Cisco Cooperative Project

Study on Coexistence of LAA and WiFi

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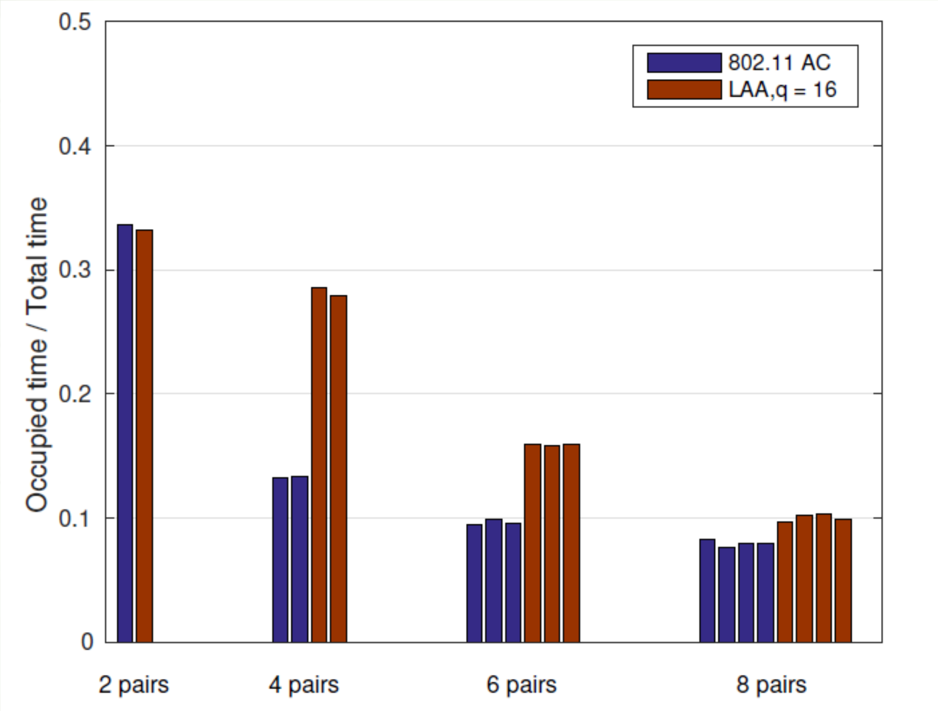
Outline

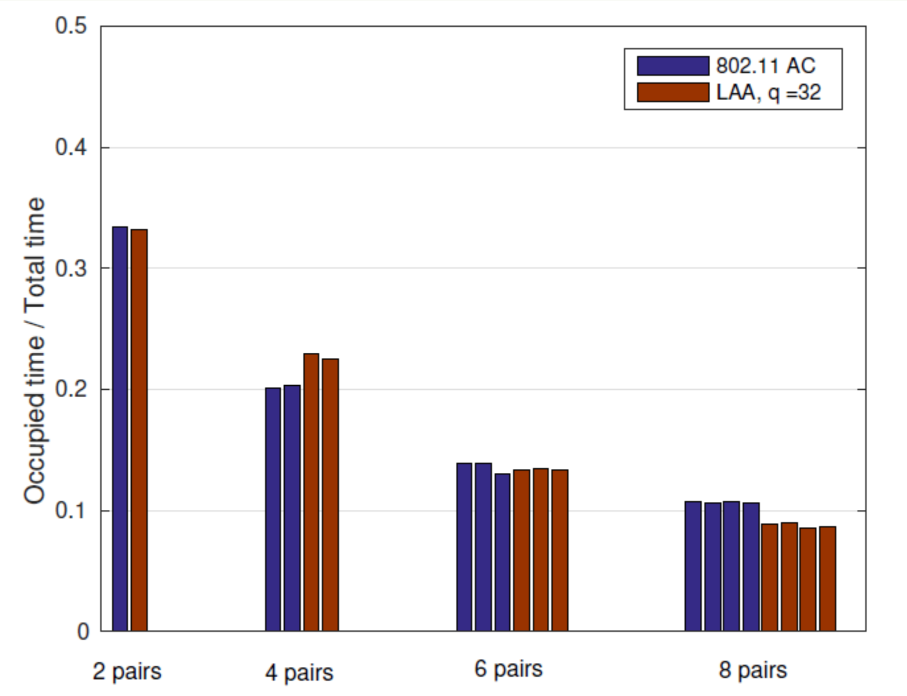
- Review Simulation
- Different locations and load rates
- Channel Selection
- Next steps

Review Simulation: Last results

q = 16



q = 32



DIFS is included for each node when there is a new transmission or when the channel changes from busy to idle.

