UNIVERSITY OF DELAWARE

Cisco Cooperative Project

Coexistence of WiFi and LAA

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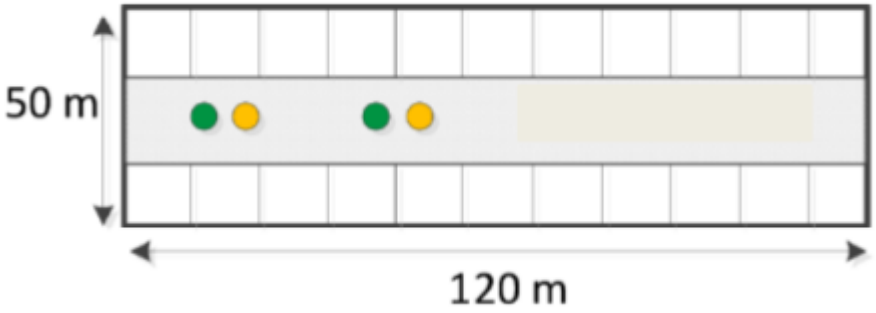
Outline

- Problem review
- Delay performance: case II
- Performance with a single user
- Performance with multiple users
- Next steps

Problem Review

❖Simulation setting

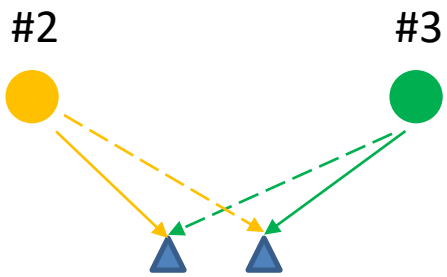
- ✓ 2 WiFi APs (green) and 2 LAA eNBs (yellow) are equally spaced [1]



- ✓ Transmit power: 18 dBm, with path loss
- ✓ Load rate of 0.8
- ✓ WiFi: CCACS = -82 dBm, CCAED = -62 dBm;
- ✓ LAA: CCAED = -65/-70/-75 dBm
- ✓ $q\_WiFi = [15,63]$, $q\_LAA = [15,63]$

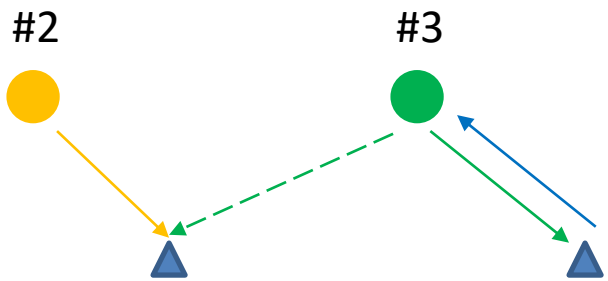
Problem Review: Different Location for Users

I:



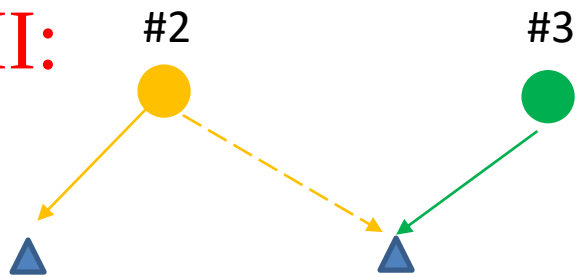
Collisions for LAA #2 user and AP #3's client

II:



Collision for LAA #2's user

III:



Collision for AP #3's client

IV:

No collisions

Problem Review (Cont'd)

- ✓ Original delay definition: For a particular packet, delay = [time of successful transmission – time of arrival], i.e., the time when the packet is popping out of the buffer - the time when the packet is pushing into the buffer. (Problem: For some pairs, due to the accumulation of packets in the buffer, the average delay can be very large.)

- ✓ Delay definition [1]: The delay for a successfully transmitted packet is defined as the time interval from the time the packet is at the head-of-line of the queue ready to be transmitted, until an acknowledgement for this packet is received. (Unless collision happens, it's more like a delay "over the air".)

[1] P. Raptis , V. Vitsas , K. Paparrizos , P. Chatzimisios , A. C. Boucouvalas , P. Adamidis, "*Packet Delay Modeling of IEEE 802.11 Wireless LANs*".

