Cisco Cooperative Project

COEXISTENCE OF WIFI AND LAA: REVIEW & DISCUSSION

Students: Li Li

Advisors: Len Cimini, Chien-Chung Shen

Feb. 11, 2016

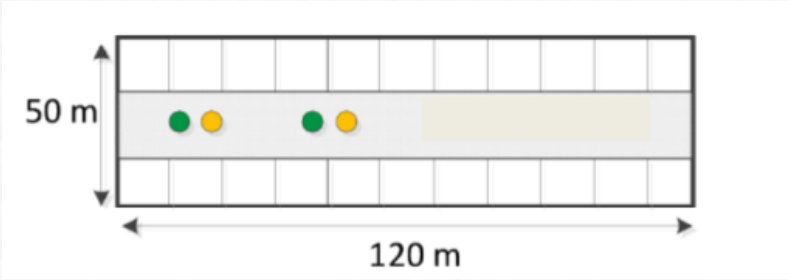
Outline

- Review & Discussion
  - ✓ Delay vs load ratio
  - ✓ Different thresholds
- Results with multiple users: Matlab
- Next Step
- Appendix
  - ✓ NS-3 results
  - ✓ Results from other companies

Review & Discussion: Delay vs Load ratio

❖Simulation Setting

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



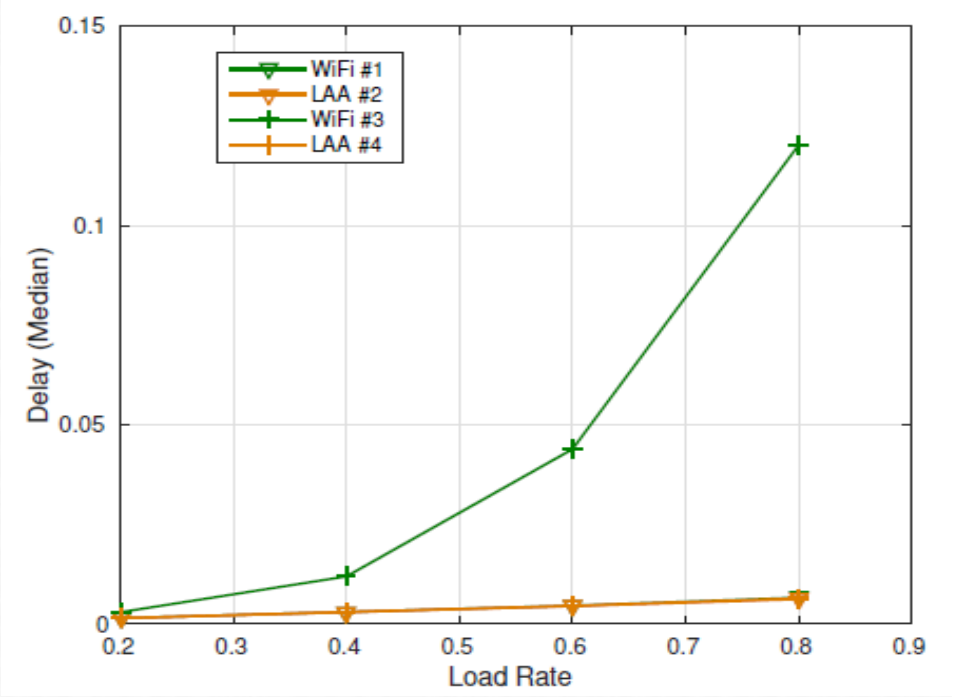
- ✓ Load ratio: 0.2/0.4/0.6/0.8
- ✓ LAA energy detection threshold: -65/-70/-75 dBm
- ✓ LAA SNR threshold: 17.5 dB; WiFi SNR threshold: 20 dB
- ✓ Definitions of delay: delay = [time of successful receiving – time of ready to be transmitted];
- ✓ Transmit power: 18 dBm, Path loss model

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

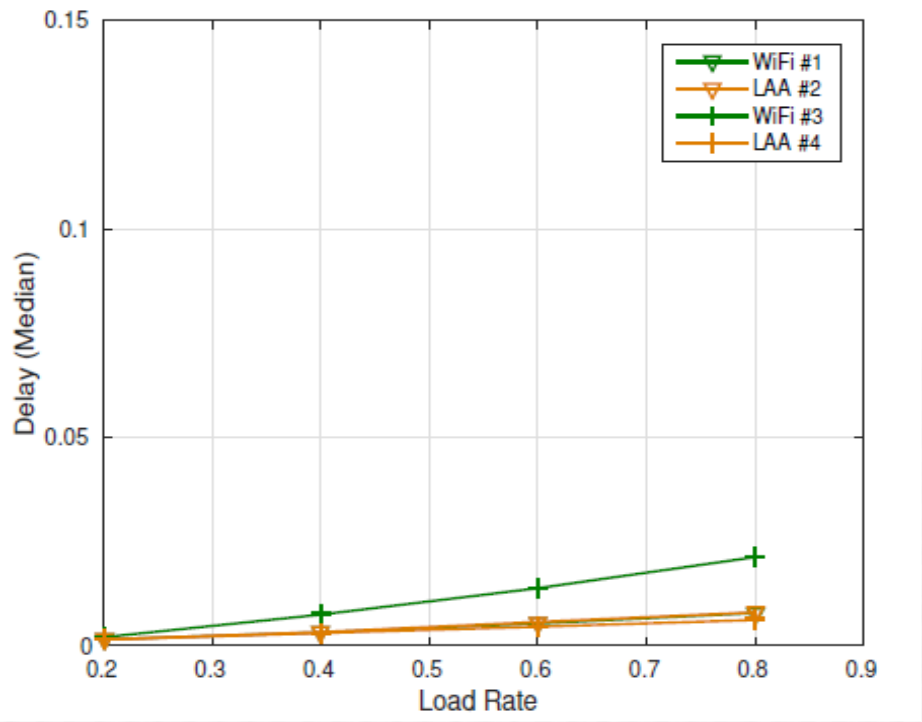
Review: Delay vs Load ratio

❖Median value, from -65 dBm to -70 dBm

LAA ED: -65 dBm



LAA ED: -70 dBm



- ✓ At -65 dBm, only WiFi #3's performance is much worse than others;
- ✓ From -65 dBm to -70 dBm, WiFi #3's performance is improving.

Discussion: Delay vs Load ratio

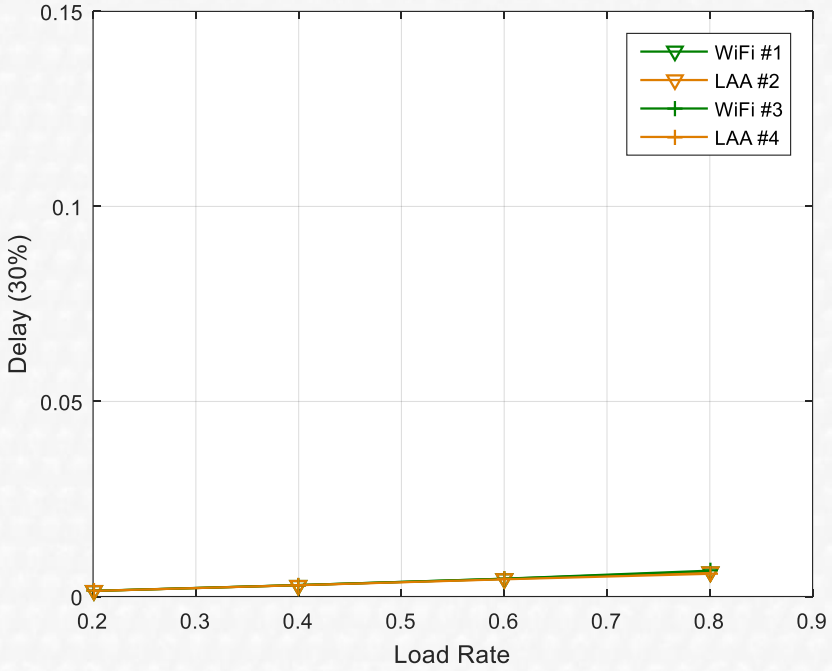
- From -65 dBm to -70 dBm, WiFi #3's performance is improving
  - ✓ At -70 dBm, LAA #2 can detect WiFi #3's transmissions, then, it will cause less interference to the users near the border of WiFi #3. Thus, WiFi #3's performance is improving.