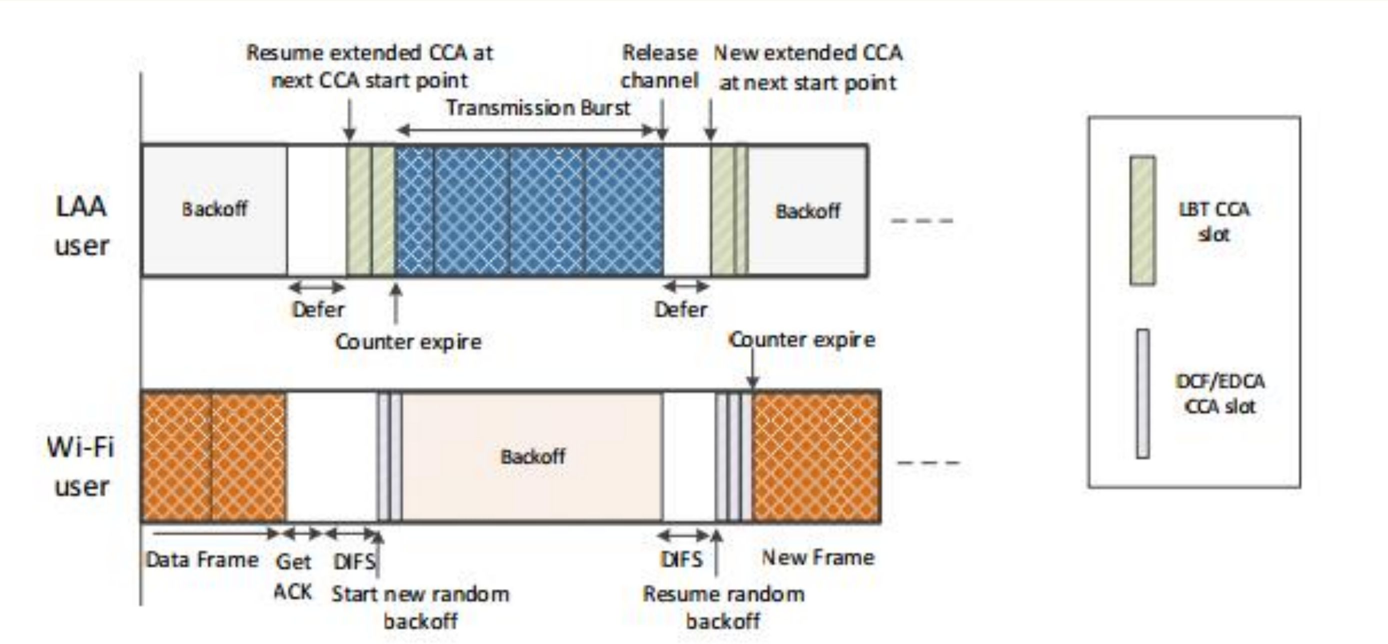
Review Simulation: CSMA/CA *vs* CAT4

- LAA CAT4 almost follows CSMA/CA, except for two main differences:
  - ✓ For a new transmission, LAA will begin immediately if the channel is idle for D_{iCCA} (e.g., 34 μs); WiFi waits for D_{DIFS} (34 μs) and a random backoff.
  - ✓ When collision happens, LAA may update q from X to Y (e.g., 4 to 32); WiFi doubles q each time from X to Y (32 to 1024).

- LAA will be more aggressive then WiFi if $D_{iCCA} = 34\ \mu s$ and $D_{eCCA} = 34\ \mu s$.

