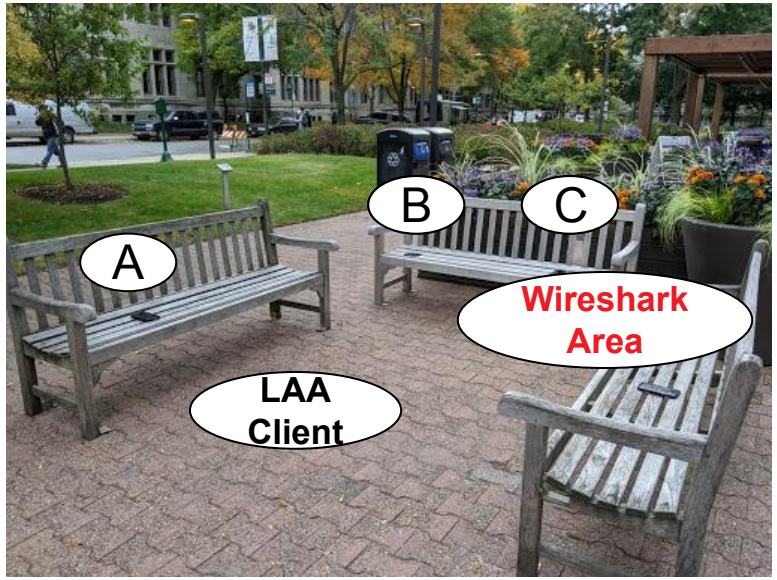
Wi-Fi AP Deployment

AT&T LAA Deployment

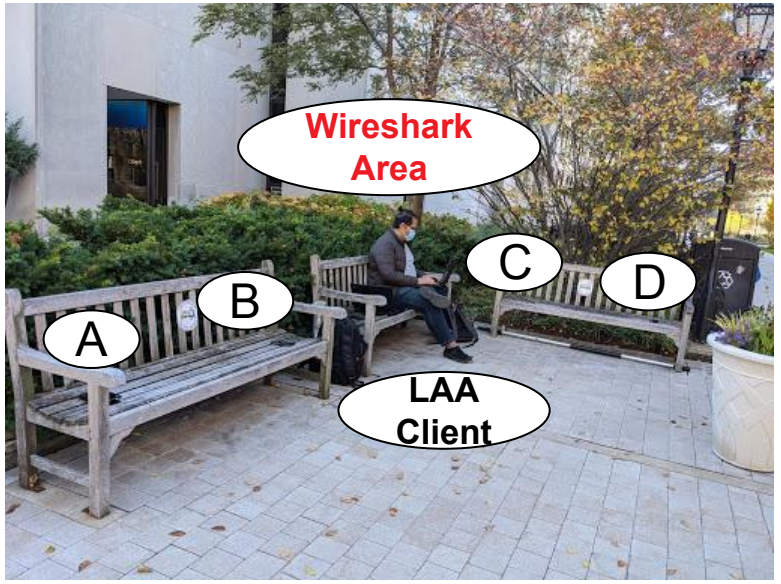


- **Note:** We deployed our own Wi-Fi APs to operate on primary channel 149, 153 and 157 with a 80 MHz. The LAA BS operates on 3 unlicensed channels: 149, 153, and 157.

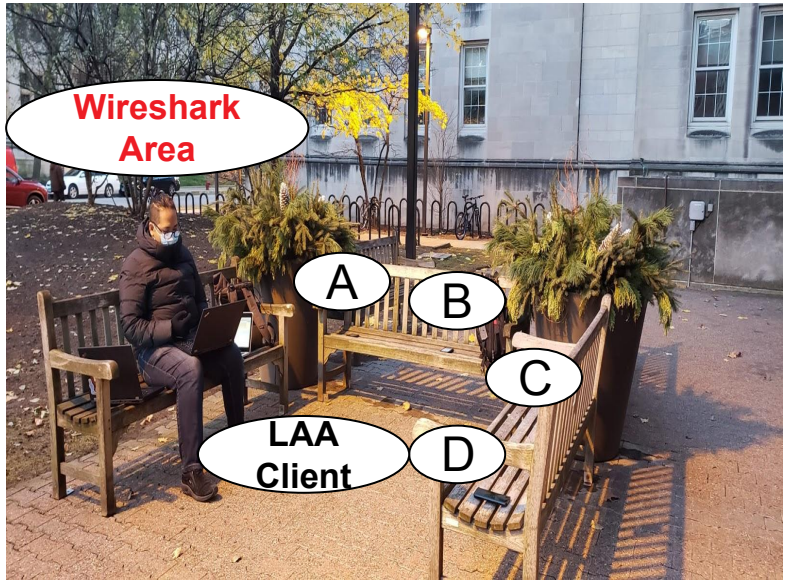
Experiment 2: Wi-Fi Clients and Wireshark Deployment