Performance: Case II

❖Case II: only collisions to LAA, load rate of 0.8

✓ Percentage of time occupation

LAA threshold (dBm)	WiFi (#1)	WiFi (#3)	LAA (#2)	LAA (#4)
-65	0.4019	0.4022	0.4450	0.4420
-70	0.4474	0.3752	0.0639	0.4440
-75	0.4455	0.4500	0.0066	0.0078

✓ Number of collisions

LAA threshold (dBm)	WiFi (#1)	WiFi (#3)	LAA (#2)	LAA (#4)
-65	1052	567	1101	608
-70	1316	1161	4428	451
-75	1294	1259	3359	3445

✓ Number of transmissions

LAA threshold (dBm)	WiFi (#1)	WiFi (#3)	LAA (#2)	LAA (#4)
-65	10465	10475	11588	11511
-70	11651	9770	1664	11502
-75	11602	11719	172	203

Performance: Case II (Cont'd)

❖Case II: only collisions to LAA, load rate of 0.8

✓ Average delay with original definition (in seconds)

LAA threshold (dBm)	WiFi #1	WiFi #3	LAA #2	LAA #4
-65 dB	6.5686	7.6698	0.0073	0.0073
-70 dB	0.0472	11.6686	64.4340	0.0072
-75 dB	0.0829	0.0801	76.9641	79.1500

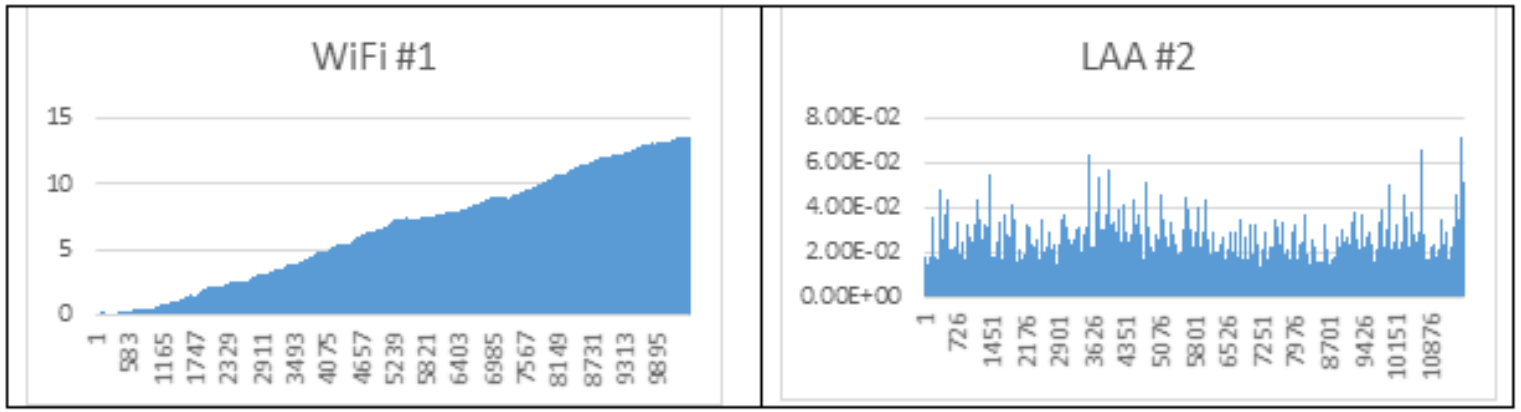
✓ Average delay with new definition (in seconds)

LAA threshold (dBm)	WiFi #1	WiFi #3	LAA #2	LAA #4
-65	0.0075	0.0076	0.0062	0.0062
-70	0.0073	0.0078	0.0840	0.0060
-75	0.0071	0.0072	0.8223	0.7769