- At -65 dBm, only WiFi #3's performance is much worse than others (???)

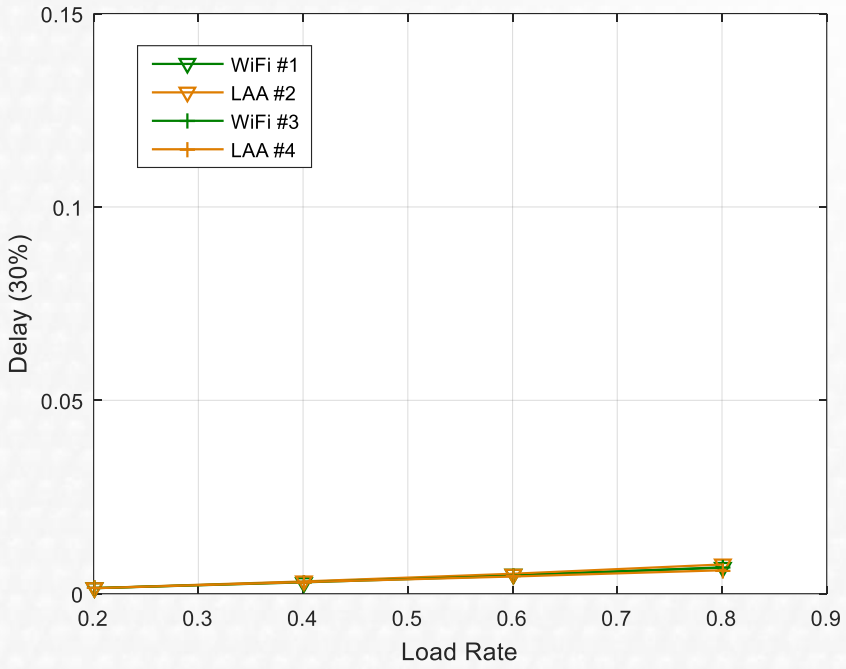
Review: Delay vs Load ratio

❖30-percentile value, from -65 dBm to -70 dBm

LAA ED: -65 dBm



LAA ED: -70 dBm



All APs and eNBs almost have the same performance.

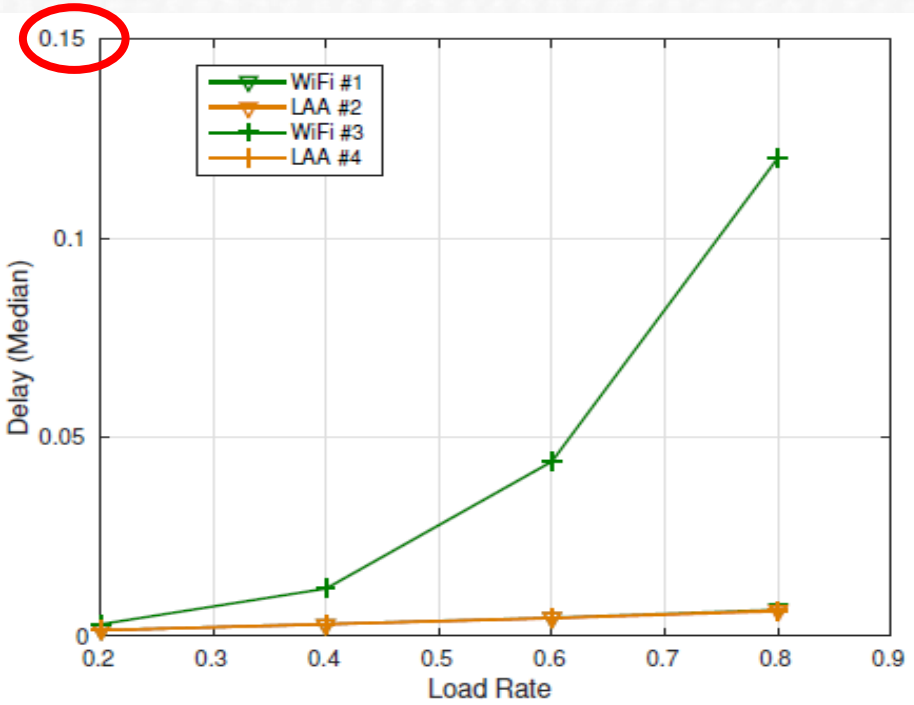
Discussion: Delay vs Load ratio

- At -65 dBm, for 30-percentile value, all nodes have similar performance; for median value, WiFi #3's performance is much worse than others
  - ✓ The users are randomly located in a circle, at "good" locations, SNR would be high enough even with interference; at "bad" locations, other neighbor nodes' transmissions will cause collisions.
  - ✓ At -65 dBm, LAA #2 and WiFi #3 cannot block each other.
  - ✓ For 30-percentile values, all users are still at "good" locations (i.e., users can decode signals successfully even with interference): all of them have similar performance.
  - ✓ For median values, WiFi #3's user may be at "not-so-good" locations (25 meters away, SNR_{th} = 20/17.5 dB, p_{col} = 0.58/0.41): WiFi #3's performance is the worst one.
- From -65 dBm to -70 dBm, for median value, WiFi #3's performance is improving.
  - ✓ At -70 dBm, LAA #2 will backoff if WiFi #3 transmits first; WiFi #3 will still transmit if LAA #2 transmits first: WiFi #3's performance improves but still the worst one.

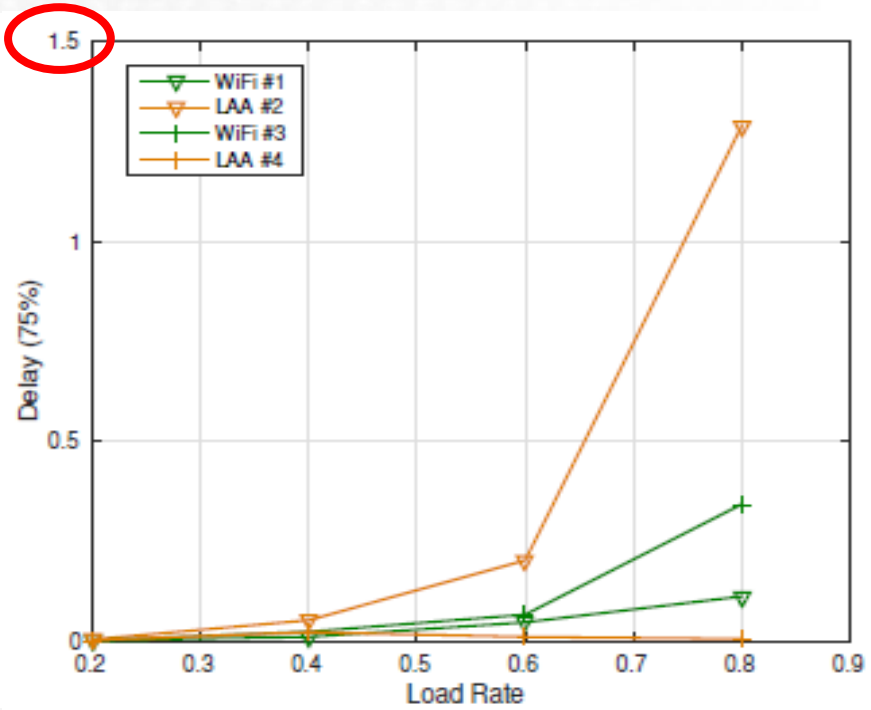
Review: Delay vs Load ratio

❖Different trend for median and 75-percentile value (-65 dBm)

Median



75 percentile



For median value, WiFi #3's performance is much worse than others; but for 75-percentile value, LAA #2's performance is the worst one. (Note that, the plots have different scales in Y-axis)

