Cisco Cooperative Project

COEXISTENCE OF WIFI AND LAA: SIMULATION RESULTS & DISCUSSION

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Jan. 29, 2016

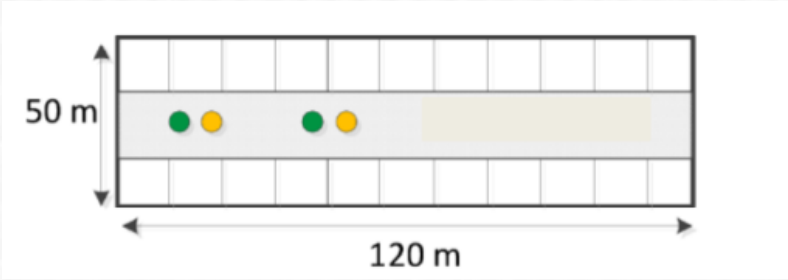
Outline

- Review & Discussion
- Simulation results with multiple users
- Next Step

Review & Discussion: Delay vs Load ratio

❖Simulation Setting

- ✓ 2 APs, 2 eNBs, each AP has one client, and each eNB has one user

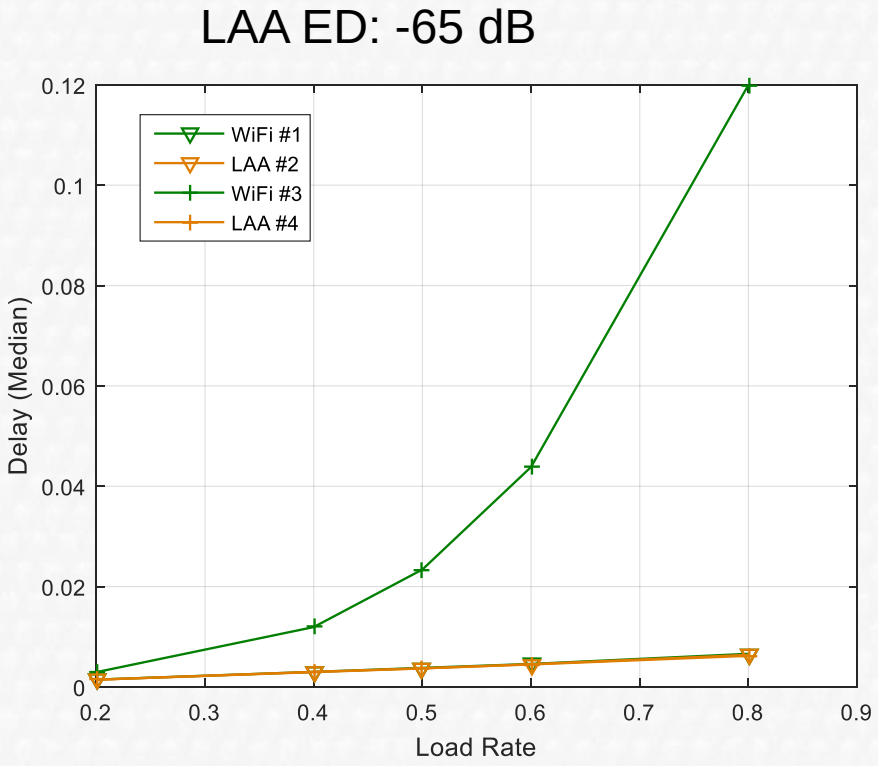


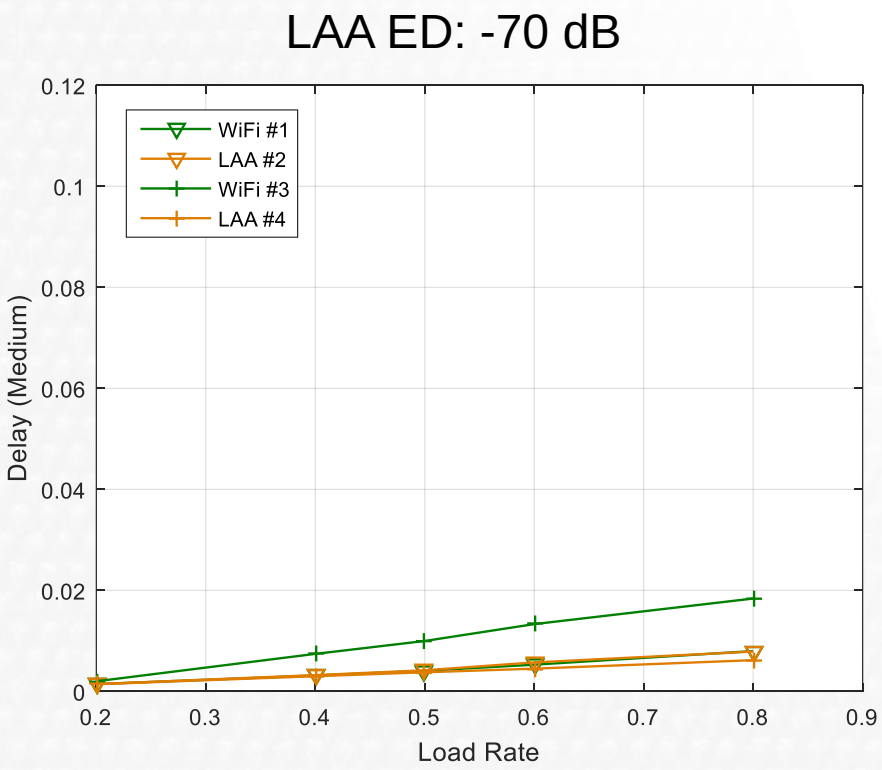
- ✓ Load ratio: 0.2/0.4/0.5/0.6/0.8
- ✓ LAA energy detection threshold: -65/-70 dBm
- ✓ LAA SNR threshold: 17.5; WiFi SNR threshold: 20 dB
- ✓ Definitions of delay: delay = [time of successful receiving – time of ready to be transmitted];
- ✓ Transmit power: 18 dBm, Path loss model

