UNIVERSITY OF DELAWARE

Cisco Cooperative Project

Coexistence of WiFi and LAA: Detection Thresholds

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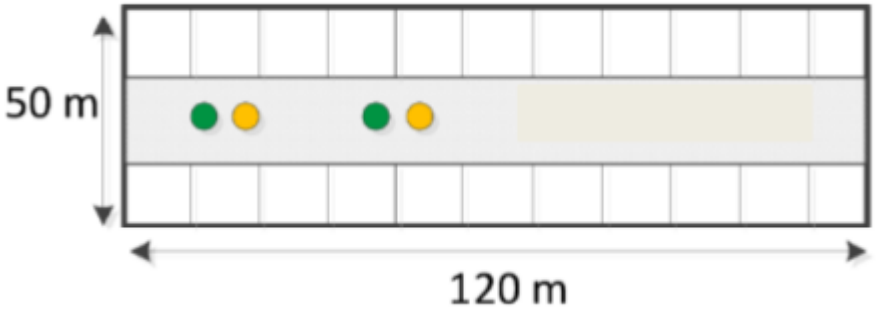
Outline

- Collisions for WiFi and LAA
- Performance with different LAA thresholds
- Next Steps

Collisions for WiFi and LAA

❖Simulation setting

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



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

Collisions for WiFi and LAA

❖ Transmission range

LAA threshold (dBm)	WiFi (#1)	WiFi (#3)	LAA (#2)	LAA (#4)
-65	2,3	1,4	1	3
-70	2,3	1,2,4	1	3
-75	2,3,4	1,2,4	1,4	2,3

❖Number of blocks due to others' transmission

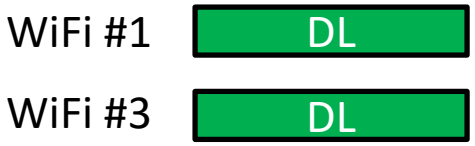
LAA threshold (dBm)	WiFi (#1)	WiFi (#3)	LAA (#2)	LAA (#4)
-65	2	2	1	1
-70	2	2	2	1
-75	2	2	3	3

Collisions for WiFi and LAA

❖ When will collisions happen among WiFi pairs?

- ✓ WiFi #1 and WiFi #3 will block each other if they do not transmit simultaneously (No collision)

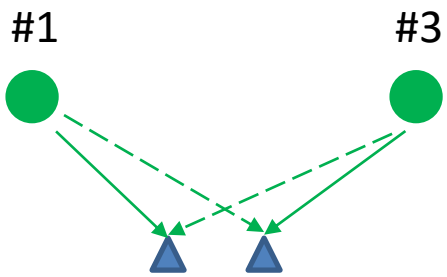
- ✓ If WiFi # 1 and WiFi #3 transmit simultaneously: have data to transmit and have the same random backoff (collisions may happen, probability of 1/16 with CW = 16), and assume they have the same packet length)



Depends on locations of clients.

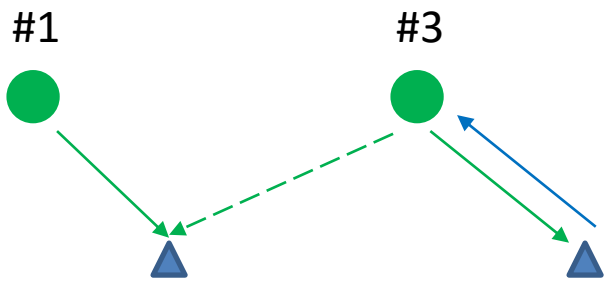
Collisions for WiFi and LAA

I:



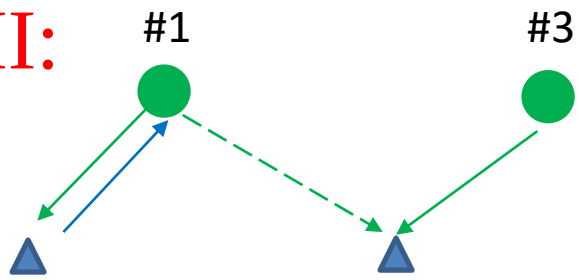
Collisions for both AP #1 and #3's clients

II:



Collision for AP #1's client

III:



Collision for AP #3's client

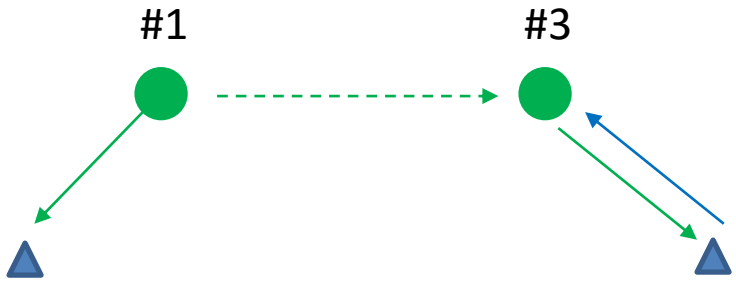
IV:

No collisions

Collisions for WiFi and LAA

❖How to simulate collisions among WiFi pairs?