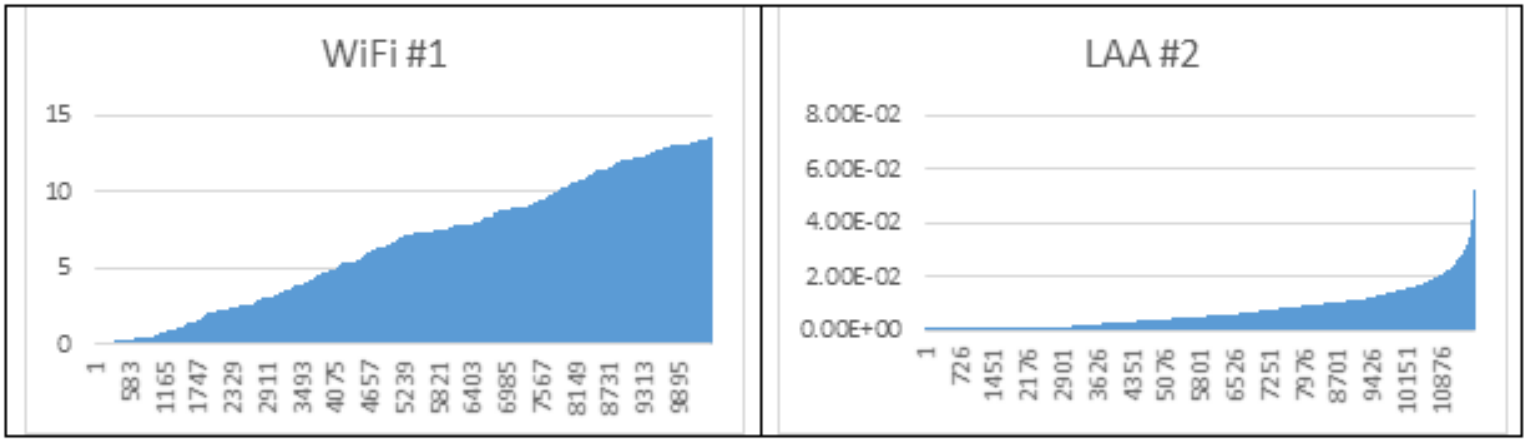
Performance: Case II (Cont'd)

❖Delay for each successful transmission (Original definition)

✓ LAA threshold: -65 dBm



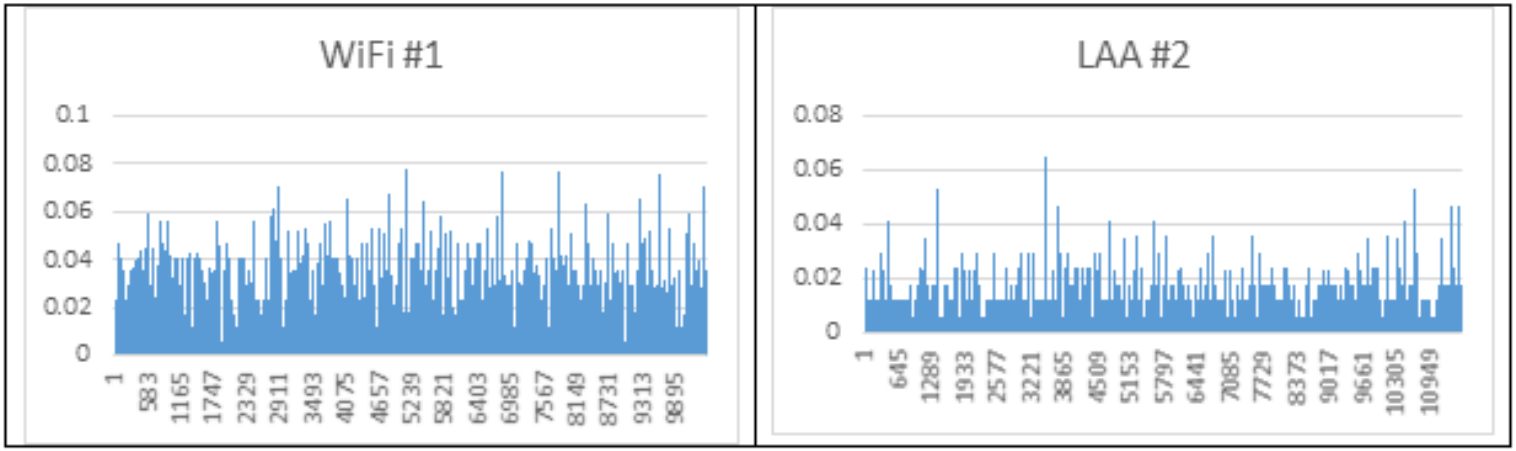
✓ LAA threshold: -65 dBm (from low to high)