$$PL = 43.3\log_{10}(d) + 11.5 + 20\log_{10}(f_c)$$

Review & Discussion: Delay vs Load ratio

❖Delay versus Load ratio (median)



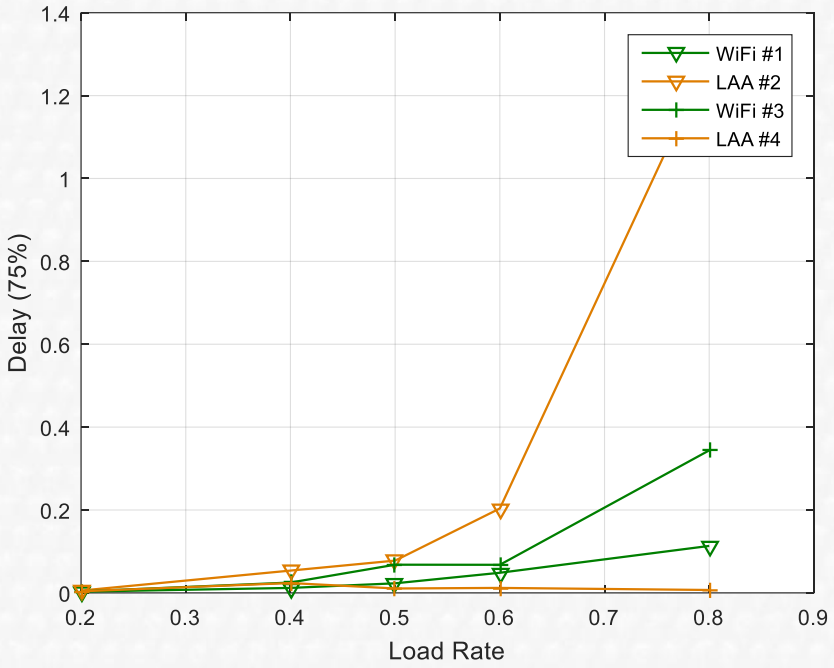


Delay increases quickly at low LAA ED.

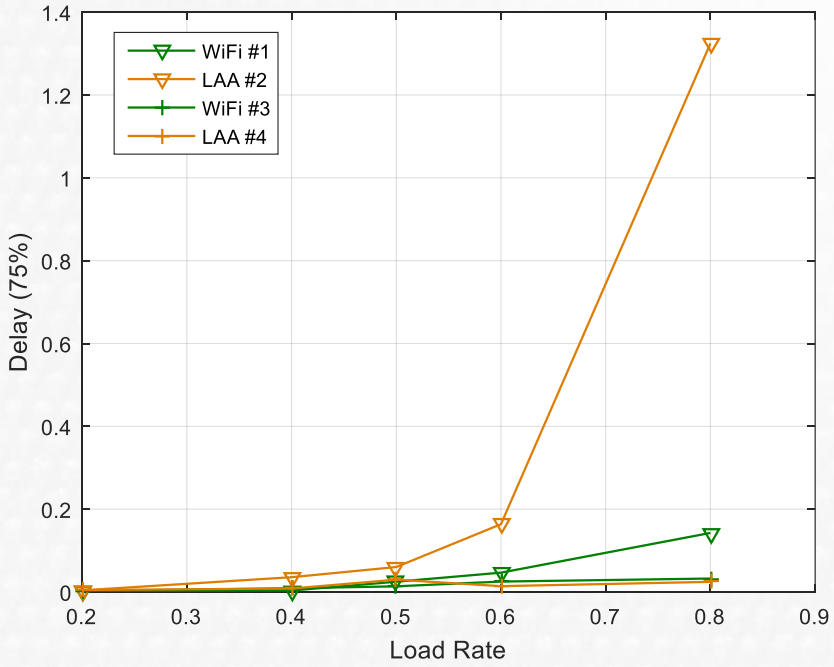
Review & Discussion: Delay vs Load ratio