Discussion: Delay vs Load ratio

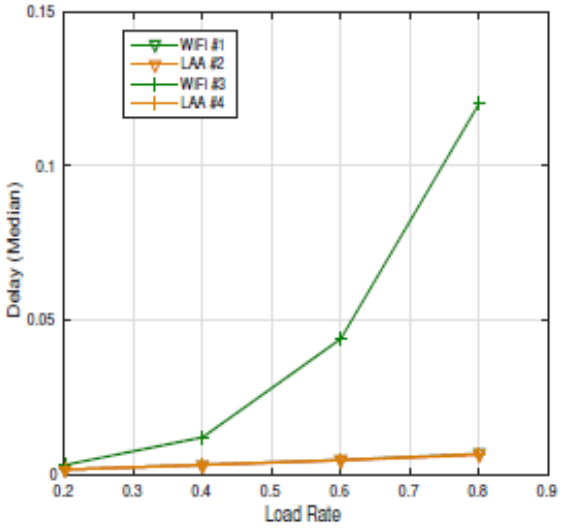
- For 75-percentile value, LAA #2's performance is the worst one; WiFi #3's performance is also bad but not so bad.
  - ✓ At -65 dBm, LAA #2 and WiFi #3 cannot block each other.
  - ✓ For 75-percentile values, users are at "bad" locations. LAA #2 suffers interference from both WiFi #3 and LAA #4; WiFi #3 only suffers interference from LAA #2 (WiFi #1 and WiFi #3 will block each other)

Due to SNR threshold, WiFi #3 will suffer from performance loss first; then, due to collisions, LAA #2 will get an even worse performance at a later time.

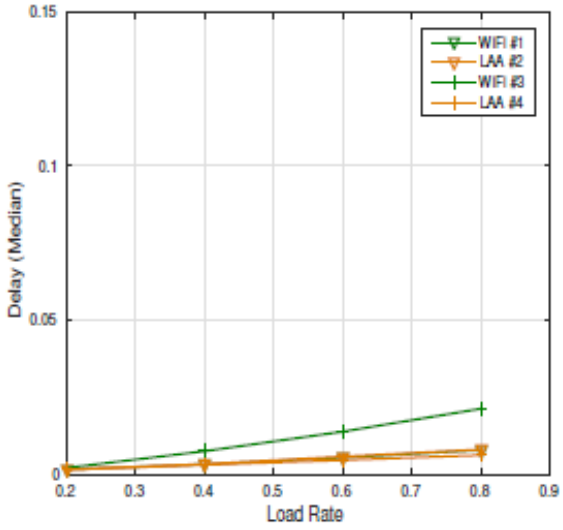
Review: Delay vs Load ratio

❖Median value, from -65 dBm to -75 dBm

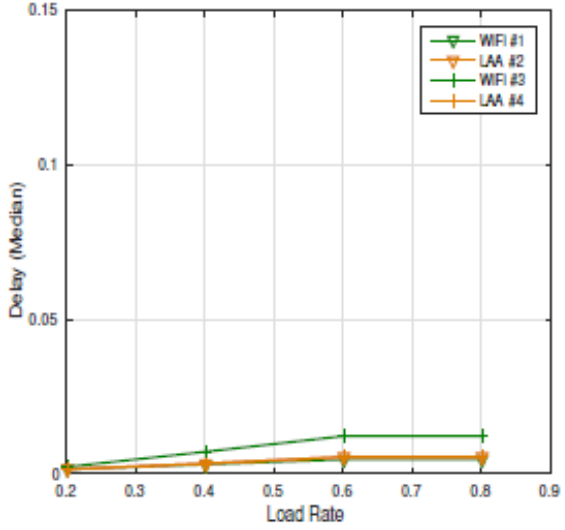
LAA ED: -65 dBm



LAA ED: -70 dBm



LAA ED: -75 dBm

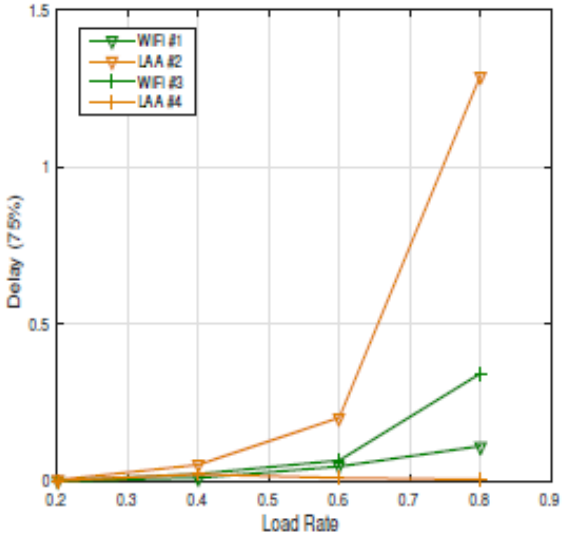


The performance is even better at -75 dBm.

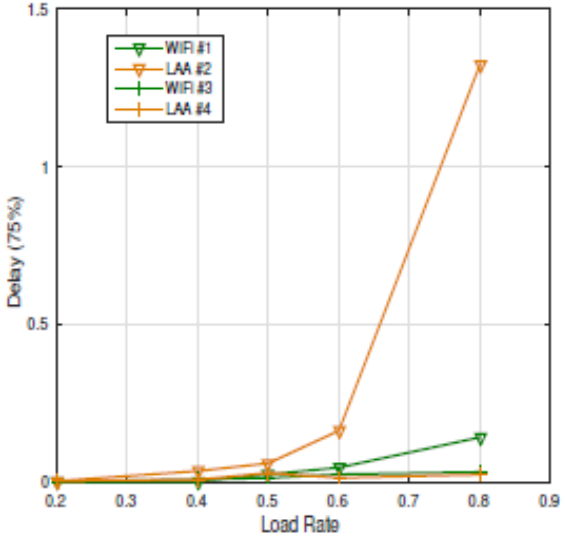
Review: Delay vs Load ratio

❖75-percentile value, from -65 dBm to -75 dBm

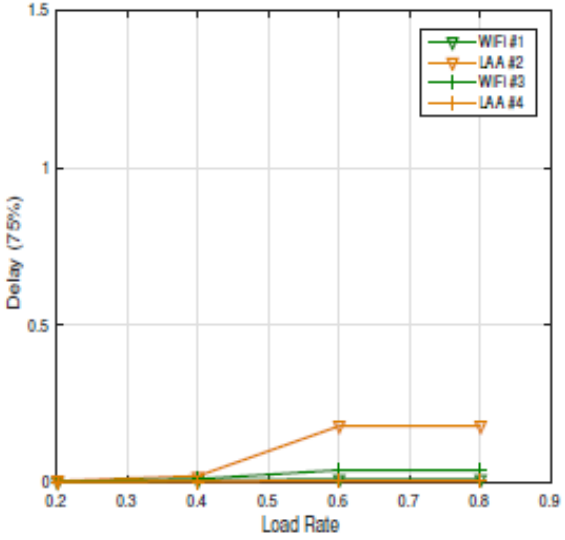
LAA ED: -65 dBm



LAA ED: -70 dBm



LAA ED: -75 dBm



The performance is even better at -75 dBm.