Clients at Center



Clients Close to Wi-Fi AP



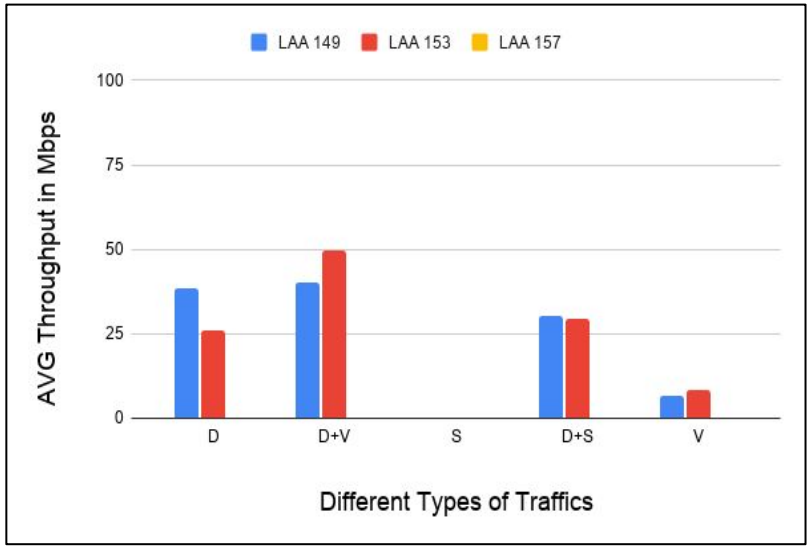
Clients Close to LAA

- All 5 Wi-Fi clients are associated with one AP on channel 157. Both LAA and Wi-Fi clients initiate the same traffic as explained in the next slide.

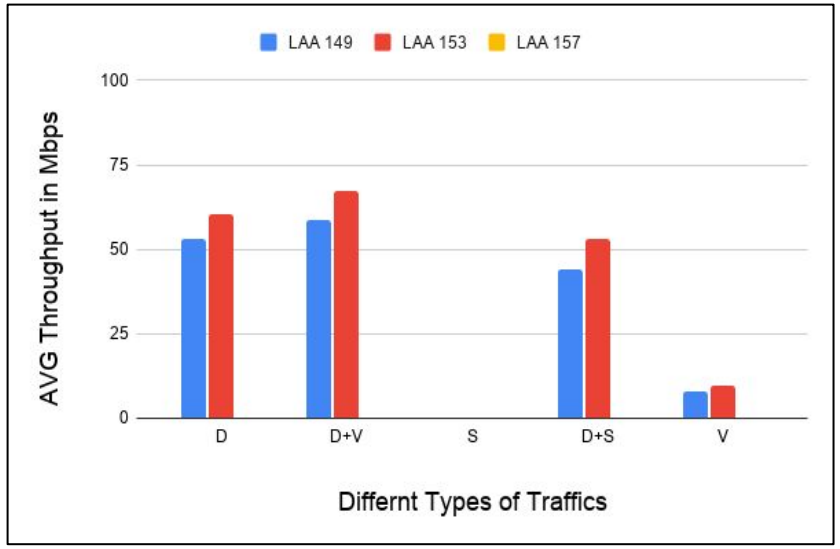
Experiment 2: parameters

- We assume that we are the only LAA user in the vicinity
  - LAA-capable phones are new and expensive, therefore not widely used
    - Confirmed by measurements showing all RBs allocated to our device.
- We used 5 different traffic types on all clients:
  - **Data (D):** Pure data traffic is generated by downloading a large YUV dataset (>10 GB) from Derf Test Media Collection
  - **Video (V):** A Youtube video is downloaded, with a resolution of 1920×1080 and bit-rate of around 12 Mbps.
  - **Streaming (S):** A live stream video on Youtube is loaded, with a resolution of 1280×720 and bit rate of around 7.5 Mbps.
  - **Data + Video (D+V):** Combination of data and video traffic as described above.
  - **Data + Streaming (D+S):** Combination of data and streaming traffic as described above.
- Initiated traffic on all clients for 2 minutes each