❖Delay versus Load ratio (75th-percentile)

LAA ED: -65 dB



LAA ED: -70 dB

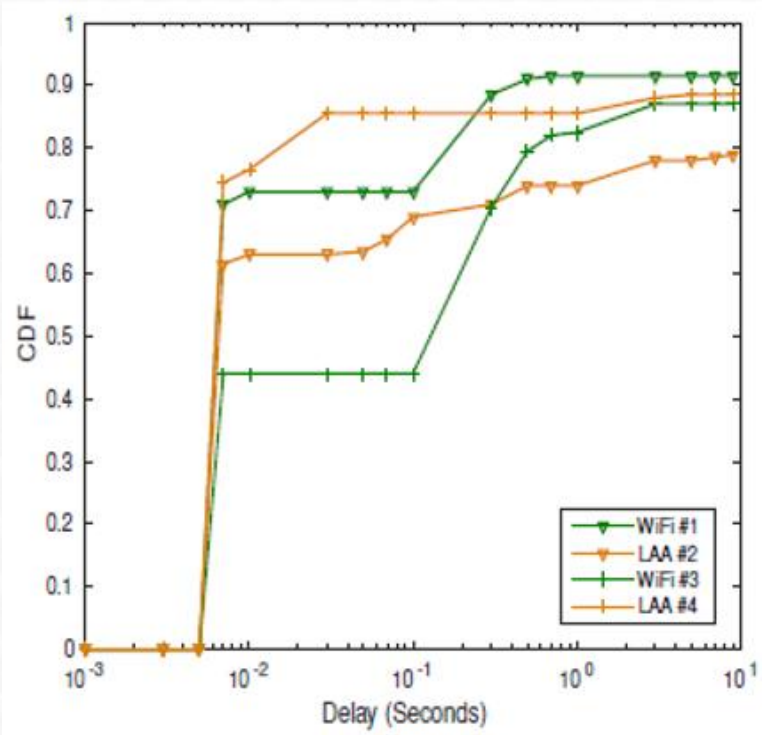


Delay increases quickly at low LAA ED, but the difference is not so large.

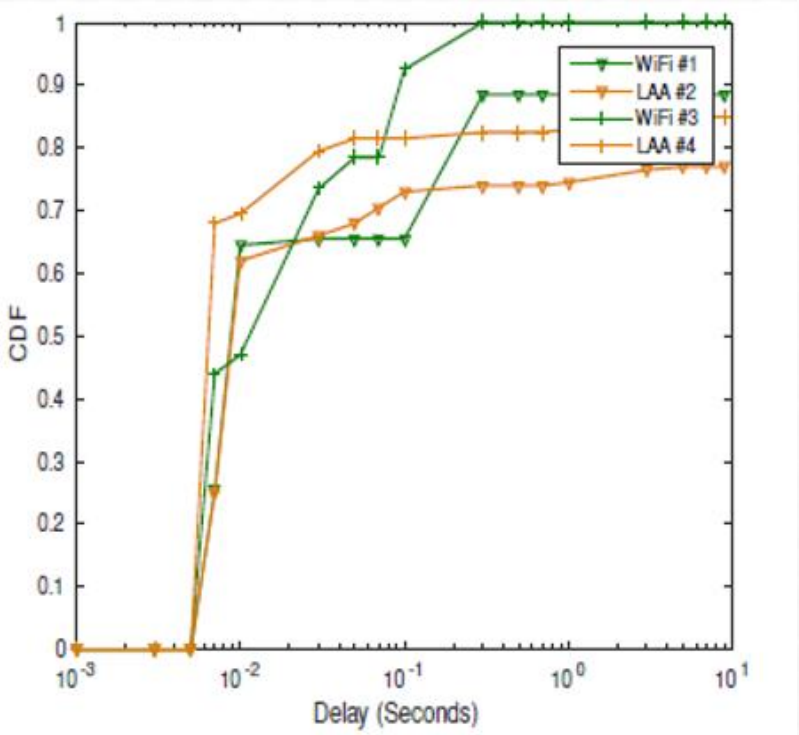
Review & Discussion: Delay vs Load ratio