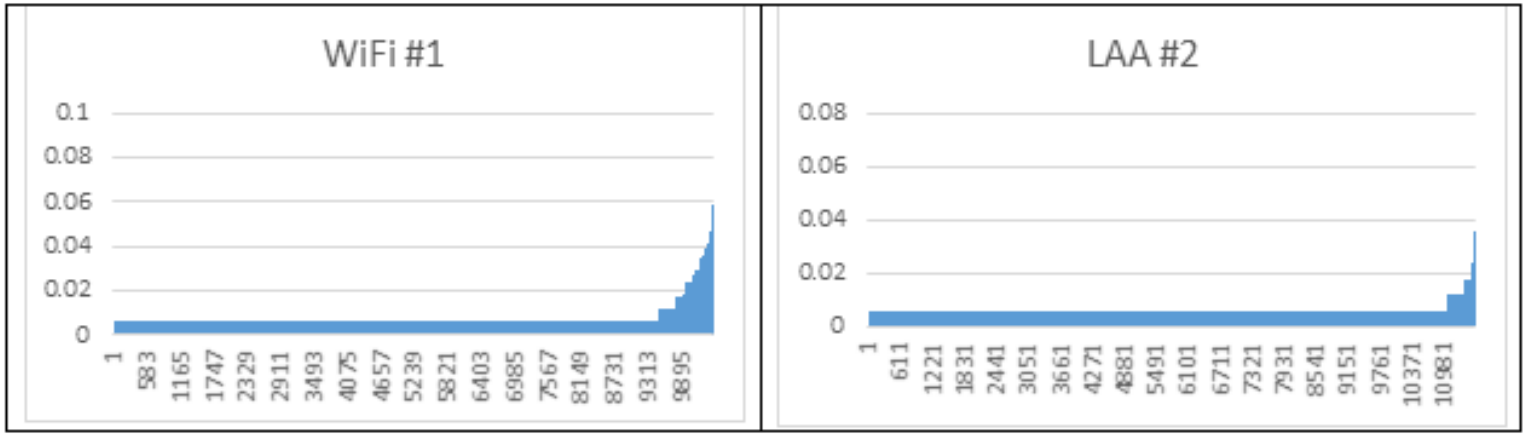
Performance: Case II (Cont'd)

❖Delay for each successful transmission ("New" definition)

✓ LAA threshold: -65 dBm



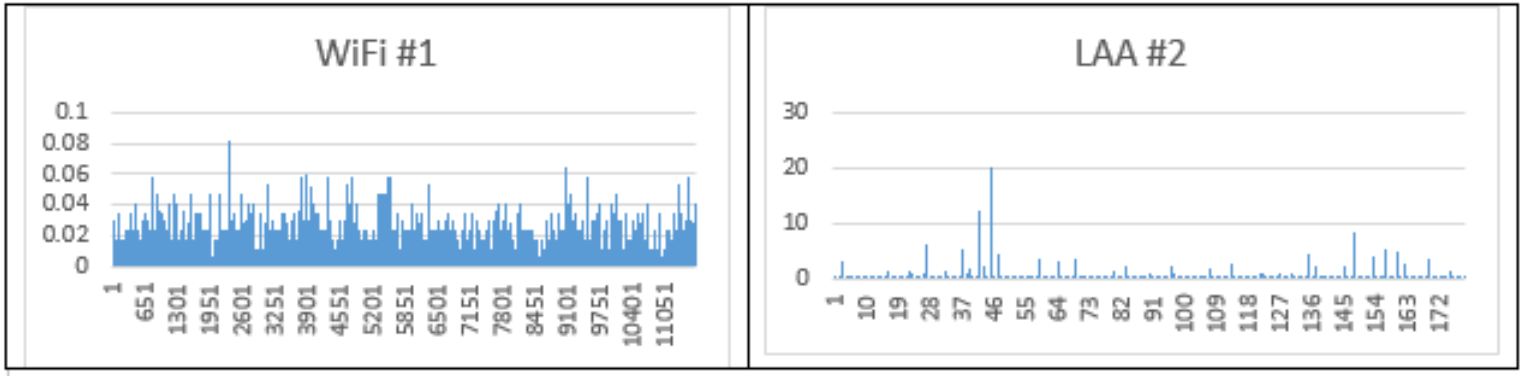
✓ LAA threshold: -65 dBm (from low to high)