Review: Delay vs Load ratio

❖Number of successful transmissions and collisions (mean, load ratio of 0.8)

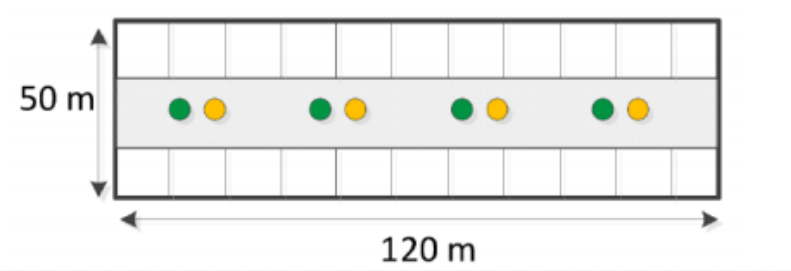
	# of successful transmissions				# of collisions			
ED	WiFi 1	WiFi 3	LAA 2	LAA 4	WiFi 1	WiFi 3	LAA 2	LAA 4
-65	8499	5209	7446	9490	2722	5011	5546	3429
-70	7469	6569	6510	8925	3014	4346	3624	3890
-75	9118	6576	5640	8056	2917	4798	1680	1156

- ✓ At -75 dBm, LAA #4 can be blocked by WiFi # 1's transmissions (WiFi #3 blocks LAA #2 at -70 dBm).
- ✓ LAA #2 and LAA #4 will also block each other.
- ✓ Low ED means the transmitting opportunity decreases, but collisions also decreases. For example, no collisions between #2 and #4.
- ✓ The measured delay is the delay for successfully transmitted packages, so the delay performance may be even better at -75 dBm.

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

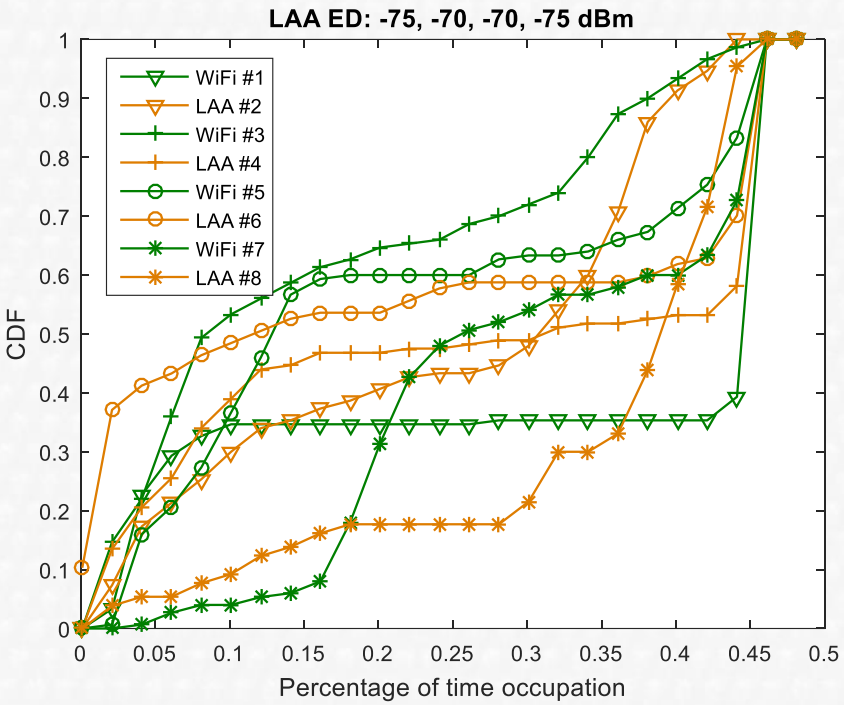
LAA threshold (dBm)	WiFi	LAA	WiFi (#1)	WiFi (#3)	WiFi (#5)	WiFi (#7)	LAA (#2)	LAA (#4)	LAA (#6)	LAA (#8)
-65	0.7695	0.9903	0.3557	0.0922	0.1135	0.2080	0.2925	0.1855	0.1770	0.3353
-70	0.9203	1.0265	0.2915	0.1587	0.1790	0.2911	0.2864	0.1947	0.1775	0.3679
-75	1.1362	0.7790	0.4017	0.1704	0.2443	0.3199	0.2603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

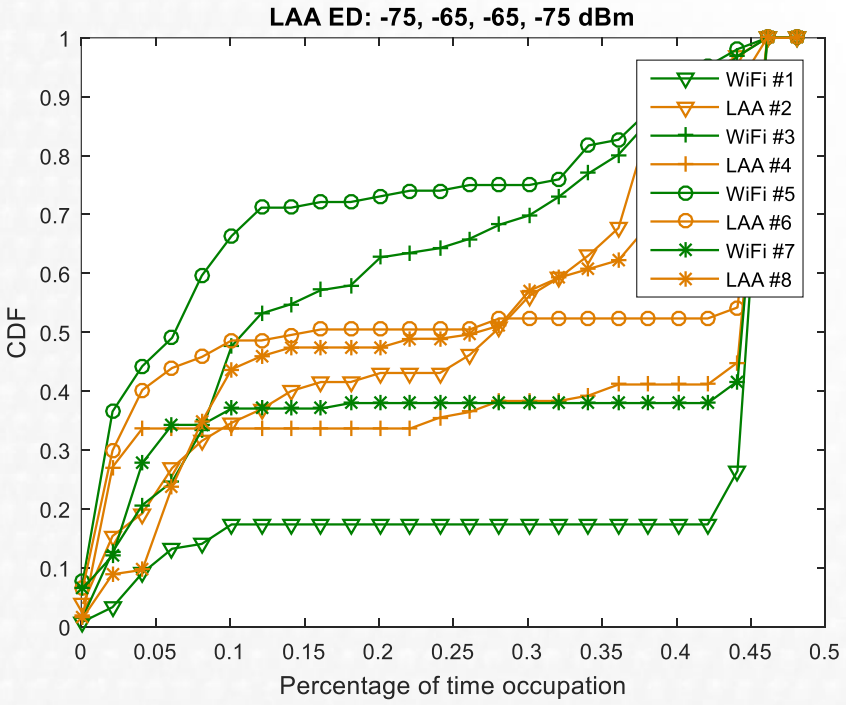
LAA threshold (dBm)	WiFi	LAA	WiFi (#1)	WiFi (#3)	WiFi (#5)	WiFi (#7)	LAA (#2)	LAA (#4)	LAA (#6)	LAA (#8)
-70,-65,-65,-70	0.7891	0.9444	0.3234	0.1303	0.1399	0.1955	0.2806	0.1857	0.1616	0.3165
-75,-65,-65,-75	0.7494	0.7705	0.3021	0.1501	0.0892	0.2080	0.1962	0.2057	0.1645	0.2041
-75,-70,-70,-75	0.9786	0.9026	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

1.76	**1.95**	**1.92**	**1.73**	**1.52**	**1.88**	**1.93**	**1.99**

✓ LAA nodes in the middle prefer low ED to avoid simultaneous transmissions, and LAA nodes in the margin prefer high ED to encourage simultaneous transmissions. (“-75,-65,-65,-75” gets the worst overall performance, “-65,-75, -75,-65” achieves the best overall performance)