❖CDF of delay at the load ratio of 0.8

LAA ED: -65 dB



LAA ED: -70 dB

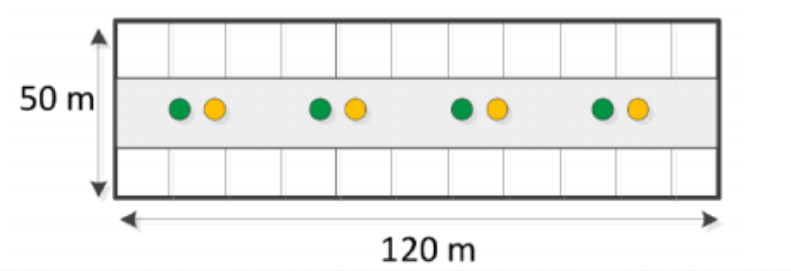


For WiFi, the probability of large delay (infinite value) is decreasing.

Review & Discussion: Threshold

❖Simulation Setting

- ✓ 4 APs, 4 eNBs, each AP has one client, and each eNB has one user



- ✓ Load ratio: 0.8
- ✓ LAA energy detection threshold: -65/-70/-75 dBm or different thresholds for different LAA
- ✓ LAA SNR threshold: 17.5; WiFi SNR threshold: 20 dB

Review & Discussion: Threshold

❖Percentage of time occupation

✓ Load ratio of 0.8

- Average percentage of time occupation

LAA threshold (dBm)	WiFi	LAA	WiFi (#1)	WiFi (#3)	WiFi (#5)	WiFi (#7)	LAA (#2)	LAA (#4)	LAA (#6)	LAA (#8)
-65	0.7695	0.9903	0.3557	0.0922	0.1135	0.2080	0.2925	0.1855	0.1770	0.3353
-70	0.9203	1.0265	0.2915	0.1587	0.1790	0.2911	0.2864	0.1947	0.1775	0.3679
-75	1.1362	0.7790	0.4017	0.1704	0.2443	0.3199	0.2603	0.0831	0.0826	0.3530

LAA threshold (dBm)	WiFi	LAA	WiFi (#1)	WiFi (#3)	WiFi (#5)	WiFi (#7)	LAA (#2)	LAA (#4)	LAA (#6)	LAA (#8)
-70,-65,-65,-70	0.7891	0.9444	0.3234	0.1303	0.1399	0.1955	0.2806	0.1857	0.1616	0.3165
-75,-65,-65,-75	0.7494	0.7705	0.3021	0.1501	0.0892	0.2080	0.1962	0.2057	0.1645	0.2041
-75,-70,-70,-75	0.9786	0.9026	0.3028	0.1626	0.2144	0.2988	0.2377	0.2382	0.1339	0.2928
-65,-70,-70,-65	0.9218	1.0109	0.3346	0.1432	0.1602	0.2838	0.2868	0.2018	0.1867	0.3356
-65,-75,-75,-65	1.2553	0.7446	0.4244	0.1662	0.2765	0.3881	0.2811	0.0503	0.0453	0.3679

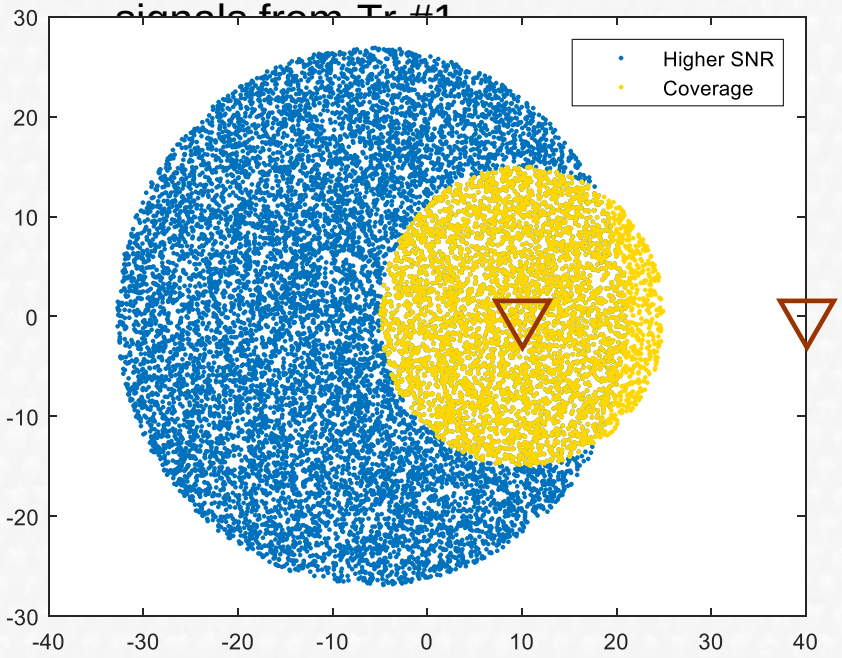
Which one is “best”?