- ✓ If the packet length are different, collisions may happen for uplink.



- ✓ In real implementations or system level simulations, APs and clients may use decoding to detect whether collision happens?

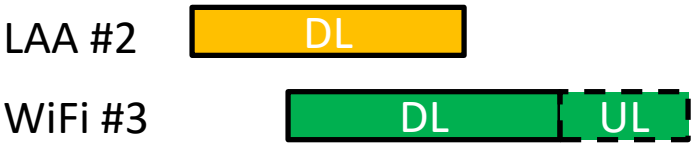
- ✓ In my simulation, I simply assume packet lengths are the same and collisions happen if AP #1 and AP #3 transmit simultaneously. (Maybe we also need to consider the location of users?)

❖It is similar for collisions among LAA pairs.

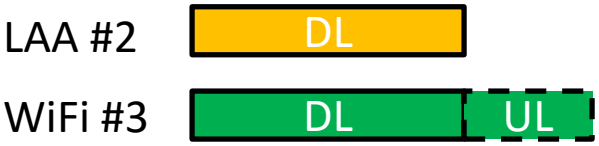
Collisions for WiFi and LAA

- When will collisions happen among WiFi/LAA pairs? (-70 dBm)
  - ✓ If WiFi #3 transmit first, LAA #2 will be blocked (No collision, LAA's uplink data, like ACK, is transmitted via licensed band.)

  - ✓ If LAA #2 transmit first, WiFi #3 will sense the channel to be idle and start to transmit. (Collisions may happen, a "hidden node" problem due to asymmetric threshold setting?)

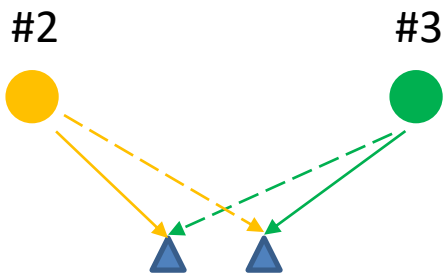


  - ✓ If LAA # 2 and WiFi #3 transmit simultaneously (collisions may happen)



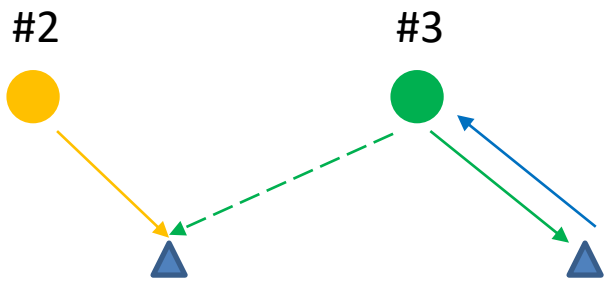
Collisions for WiFi and LAA

I:



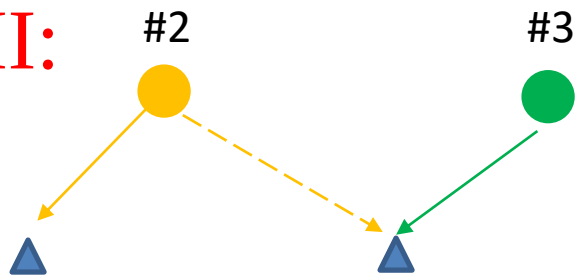
Collisions for LAA #2 user and AP #3's client

II:



Collision for LAA #2's user

III:



Collision for AP #3's client

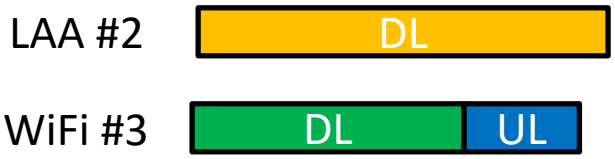
IV:

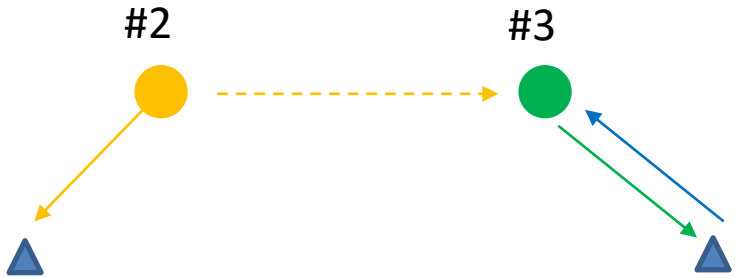
No collisions

Collisions for WiFi and LAA

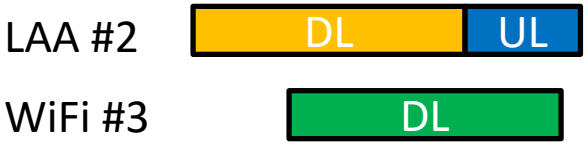
❖How to simulate collisions among WiFi and LAA pairs?