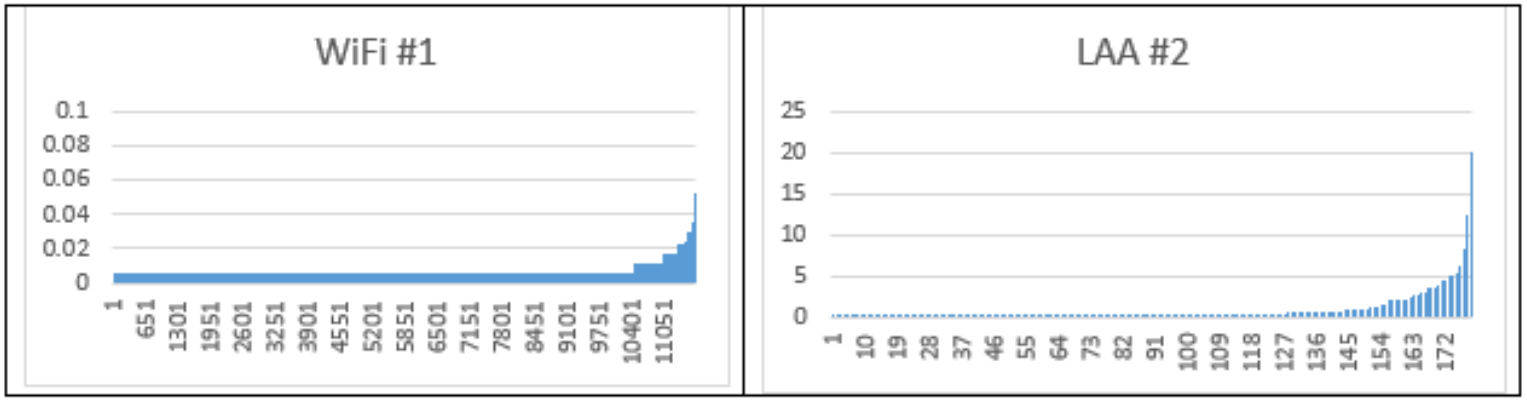
Performance: Case II (Cont'd)

❖Delay for each successful transmission ("New" definition)

✓ LAA threshold: -75 dBm



✓ LAA threshold: -75 dBm (from low to high)



Performance: Case II (Cont'd)

❖Case II: only collisions to LAA, load rate of 0.5

✓ Average delay with original definition (in seconds)

LAA threshold (dBm)	WiFi #1	WiFi #3	LAA #2	LAA #4
-65 dB	0.0048	0.0047	0.0017	0.0017
-70 dB	0.0095	0.0063	28.6761	0.0018
-75 dB	0.0051	0.0049	52.3055	51.6315

✓ Average delay with new definition (in seconds)

LAA threshold (dBm)	WiFi #1	WiFi #3	LAA #2	LAA #4
-65 dB	0.0038	0.0038	0.0037	0.0036
-70 dB	0.0043	0.0040	0.0156	0.0037
-75 dB	0.0039	0.0039	0.0325	0.0327

Performance: Case II (Cont'd)

❖Discussion

- ✓ Delay in the original definition keeps increasing, maybe it is not so suitable for the case of high load rate .
- ✓ The "new" definition of delay looks not so strange. Together with the number of successful transmissions (throughput), it may be a better definition.

Performance with a single user

❖Simulation setting

- ✓ Each AP/eNB has only one user.
- ✓ Each user locates in a circle with a uniform distribution: the center is its associated AP/eNB, and the maximum radius is 15 meters.
- ✓ 802.11ac/LTE SNR requirement (theoretical)

Mapping	Code Rate	Bandwidth	AC Min SNR(dB)	LTE Min SNR(dB)
64QAM	3/4	20 MHz	20	17.5

- ✓ Noise floor in 5G band: -90 dBm

[1] https://en.wikipedia.org/wiki/IEEE_802.11ac
[2] http://www.revolutionwifi.net/revolutionwifi/2014/09/wi-fi-snr-to-mcs-data-rate-mapping.html

Performance with a single user (cont'd)

❖ Load rate of 0.8 (200 trials, each trial last 150 s)

✓ Percentage of time occupation: mean

LAA threshold (dBm)	WiFi #1	WiFi #3	LAA #2	LAA #4
-65	0.3264	0.2000	0.2859	0.3644
-70	0.2795	0.2752	0.2740	0.3366
-75	0.3523	0.2687	0.2247	0.2961