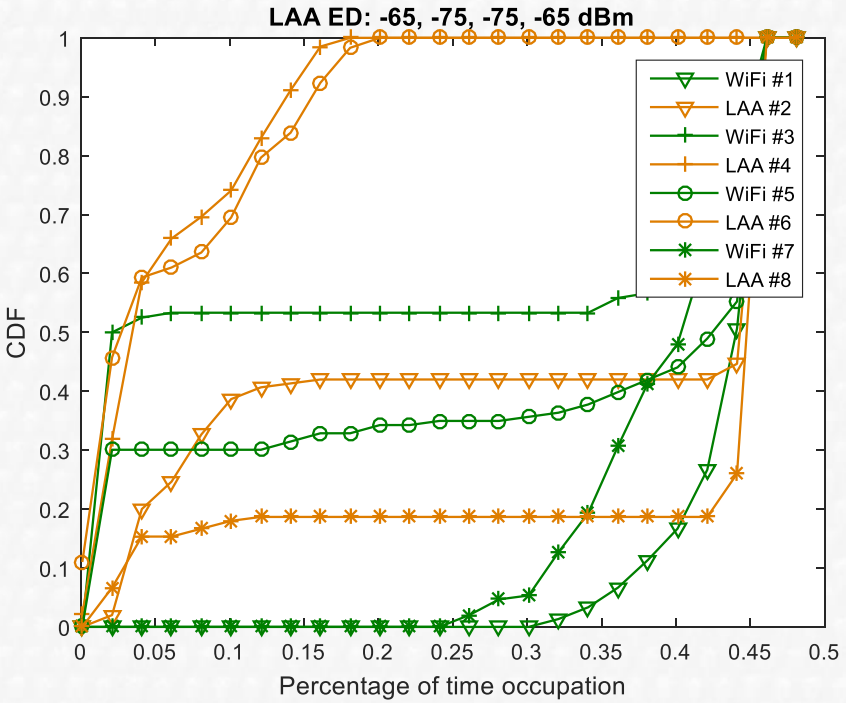
Review & Discussion: Threshold

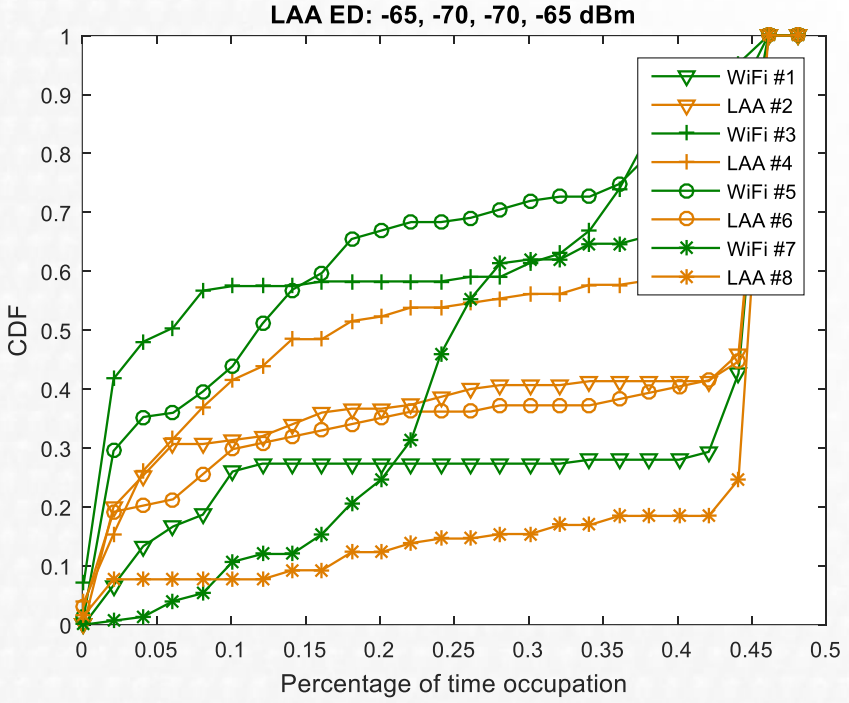




- ✓ Curves are more similar at the right figure, but it is inefficient (frequent collision for nodes in the middle, and it's a waste of time.)

Review & Discussion: Threshold





- ✓ For the case of “-65, -75, -75, -65”, WiFi #1 and WiFi #7’s performance decrease too much.

Results with multiple Users: Matlab

❖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 with multiple Users: Matlab

❖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)

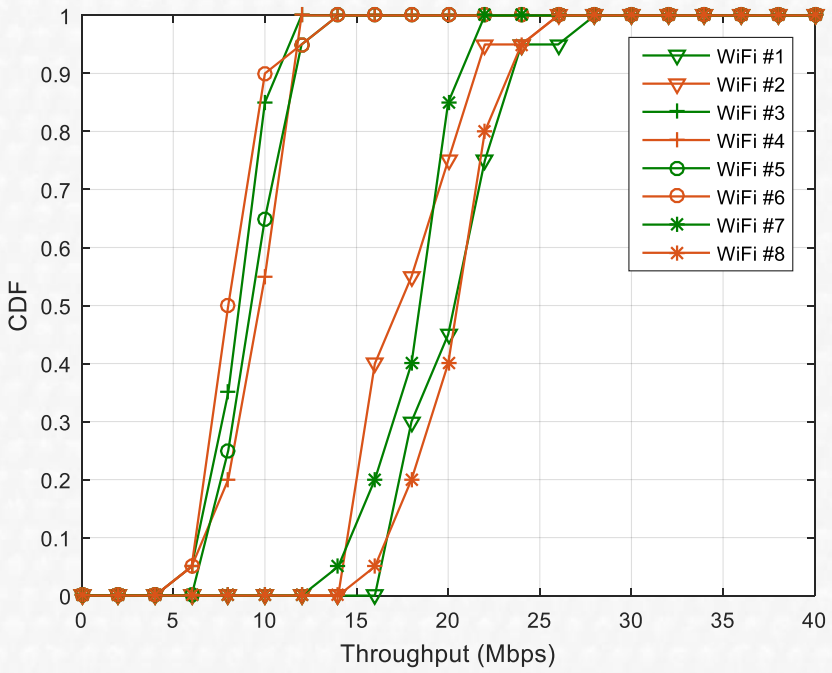
LAA threshold (dBm)	WiFi	LAA	WiFi (#1)	WiFi (#3)	WiFi (#5)	WiFi (#7)	LAA (#2)	LAA (#4)	LAA (#6)	LAA (#8)
-65	23.22	26.35	30.84	16.00	17.03	29.03	27.15	27.55	25.11	25.58
-70	23.67	27.02	32.89	14.35	19.15	28.31	27.72	28.10	25.80	26.47
-75	26.94	18.68	32.49	22.13	20.71	32.41	25.24	15.00	13.26	21.23

If Operator B is LAA, both Operator A and Operator B's performance are improved: no competition among LAA users (ideal scheduling);

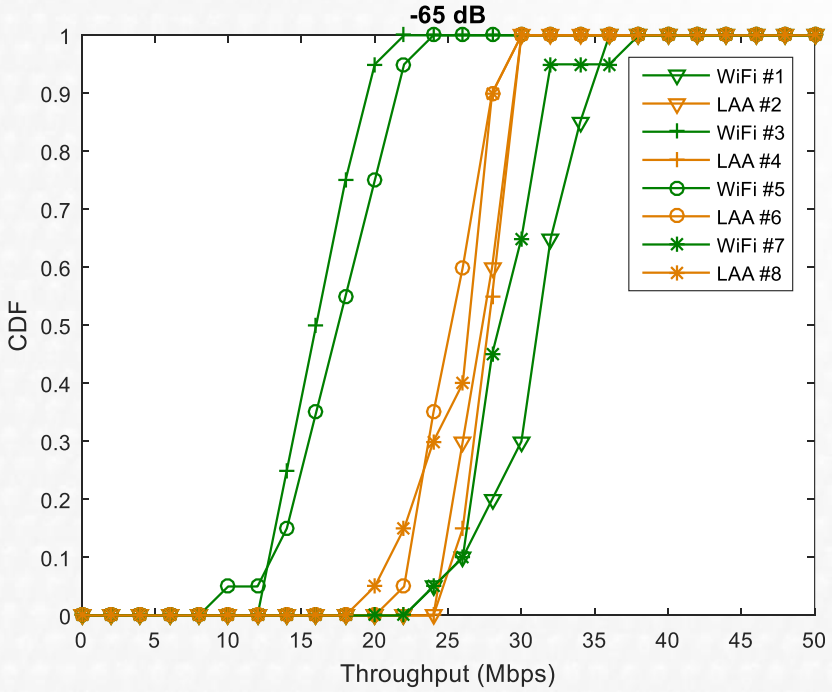
Results with multiple Users: Matlab

❖Throughput in CDF, Load ratio of 0.8

✓ Operator B: WiFi



✓ Operator B: LAA (-65 dBm)