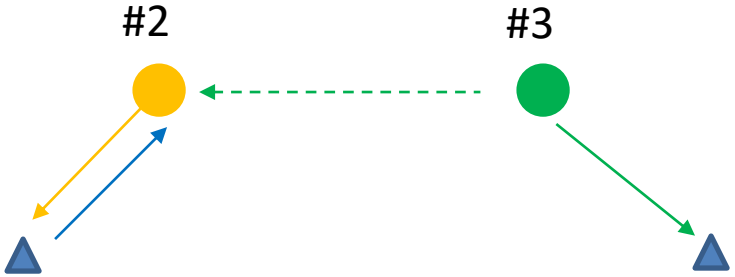
- ✓ If packet lengths are different, collisions may happen for WiFi #3's uplink transmission.





- ✓ If LAA also have uplink data on unlicensed band, collisions may happen to LAA #2's uplink when LAA #2 transmit first.





- ✓ In my simulation, I assume packet lengths are the same, uplink for LAA are sent via licensed band, and simulate different cases.

Performance with different LAA thresholds (1)

❖Only collisions to LAA in this asymmetric setting (low threshold, more sensitive)

- ✓ Percentage of time occupation (successful transmission)

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 successful 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

- ✓ 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

Performance with different LAA thresholds (1)

- ✓ LAA's performance decreases very quickly. At -70 dBm, only LAA #2 and WiFi #3 is asymmetric, so LAA #2's performance degrades a lot; at -75 dBm, LAA #2 and WiFi #3, and LAA #1 and WiFi #4 are both asymmetric, so LAA #2 and #4's performance degrades a lot.
- ✓ At -70 dBm, LAA #2's performance degrades so much, so WiFi #1 can take this advantage (#1 and #2 is only 5 meters away). For WiFi #3, they have to compete with WiFi #1 and LAA #4. One more simulation: only #1, #3, and #4:

LAA threshold (dBm)	WiFi (#1)	WiFi (#3)	LAA (#4)
-65	0.4477	0.4025	0.4479
-70	0.4477	0.4025	0.4479
-75	0.4436	0.4455	0.0272

- ✓ It is possible that some WiFi pairs' performance may decrease first and then increase. (Reason 1)

Performance with different LAA thresholds (2)

❖Not a collision in this asymmetric setting

- ✓ Percentage of time occupation (successful transmission)

LAA threshold (dBm)	WiFi (#1)	WiFi (#3)	LAA (#2)	LAA (#4)
-65	0.4019	0.4022	0.4450	0.4420
-70	0.3521	0.3992	0.3484	0.4466
-75	0.4401	0.4425	0.2021	0.1908

- ✓ Number of successful transmissions

LAA threshold (dBm)	WiFi (#1)	WiFi (#3)	LAA (#2)	LAA (#4)
-65	10465	10475	11588	11511
-70	9168	10396	9073	11631
-75	11462	11523	5264	4970

- ✓ Number of collisions

LAA threshold (dBm)	WiFi (#1)	WiFi (#3)	LAA (#2)	LAA (#4)
-65	1052	1101	567	608
-70	1623	1137	1610	618
-75	1332	1338	1859	1912

Performance with different LAA thresholds (2)

- ✓ LAA's performance will decrease, but not so quickly.
- ✓ From -65 to -70 dBm, the number of collisions for WiFi pairs increases, this lead to a decreasing in the number of successful transmissions. For example, we assume #1, #2 and #3 all have data to transmit. At -65 dBm, if #3 is transmitting first, #2 can also transmit and #1 have to wait; at -70 dBm, if #3 is transmitting first, both #1 and #2 have to wait, then this may lead to a collision. Also, a collision means doubling the contention window size.
- ✓ Even though WiFi's transmitting opportunities should increase (at least not decrease), due to collisions, it is possible that some WiFi pairs' performance may decrease first and then increase. (Reason 2)

Performance with different LAA thresholds (3)

❖Collisions to both WiFi and LAA in this asymmetric setting

- ✓ Percentage of time occupation (successful transmission)

LAA threshold (dBm)	WiFi (#1)	WiFi (#3)	LAA (#2)	LAA (#4)
-65	0.4019	0.4022	0.4450	0.4420
-70	0.4379	0.1553	0.0910	0.4450
-75	0.3260	0.3114	0	0

- ✓ Number of successful transmissions

LAA threshold (dBm)	WiFi (#1)	WiFi (#3)	LAA (#2)	LAA (#4)
-65	10465	10475	11588	11511
-70	11403	4045	2371	11589
-75	8489	8109	0	0