✓ Percentage of time occupation: 10/50/90 %

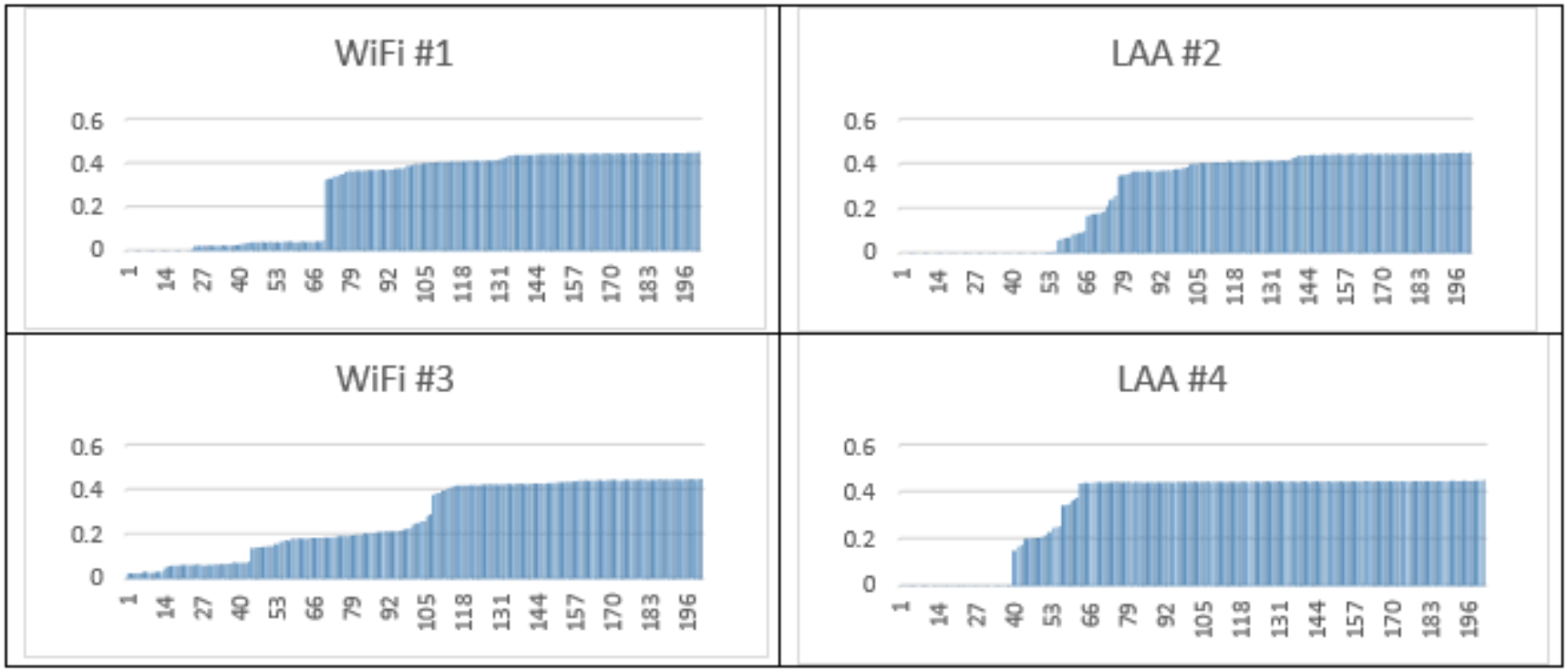
LAA threshold (dBm)	WiFi #1	WiFi #3	LAA #2	LAA #4
-65	0/**0.4411**/0.4471	0/**0.0460**/0.4463	0/**0.4423**/0.4471	0/**0.4431**/0.4488
-70	0/**0.3885**/0.4458	0.0297/**0.2397**/0.4449	0/**0.3805**/0.4468	0/**0.4428**/0.4466
-75	0.0731/**0.4429**/0.4472	0.0711/**0.2388**/0.4459	0/**0.2900**/0.4268	0/**0.3532**/0.4271

✓ Delay: 10/50/90 %

LAA threshold (dBm)	WiFi #1	WiFi #3	LAA #2	LAA #4
-65	0.0060/**0.0066**/NaN	0.0061/**0.1200**/NaN	0.0058/**0.0064**/NaN	0.0058/**0.0062**/NaN
-70	0.0060/**0.0080**/NaN	0.0060/**0.0184**/0.1790	0.0057/**0.0079**/NaN	0.0058/**0.0062**/NaN
-75	0.0058/**0.0064**/0.0733	0.0060/**0.0175**/0.0756	0.0057/**0.0087**/NaN	0.0064/**0.0081**/NaN