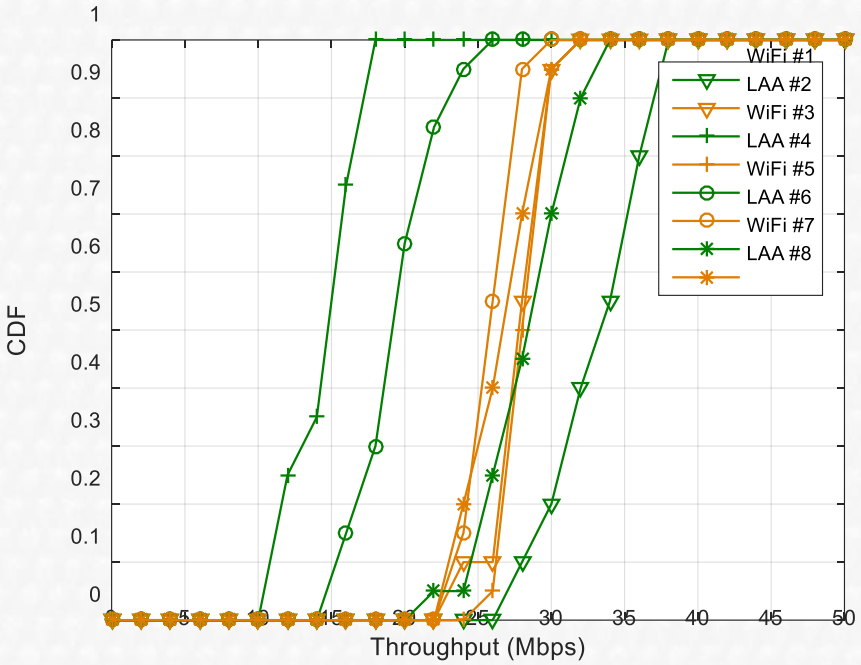
✓ Introducing LAA improves both WiFi and LAA's performance.

✓ CDF curves become smoothly compare to the case of single user: some users are in "good" location, and some of them are in "bad" location

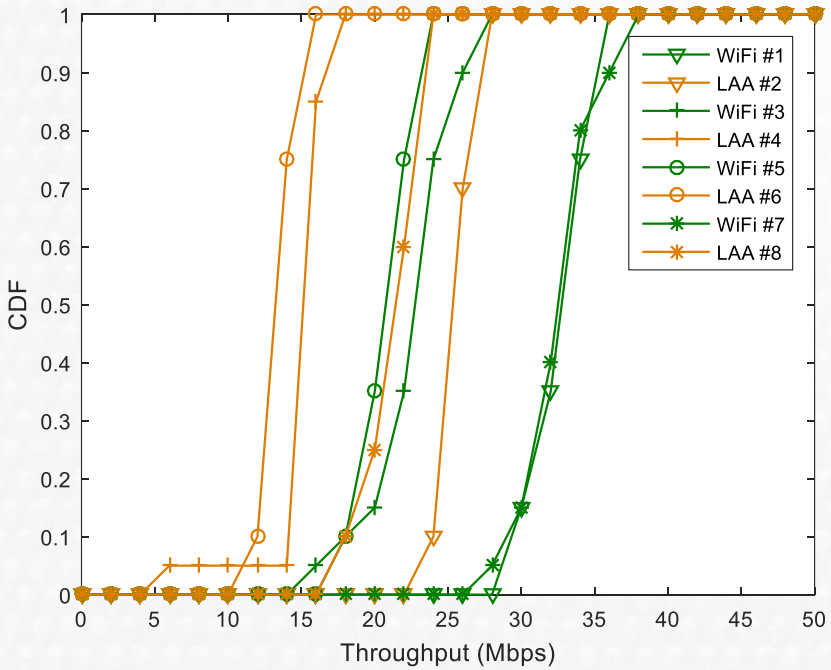
Results with multiple Users: Matlab

❖Throughput in CDF, Load ratio of 0.8

✓ Operator B: : LAA (-70 dBm)



✓ Operator B: LAA (-75 dBm)



✓ At -75 dBm, LAA #4 and LAA #6 will be blocked frequently.

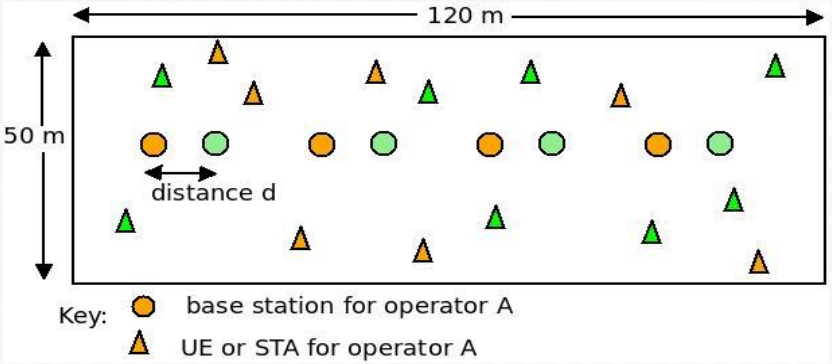
Next steps

- Continue to think about possible adaptive ED algorithms
- Try to do some analyses or optimization in a simplified layout.

Appendix: Results from NS-3

❖Simulation setting [1]

✓ Layout



✓ Traffic model: FTP Model 1 over UDP/TCP, lambda = 2.5

✓ WiFi: 1) 802.11n, channel 36 (20 MHz); 2) a standard DCF for best effort traffic; 3) CCAED = -62 dBm, CCACS = - 88dBm; 4) No beamforming

✓ LAA: 1) Cwmin = 15, Cwmax = 1023; 2) maximum TxOP length (configured from 4 msec to 20 msec); 3) CCAED = -62/-72/-82 dBm; 4) Data transfer starts at the subframe boundary. We implement reservation signals to occupy the channel until the first subframe with data, to force other nodes to defer while LAA is not occupying the channel with data. The reservation signals count against the node's TxOP time.

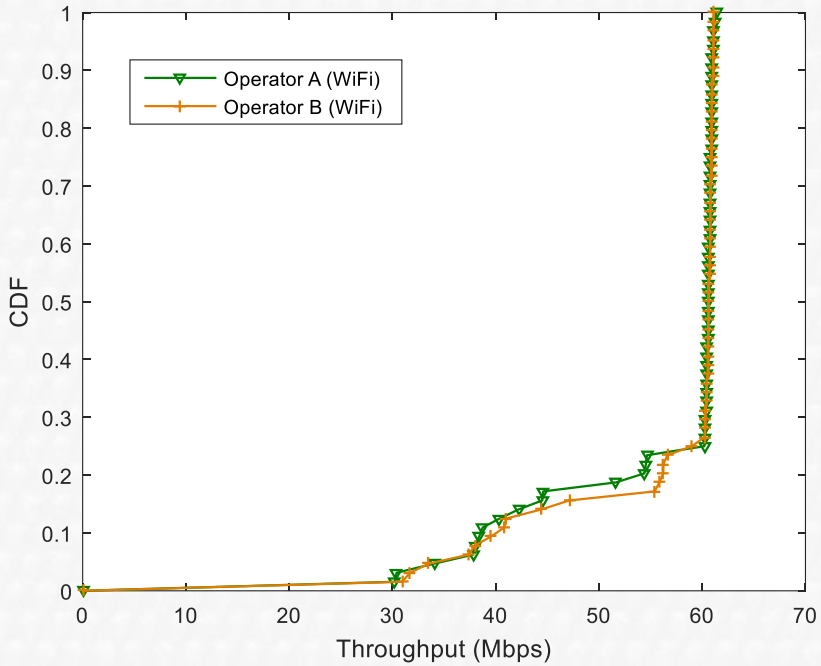
✓ UEs (STAs) move around at 3 km/h, no re-dropping.