- ✓ Number of collisions

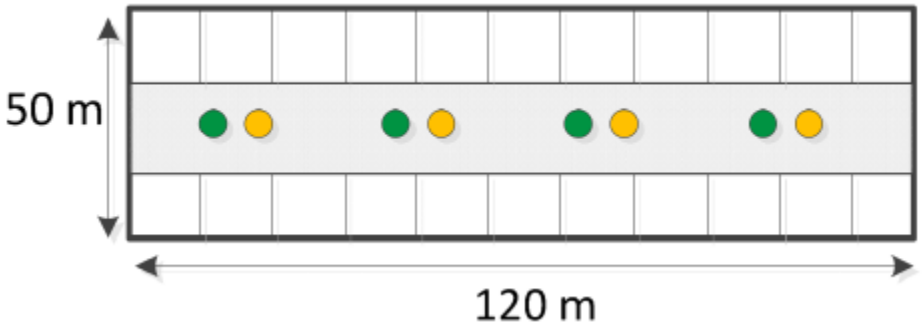
LAA threshold (dBm)	WiFi (#1)	WiFi (#3)	LAA (#2)	LAA (#4)
-65	1052	1101	567	608
-70	884	5972	5966	315
-75	4662	4749	4233	4164

Performance with different LAA thresholds (3)

- ✓ LAA's performance will decrease quickly.
- ✓ At -70 dBm, LAA #2 and WiFi #3 is asymmetric, LAA #2 and WiFi #3's performance both degrade; at -75 dBm, LAA #2 and WiFi #3, and LAA #1 and WiFi #4 are asymmetric, all pairs' performance degrade.
- ✓ It is possible that some WiFi pairs' performance decrease first and then increase; it is also possible that all WiFi pairs' performance decrease.

Performance with different LAA thresholds (4)

❖ Layout



❖ Transmission range

LAA threshold (dBm)	WiFi (#1)	WiFi (#3)	WiFi (#5)	WiFi (#7)	LAA (#2)	LAA (#4)	LAA (#6)	LAA (#8)
-65	2,3	1,4,5	3,6,7	5,8	1	3	5	7
-70	2,3	1,2,4,5	3,4,6,7	5,6,8	1	3	5	7
-75	2,3,4	1,2,4,5,6	3,4,6,7,8	5,6,8	1,4	2,3,6	4,5,8	6,7

❖Number of blocks due to others' transmission

LAA threshold (dBm)	WiFi (#1)	WiFi (#3)	WiFi (#5)	WiFi (#7)	LAA (#2)	LAA (#4)	LAA (#6)	LAA (#8)
-65	2	3	3	2	1	1	1	1
-70	2	3	3	2	2	2	2	1
-75	2	3	3	2	3	5	5	3

Performance with different LAA thresholds (4)

❖ Collision to LAA

LAA threshold (dBm)	WiFi (#1)	WiFi (#3)	WiFi (#5)	WiFi (#7)	LAA (#2)	LAA (#4)	LAA (#6)	LAA (#8)
-65	0.4341	0.3158	0.3172	0.4331	0.4445	0.4458	0.4440	0.4460
-70	0.4433	0.2500	0.3442	0.4140	0.1657	0.2247	0.0968	0.4449
-75	0.4450	0.3649	0.3639	0.4474	0.0639	0.0015	0.0014	0.0657

❖Not a collision

LAA threshold (dBm)	WiFi (#1)	WiFi (#3)	WiFi (#5)	WiFi (#7)	LAA (#2)	LAA (#4)	LAA (#6)	LAA (#8)
-65	0.4341	0.3158	0.3172	0.4331	0.4445	0.4458	0.4440	0.4460
-70	0.3767	0.2797	0.2343	0.4418	0.3811	0.4441	0.4249	0.4439
-75	0.4171	0.3558	0.3546	0.4196	0.2823	0.1006	0.1015	0.2806

❖Collision to both LAA and WiFi

LAA threshold (dBm)	WiFi (#1)	WiFi (#3)	WiFi (#5)	WiFi (#7)	LAA (#2)	LAA (#4)	LAA (#6)	LAA (#8)
-65	0.4341	0.3158	0.3172	0.4331	0.4445	0.4458	0.4440	0.4460
-70	0.4455	0.0346	0.0965	0.1838	0.2988	0.4422	0.1735	0.4438
-75	0.4434	0.1300	0.1246	0.44445	0.0548	0.0024	0.0020	0.0566

Similar trend, but more interactions.

Next steps

- ✓ Compute the latency for different detection thresholds: average delay for each pair (delay = successful transmitted time - arrival time)
- ✓ Continue study this threshold problem;
- ✓ Simulate multi-carrier LBT with some legacy pairs;
- ✓ Simulate multi-carrier LBT with at different locations, and study the channel selection problem.