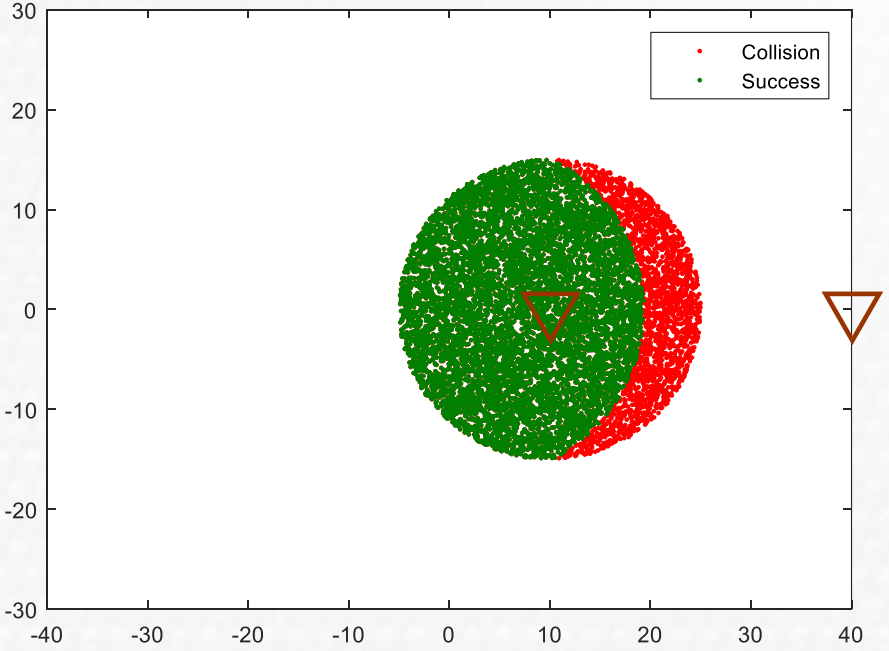
Review & Discussion: Threshold

❖Simultaneous transmission is good or not?

✓ Two transmitters (25 meters away) transmit data at the same time, SNR threshold: 15 dB

- Left figure: yellow region: the coverage of Tr #1; blue region: Received power from Tr #1/Received power from Tr #2 > 10^1.5 (only consider path loss, a circle)
- Right figure: Green/Red region: the region that users can/cannot successfully detect signals from Tr #1





Review & Discussion: Threshold

❖Simultaneous transmission is good or not?

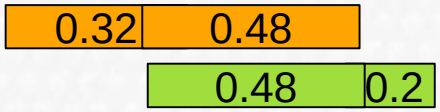
✓ Collision probability:

- 25/30 meters away, SNR_{th}= 20 dB: p_{col} = 0.58/0.40
- 25/30 meters away, SNR_{th}= 17.5 dB: p_{col} = 0.41/0.30

✓ Two pairs (#1: WiFi, #2: LAA), 30 meters away

- No simultaneous transmission: p_{e1} = 0.5; p_{e2} = 0.5.
- Both transmit all the time: p_{e1} = 1-0.4 = 0.6; p_{e2} = 1-0.3 = 0.7
- Both WiFi and LAA Transmit according to the users location

$$\begin{cases} p_1 * 0.4 + p_2 * 0.3 + p_{12} = 1 \\ p_{12} \le 0.6 p_1 \\ p_{12} \le 0.7 p_2 \end{cases} \rightarrow \begin{cases} p_{e1\_} p_1 = 0.8 \\ p_{e2\_} p_2 = 0.68 \\ p_{12} = 0.48 \end{cases}$$



Review & Discussion: Threshold

❖Simultaneous transmission is good or not?

- Only LAA Transmit according to the users location (according to the feedback of SNR)

$$\begin{cases} p_1 + 0.3p_2 = 1 \\ p_{12} \le 0.7p_2 \end{cases} \rightarrow \begin{cases} p_1 = 0.9 \\ p_2 = 0.33 \end{cases} \rightarrow \begin{cases} p_{e1\_1\_} p_2 + 0.6p_{12} = 0.81 \\ p_{e2\_} p_2 = 0.33 \end{cases}$$

$$\rightarrow \begin{cases} p_1 = 0.8 \\ p_2 = 0.68 \end{cases} \rightarrow \begin{cases} p_{e1\_1\_} p2 + 0.6p_{12} = 0.61 \\ p_{e2\_} p_2 = 0.68 \end{cases}$$

- For the nodes in the middle, the collision probability may be higher than the successful transmission probability. The LAA nodes in the margin prefer to have a high ED, and LAA nodes in the middle prefer to have low ED? (-65,-75.-75,-65). However, it may be not fair (how to add this constraint?).