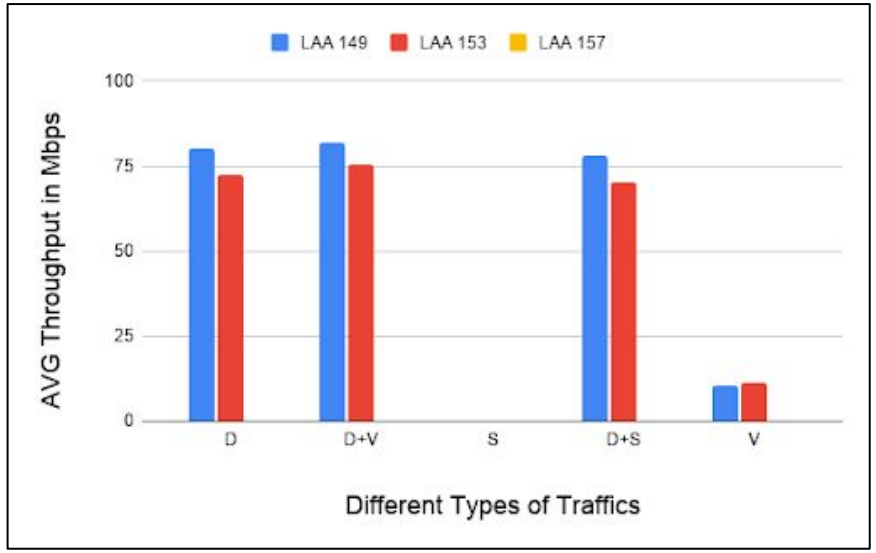
Experiment 2: LAA throughput



(a) Clients at Center



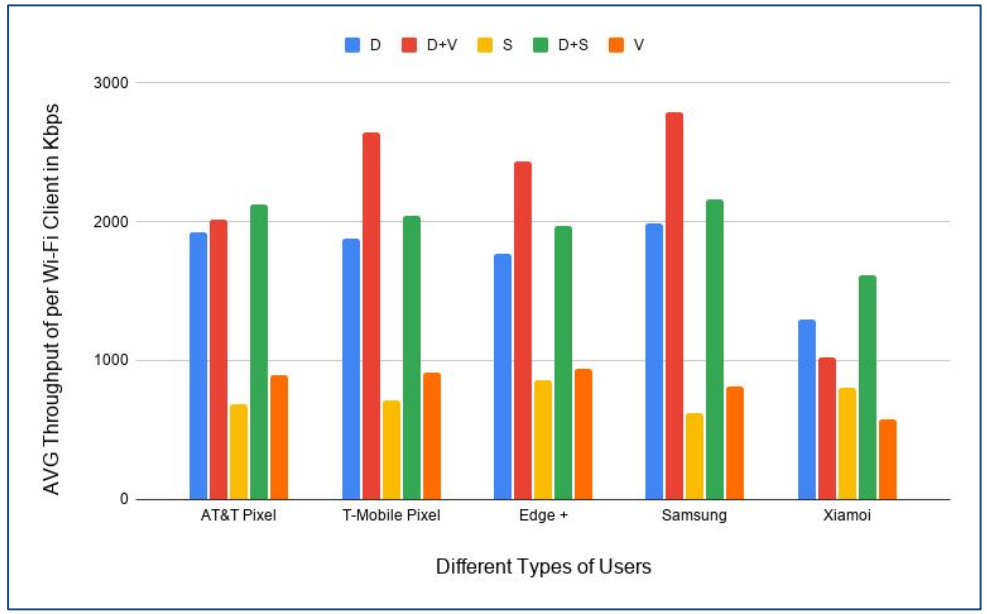
(b) Clients Close to Wi-Fi AP



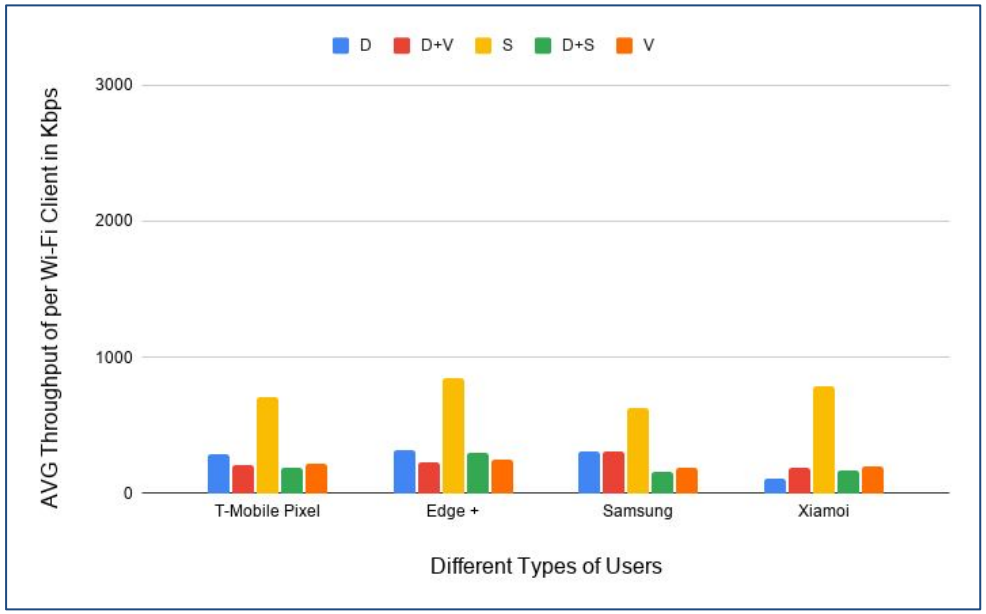
(c) Clients Close to LAA

- The LAA and Wi-Fi Clients are deployed close to the same location.
- The LAA BS turns the transmission OFF on Channel 157 because the SINR on this channel is -3 dB.
- No transmission on unlicensed channel for Streaming traffic due to QoS (transmission only on licensed)
- The LAA BS operates with a maximum transmission opportunity (TXOP) of 8ms on channel 149 and 153.