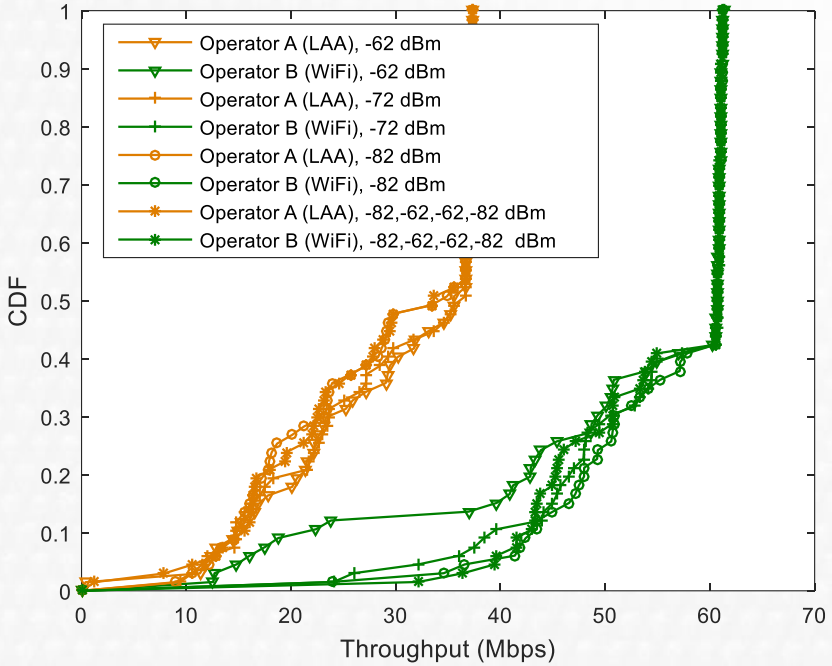
[1] B. Bojovic, L. Giupponi, T. R. Henderson, M. Miozzo, "*Simulation results for LAA LBT indoor scenario using the ns-3 network simulator*".

Appendix: Results from NS-3

❖Simulation Results, 802.11n SISO

✓ Throughput, lambda = 2.5





✓ Introducing LAA degrades both WiFi and LAA's performance.

✓ LAA's performance is worse than WiFi's performance.

✓ There is only a small difference by changing ED.

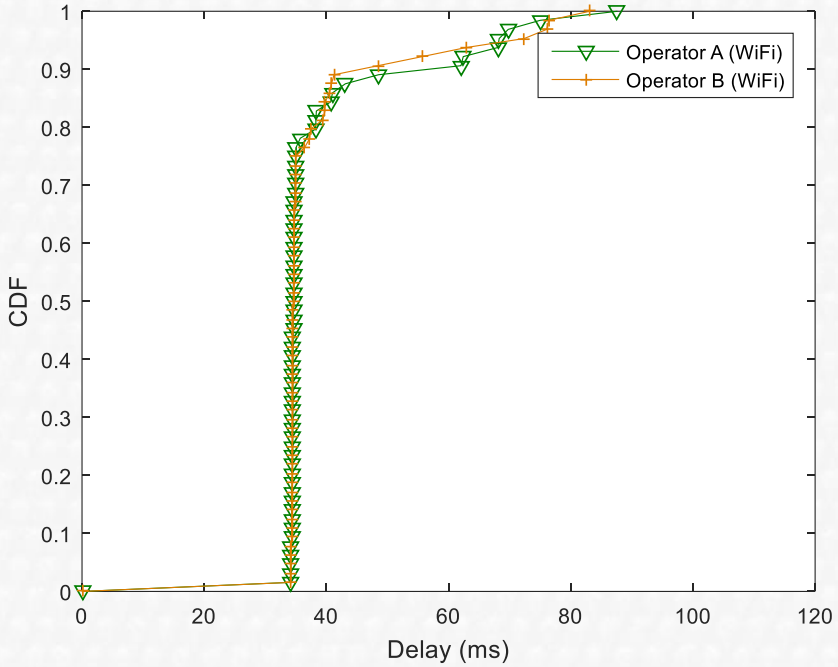
Appendix: Results from NS-3

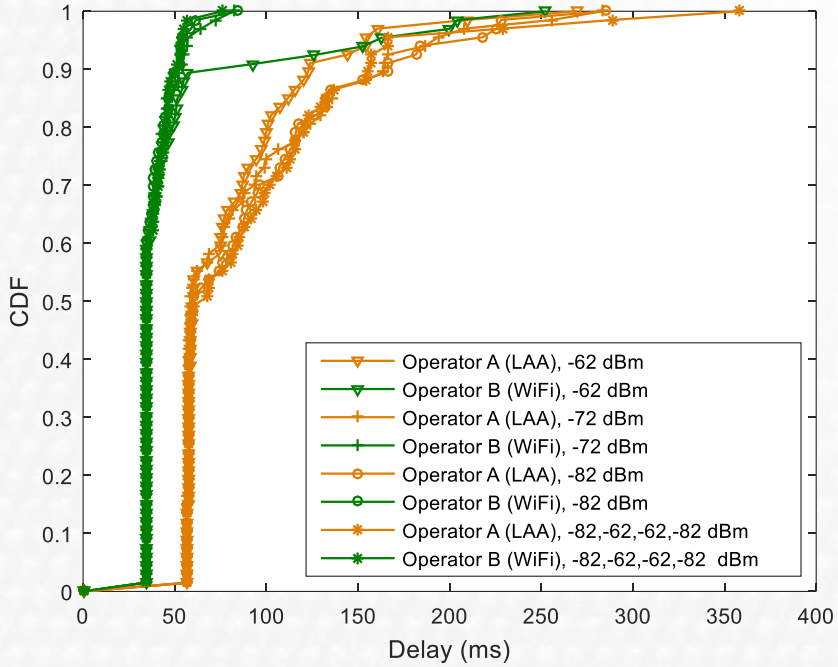
- LAA's performance depends on scheduling
  - ✓ If TxOP is always filled with data, since there is no competition among users belonging to the same eNB, both WiFi and LAA's performance can be improved
  - ✓ If TxOP is not saturated frequently, then it will be inefficient to always reserve this TxOP (adaptive TxOP?)
- The upper layer dominates the performance? For example, the performance will become much worse if the traffic model is FTP over TCP.

Appendix: Results from NS-3

❖Simulation Results, 802.11n SISO

✓ Latency, lambda = 2.5



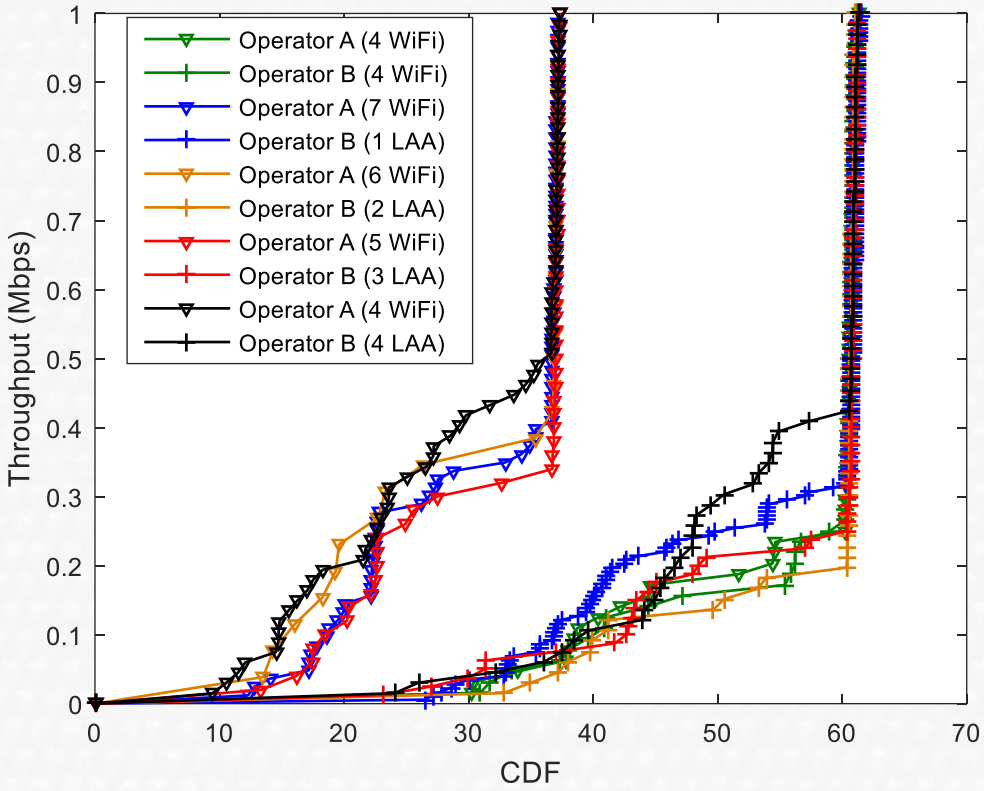


✓ The performance of delay is similar to that of throughput.