1.76	1.95	1.92	1.73	1.52	1.88	1.93	1.99

Results: Multiple Users

❖Simulation setting

- ✓ Operator A: 4 APs, Operator B: 4 eNBs (APs), and each AP/eNB has five users
- ✓ 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

- ✓ CW is updated if NACK is received from all users

Results: Multiple Users

❖Throughput, Load ratio of 0.8

- Operator A: WiFi #1,3,5,7; Operator B: WiFi # 2,4,6,8

WiFi A	WiFi B	WiFi (#1)	WiFi (#3)	WiFi (#5)	WiFi (#7)	WiFi (#2)	WiFi (#4)	WiFi (#6)	WiFi (#8)
13.96	13.94	20.14	8.44	9.26	18.02	17.89	9.47	8.16	20.23

- Operator A: WiFi #1,3,5,7; Operator B: LAA # 2,4,6,8 (MCS 1~6)

LAA threshold (dBm)	WiFi	LAA	WiFi (#1)	WiFi (#3)	WiFi (#5)	WiFi (#7)	LAA (#2)	LAA (#4)	LAA (#6)	LAA (#8)
-65	23.22	26.35	30.84	16.00	17.03	29.03	27.15	27.55	25.11	25.58
-70	23.67	27.02	32.89	14.35	19.15	28.31	27.72	28.10	25.80	26.47
-75	26.94	18.68	32.49	22.13	20.71	32.41	25.24	15.00	13.26	21.23

- Operator A: WiFi #1,3,5,7; Operator B: LAA # 2,4,6,8 (MCS 6)

LAA threshold (dBm)	WiFi	LAA	WiFi (#1)	WiFi (#3)	WiFi (#5)	WiFi (#7)	LAA (#2)	LAA (#4)	LAA (#6)	LAA (#8)
-65	17.93	21.88	26.59	12.99	12.27	19.88	21.87	22.75	17.29	25.58
-70	17.33	20.67	27.49	9.14	11.79	20.90	18.69	18.44	20.81	24.75
-75	24.75	11.22	32.52	16.93	18.80	30.76	13.76	7.27	6.05	17.80

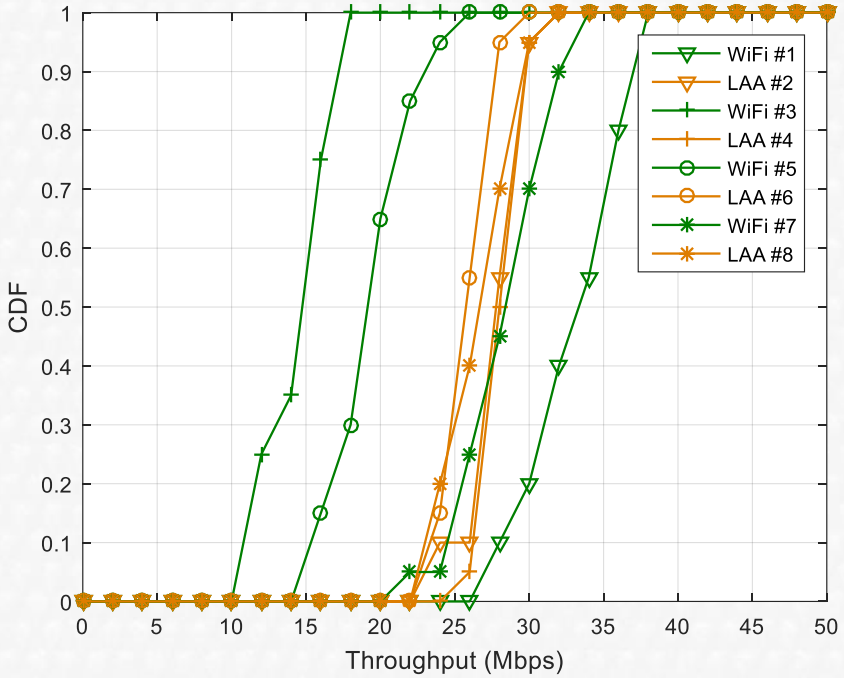
Results: Multiple Users

- With 8 WiFi APs, it is fair to the overall performance, however, it is also unfair to the APs in the middle;
- If Operator B is LAA, both Operator A and Operator B's performance are improved, since there is no competition among LAA users (ideal scheduling);
- Analyses in the case of multiple users and mixed MCS will be more difficult.