Experiment 2 Wi-Fi throughput, all clients at center



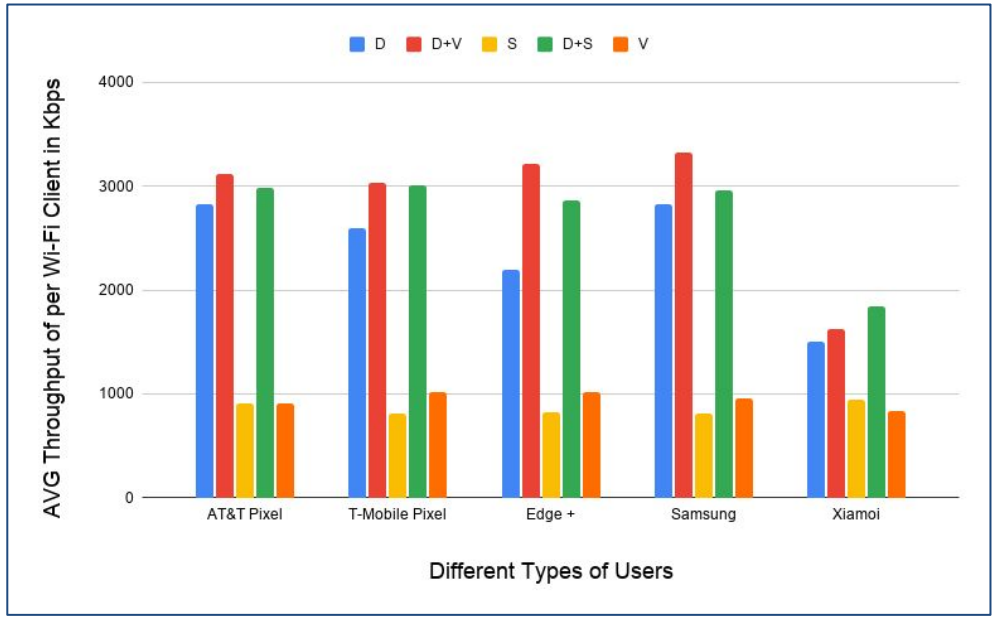
(a) Wi-Fi/Wi-Fi Scenario



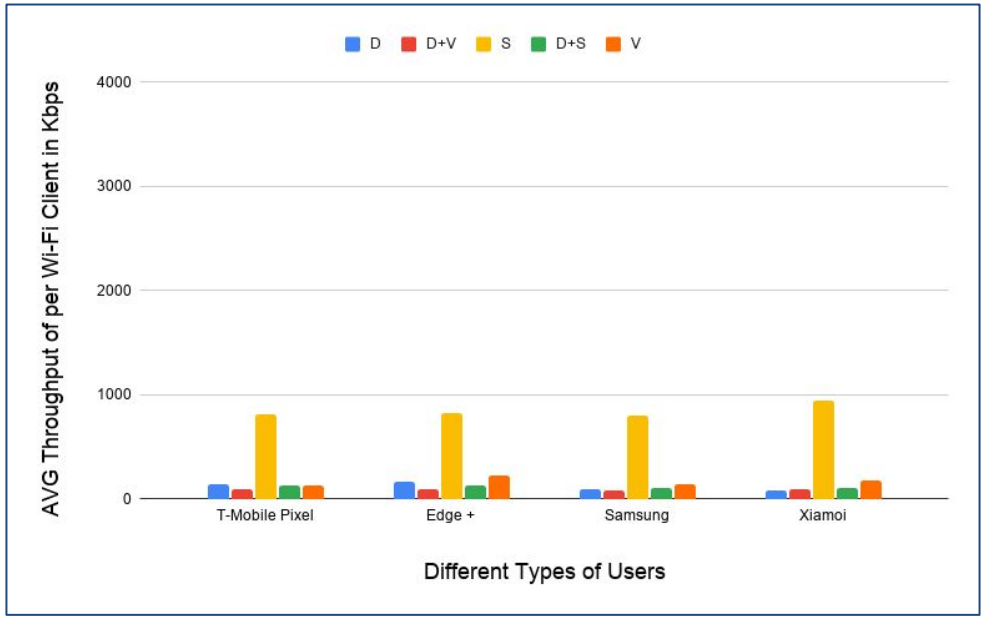
(b) Wi-Fi/LAA Scenario

- The LAA transmission on channel 149 and 153 impacts the Wi-Fi/LAA scenario in terms of number of transmission streams, modulation coding schemes, Wi-Fi bandwidth scaling (e.g., 80 MHz to 40 MHz)