Appendix: Results from NS-3

❖Simulation Results, 802.11n SISO

✓ Throughput, lambda = 2.5

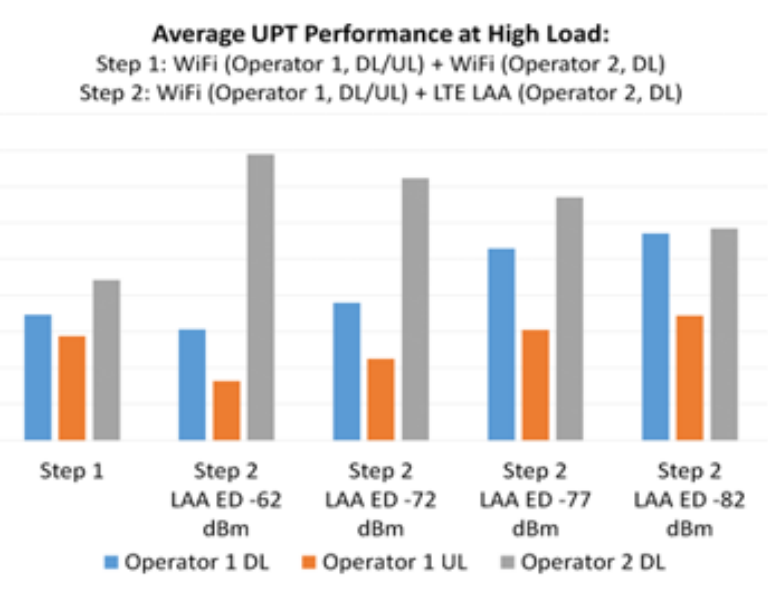


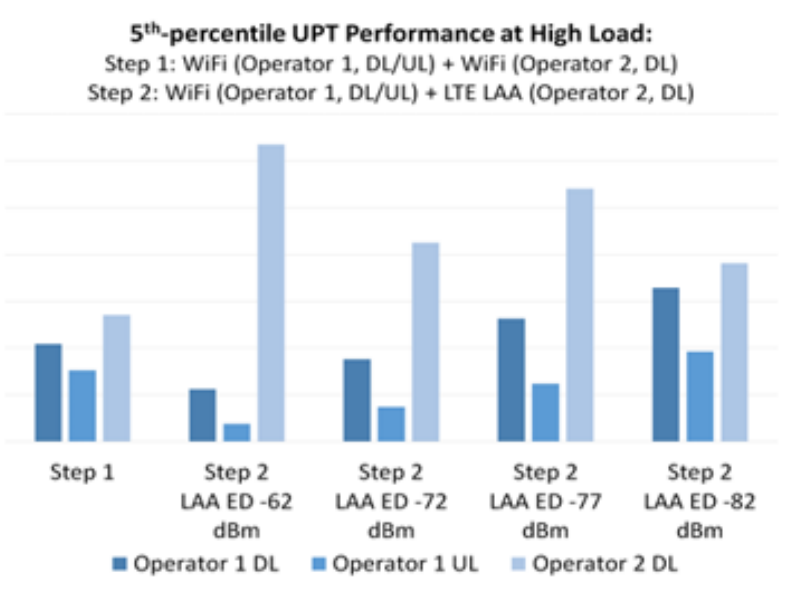
✓ The difference is not large with different number of LAA eNBs.

Appendix: Results from Intel

❖Simulation Results, 802.11n SISO

✓ Throughput, lambda = 2.5





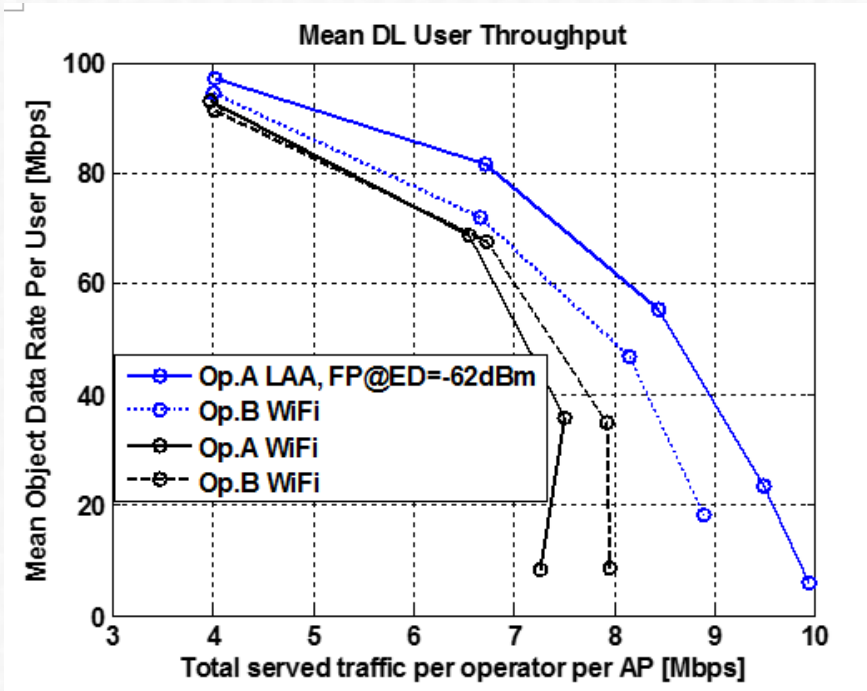
✓ LAA's performance is better than WiFi.

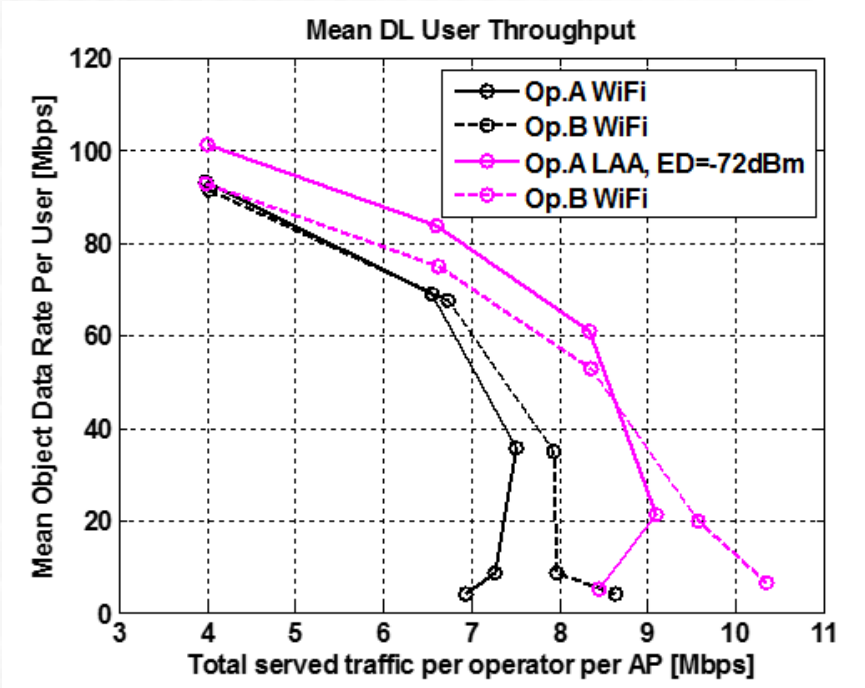
✓ By decreasing LAA ED, WiFi's performance is always improving, and LAA's performance is decreasing.

Appendix: Results from Ericsson

❖Simulation Results, 802.11n SISO

✓ Throughput, lambda = 2.5





✓ LAA's performance is better than WiFi.