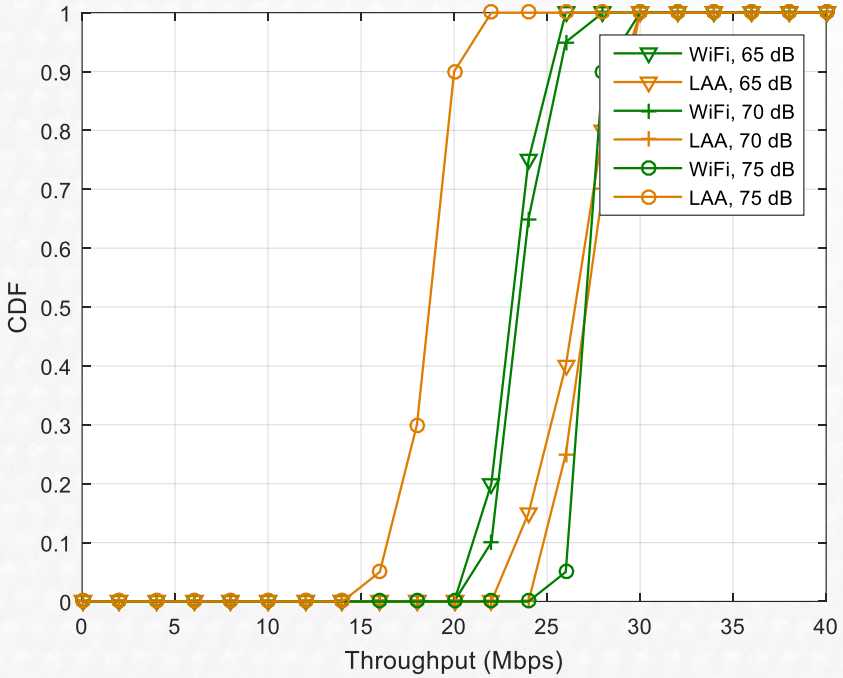
Results: Multiple Users

❖Throughput in CDF, Load ratio of 0.8

✓ Operator B: LAA (MCS 1-6, -70 dB)



✓ Operator B: LAA (MCS 1-6, Overall)



Results: Multiple Users

❖Delay, Load ratio of 0.8

- Operator A: WiFi #1,3,5,7; Operator B: WiFi # 2,4,6,8

WiFi A	WiFi B	WiFi (#1)	WiFi (#3)	WiFi (#5)	WiFi (#7)	WiFi (#2)	WiFi (#4)	WiFi (#6)	WiFi (#8)
105.25	102.42	59.74	149.94	140.33	70.98	70.72	121.60	157.91	59.45

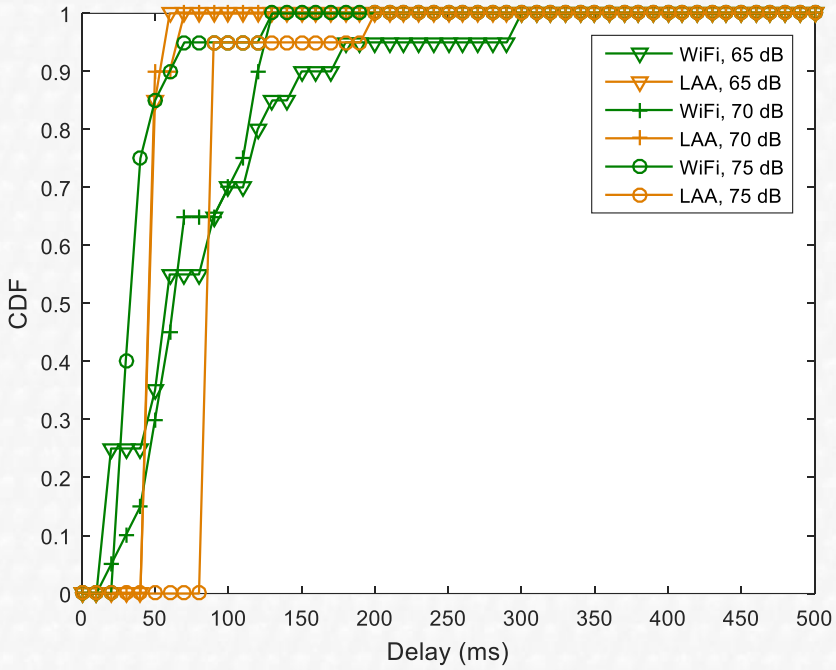
- Operator A: WiFi #1,3,5,7; Operator B: LAA # 2,4,6,8 (MCS 1~6)

LAA threshold (dBm)	WiFi	LAA	WiFi (#1)	WiFi (#3)	WiFi (#5)	WiFi (#7)	LAA (#2)	LAA (#4)	LAA (#6)	LAA (#8)
-65	81.95	49.89	18.40	138.32	93.69	77.38	47.61	52.66	52.66	46.65
-70	71.73	46.80	22.79	163.26	61.39	39.50	43.17	51.87	43.88	48.30
-75	38.74	85.65	23.42	64.60	35.16	31.76	78.78	100.79	111.40	51.64