Experiment 2: Wi-Fi throughput, all clients close to Wi-Fi



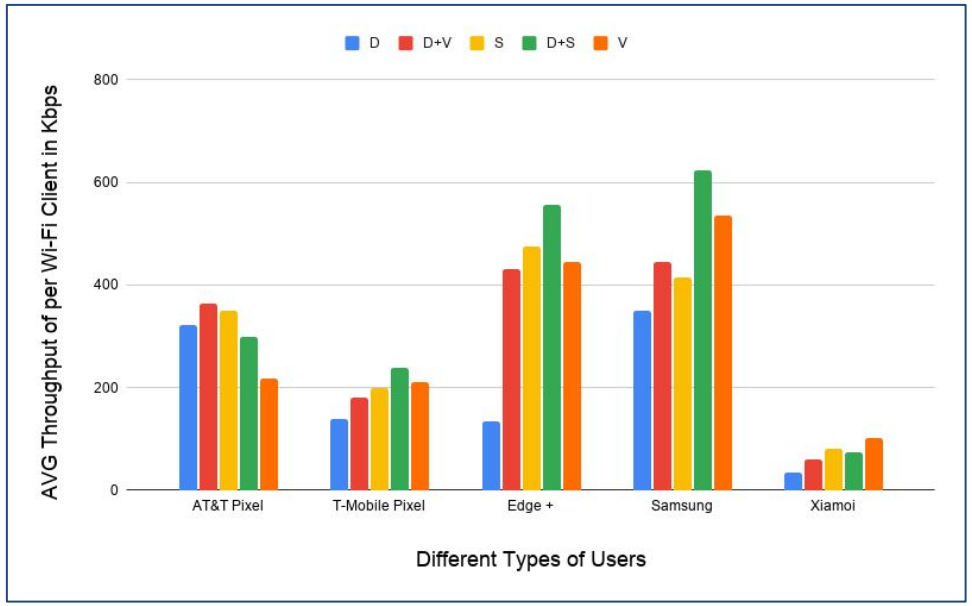
(a) Wi-Fi/Wi-Fi Scenario



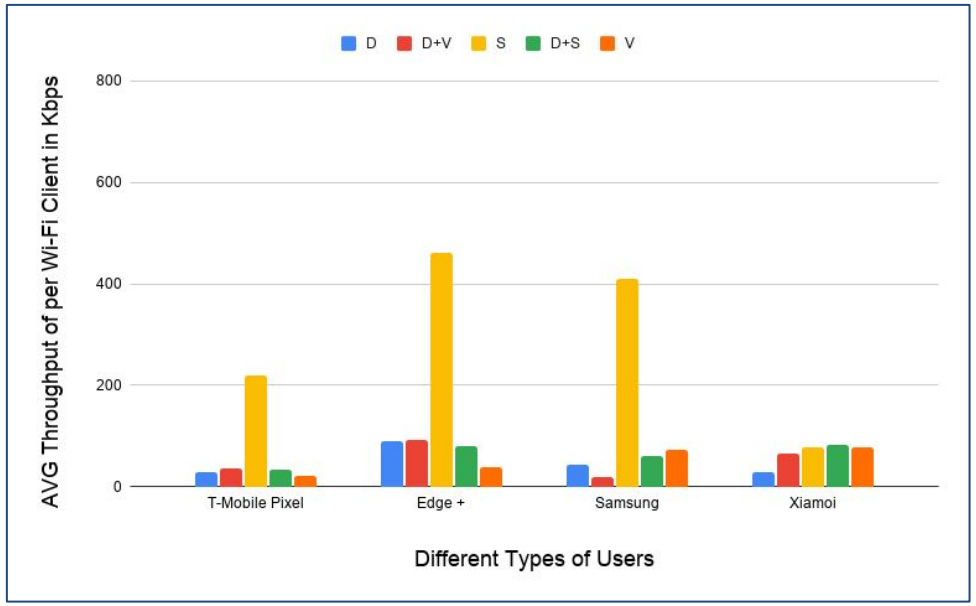
(b) Wi-Fi/LAA Scenario

- All clients are close to Wi-Fi AP, the Wi-Fi AP and LAA BS are in a clear line of sight.
- The streaming traffic on Wi-Fi does not have much impact on LAA transmission, since LAA transmits streaming traffic only on the licensed spectrum.
- Lower throughput on Xiaomi phone due to being limited by 11n only.

Experiment 2: Wi-Fi throughput, all clients close to LAA



(a) Wi-Fi/Wi-Fi Scenario



(b) Wi-Fi/LAA Scenario

- Since the clients are distant from the Wi-Fi AP, even without LAA the throughput is low.
- The throughput decreases further when LAA transmits since there is additional interference from LAA as well, but the percentage decrease is less compared to the previous cases.

Conclusions and ongoing work

- Even though Wi-Fi is deployed indoors and LAA outdoors, in typical outdoor Wi-Fi usage prevalent on college campuses, we observe a degradation of Wi-Fi performance.
- The hidden node scenario will impact association of Wi-Fi clients.
- Even though LAA does not use the primary channel of a 80 MHz Wi-Fi AP, throughput of the Wi-Fi transmission over 80 MHz suffers.
- We observed similar performance when all APs use Channel 149 as the primary channel
- When Wi-Fi clients are just associated, without transmitting any data, the LAA BS operates on all 3 channels.
- We continue to make measurements with different scenarios and combinations of all 3 APs: we welcome input on scenarios of interest to the community.

References

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