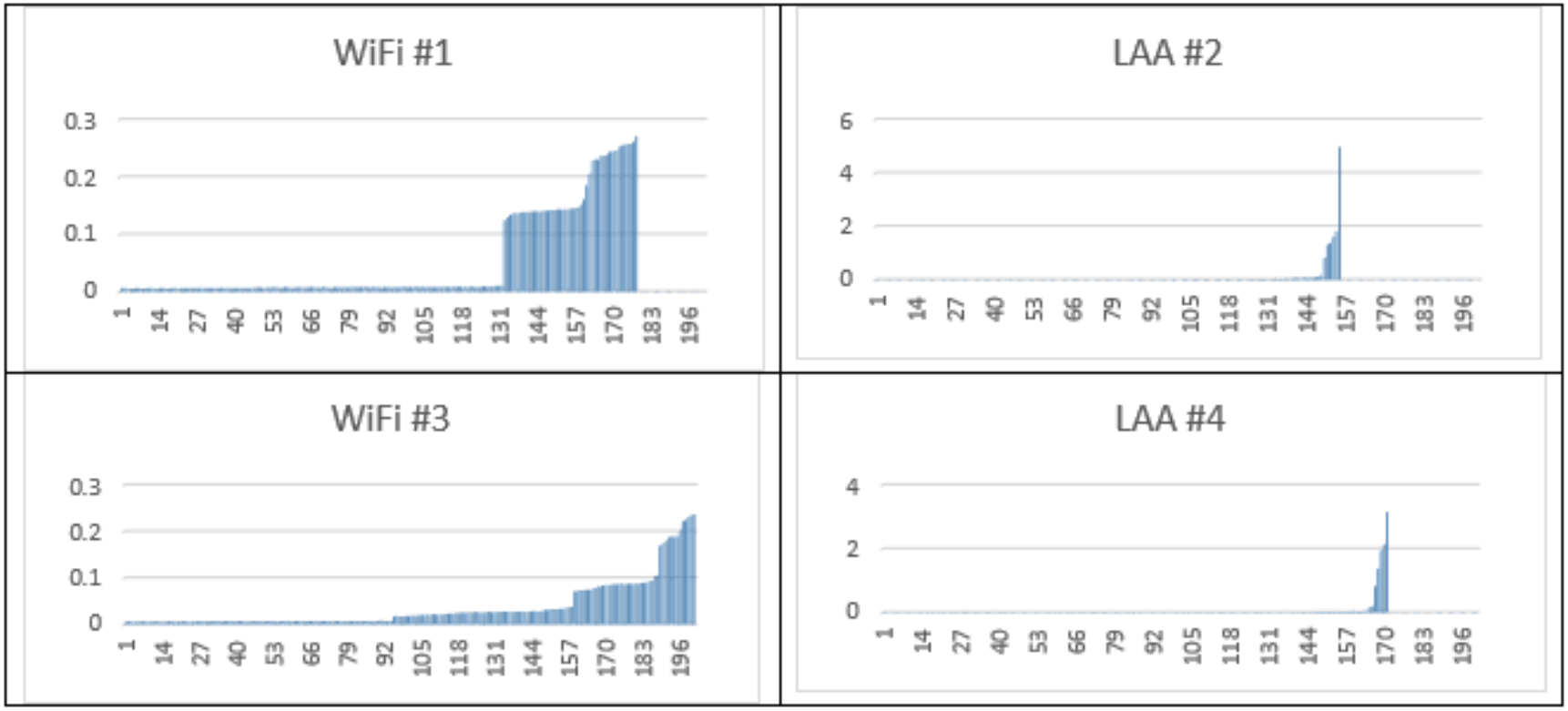
Performance with a single user (cont'd)

❖Average percentage of time occupation for each random dropping, -70 dB (in an increasing order, 200 trials)



Performance with a single user (cont'd)

❖Average delay for each random dropping, -70 dB (in an increasing order, 200 trials)



Performance with a single user (cont'd)