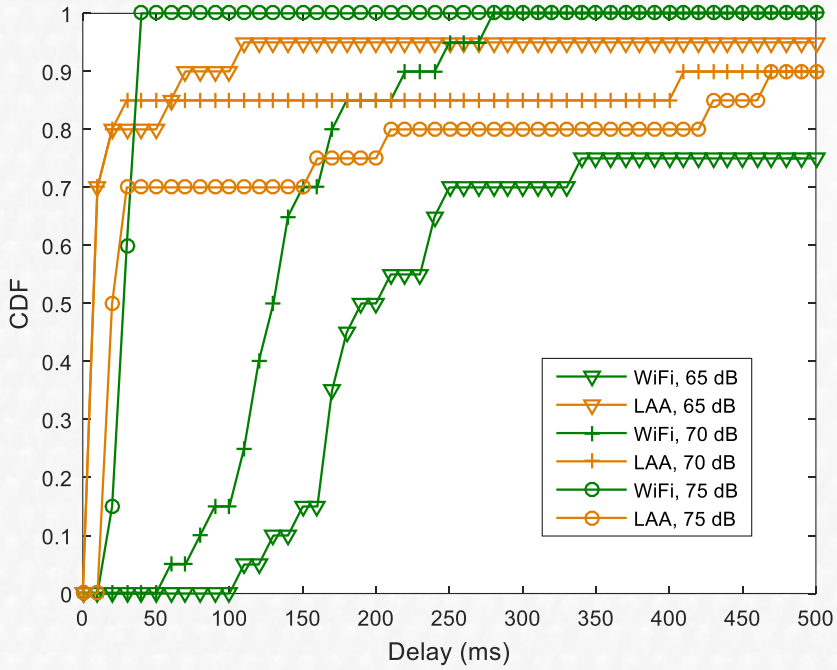
Results: Multiple Users

❖Delay, Load ratio of 0.8

- Operator B: LAA(MCS 1-6)



- Operator B: LAA (MCS 6)



For MCS 6, it is possible that some users will never get a chance to successfully access the channel.

Results: Multiple Users

❖Throughput, Load ratio of 0.5

- Operator A: WiFi #1,3,5,7; Operator B: WiFi # 2,4,6,8

WiFi A	WiFi B	WiFi (#1)	WiFi (#3)	WiFi (#5)	WiFi (#7)	WiFi (#2)	WiFi (#4)	WiFi (#6)	WiFi (#8)
13.24	13.49	18.20	8.43	9.03	17.31	17.40	9.60	8.09	18.86

- Operator A: WiFi #1,3,5,7; Operator B: LAA # 2,4,6,8 (MCS 1~6)

LAA threshold (dBm)	WiFi	LAA	WiFi (#1)	WiFi (#3)	WiFi (#5)	WiFi (#7)	LAA (#2)	LAA (#4)	LAA (#6)	LAA (#8)
-65	22.62	20.94	26.44	19.78	19.10	25.18	21.49	21.05	20.10	21.12
-70	23.18	20.90	27.27	20.66	19.14	25.66	21.56	21.19	19.39	21.45
-75	24.05	17.29	27.31	21.58	20.85	26.46	20.20	16.06	13.48	19.45

Results: Multiple Users

❖Delay (ms), Load ratio of 0.5

- Operator A: WiFi #1,3,5,7; Operator B: WiFi # 2,4,6,8

WiFi A	WiFi B	WiFi (#1)	WiFi (#3)	WiFi (#5)	WiFi (#7)	WiFi (#2)	WiFi (#4)	WiFi (#6)	WiFi (#8)
61.19	62.01	35.19	88.95	81.52	39.13	36.67	80.29	97.59	33.52

- Operator A: WiFi #1,3,5,7; Operator B: LAA # 2,4,6,8 (MCS 1~6)

LAA threshold (dBm)	WiFi	LAA	WiFi (#1)	WiFi (#3)	WiFi (#5)	WiFi (#7)	LAA (#2)	LAA (#4)	LAA (#6)	LAA (#8)
-65	30.82	33.27	8.67	43.17	52.36	19.28	32.64	32.62	33.12	32.64
-70	21.86	33.16	9.89	26.30	36.09	15.03	27.98	30.81	29.63	32.15
-75	18.49	44.37	10.92	26.63	20.81	15.23	40.96	49.25	53.12	34.23

The difference is not large in throughput; the difference is obvious in delay. (The channel is overloaded at the load ratio of 0.8.)

Next steps

- Continue to think about some adaptive algorithms for LAA ED
- Continue to think about the scheduling of transmissions to users at different locations