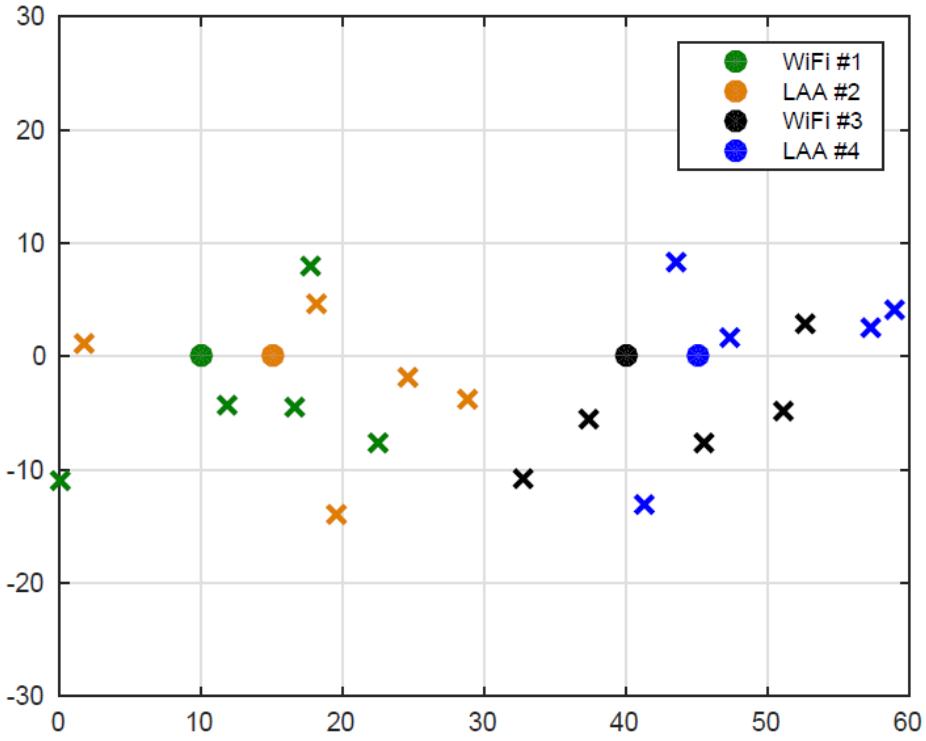
❖Discussion

- ✓ At most of time, LAA and WiFi can coexist with each other pretty well: high percentage of time occupation, low delay.
- ✓ In general, "mean" is a good choice to evaluate the percentage of time occupation (throughput). For delay, how to deal with the case of NaN.
- ✓ The performance highly depends on the layout (location).

Performance with multiple users

❖Simulation setting

✓ Each AP/eNB have five users (One example of the layout.)



✓ Each user has the same probability to access the channel, and they occupy the channel with the same amount of time.

Performance with multiple users (Cont'd)

❖Simulation setting

✓ 802.11ac/LTE theoretical throughput and minimum SNR requirement (20 MHz, normal CP) (AC: MCS 0~11, LTE: MCS 0~14)

Modulation type	Coding Rate	AC SNR	LTE SNR	AC throughput	LTE throughput
QPSK	1/2	5	2.0	14.4	16.8
QPSK	3/4	9	5.5	21.7	25.2
16-QAM	1/2	11	7.9	28.9	33.6
16-QAM	3/4	15	12.2	43.3	50.4
64-QAM	2/3	18	15.3	57.8	67.2
64-QAM	3/4	20	17.5	65	75.6

[1] https://en.wikipedia.org/wiki/IEEE_802.11ac

[2] C. Johnson, "Long Term Evolution IN BULLETS" (Chapter 17.1).

[3] http://www.revolutionwifi.net/revolutionwifi/2014/09/wi-fi-snr-to-mcs-data-rate-mapping.html

Different Location for Users (Cont'd)

- Load rate of 0.8
  - ✓ Average throughput, 802.11ac with MU-MIMO

LAA threshold (dBm)	WiFi #1	WiFi #3	LAA #2	LAA #4
-65	26.88	13.23	22.55	31.96
-70	24.67	18.64	20.42	31.72
-75	28.65	20.31	16.21	24.05

  - ✓ Average throughput, 802.11ac without MU-MIMO

LAA threshold (dBm)	WiFi #1	WiFi #3	LAA #2	LAA #4
-65	21.86	20.67	24.53	22.76
-70	23.65	19.87	22.30	23.13
-75	24.18	24.77	18.68	20.58

Performance with a single user (cont'd)

❖Discussion

- ✓ With MU-MIMO, the sum throughput is higher, since there is less overhead caused by CSMA/CA.
- ✓ With MU-MIMO, it's possible to support higher load rate (for example, each user with a load rate of 0.8). In this case, AC will have more advantages.
- ✓ To evaluate the performance of delay, we should assume each user has the same amount of data to be received. Different locations lead to different MCS.

Next steps

- ✓ Continue to think about the simulation of LAA/WiFi with multiple users;
- ✓ Try to get more theoretic analysis.
- ✓ Study the case when there are multiple subchannels.