Review Simulation: CSMA/CA *vs* CAT4

- Ericsson [1] suggests to incorporate a defer period of at least 20 μs after a busy channel has just become free (this is equivalent to increase D_{eCCA})



[1] A. Mukherjee, "*System architecture and coexistence evaluation of licensed-assisted access LTE with IEEE 802.11*," ICC 2015.

Review Simulation: Results (pairs)

- Simulation setting
  - ✓ All nodes are deployed at same location
  - ✓ Load rate: average package arrival time: every 800 slots (Poisson), package size: 400 slots
  - ✓ One pair means one transmitter(eNB/AP) and one receiver(UE/client)

- 2 Pairs

	WiFi	LAA
Defer = 0	0.3365	0.3393
Defer = 1	0.3340	0.3376
Defer = 2	0.3299	0.3367
Defer = 3	0.3333	0.3280

Review Simulation: Results

- 4 Pairs

	WiFi		LAA	
Defer = 0	0.1605	0.1472	0.2820	0.2794
Defer = 1	0.1818	0.1977	0.2490	0.2421
Defer = 2	0.2255	0.2316	0.2070	0.2086
Defer = 3	0.2595	0.2687	0.1781	0.1725

- 8 Pairs

	WiFi				LAA			
Def=0	0.0437	0.0434	0.0458	0.0478	0.1467	0.1521	0.1511	0.1459
Def=1	0.0665	0.0690	0.0662	0.0699	0.1223	0.1273	0.1271	0.1223
Def=2	0.0937	0.0901	0.0967	0.0911	0.0965	0.1071	0.1007	0.1028
Def=3	0.1207	0.1176	0.1175	0.1172	0.0788	0.0796	0.0832	0.0803

Review Simulation: Results (load rate)

Change packet size (load rate)

- 4 Pairs (packet size of 160)

	WiFi		LAA	
Defer = 0	0.1732	0.1634	0.1669	0.1693
Defer = 1	0.1626	0.1658	0.1686	0.1676
Defer = 2	0.1675	0.1643	0.1669	0.1671
Defer = 3	0.1667	0.1708	0.1669	0.1659

- 4 Pairs (packet size of 640)

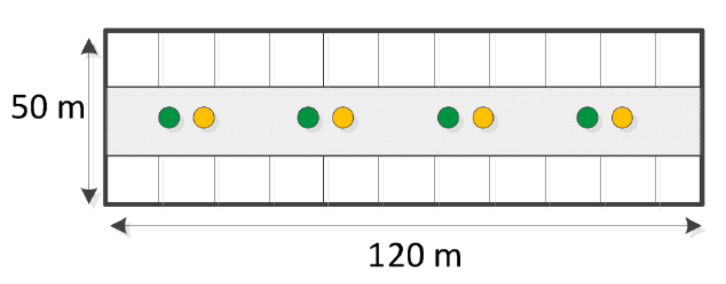
	WiFi		LAA	
Defer = 0	0.1411	0.1451	0.2935	0.2959
Defer = 1	0.1785	0.1646	0.2654	0.2673
Defer = 2	0.2111	0.2093	0.2324	0.2275
Defer = 3	0.2446	0.2442	0.1993	0.1978

Review Simulation: Discussion

- For “2 pair” or low load rate case, WiFi and LAA can both work very well since there is not much competition;
- As the number of defer slots increases (one slot is 9 μs), WiFi has more opportunities to access the channel;
- As the number of pairs or the load rate increases: LAA will have more opportunities to access the channel (large q for WiFi).

Different location and load rates

- Simulation setting
  - ✓ single-floor building, 4 APs (green) and 4 eNBs (yellow) are equally spaced, two closest nodes from two operators is 5 m.



  - ✓ Transmit power: 18 dBm, distance dependent path loss model:

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

  - ✓ Shadow fading standard deviation: $\sigma = 4$; fast fading: Rayleigh fading
  - ✓ Defer slots: 2
  - ✓ Load rate: average package arrival time: every 800 slots (Poisson), package size: 160/400/640 slots (0.2/0.5/0.8)
  - ✓ WiFi (LAA) CCA level: -82 dBm for WiFi (LAA) signal, -62 dBm for non-WiFi (non-LAA) signal

[1] *3GPP TR 36.889 V1.0.0 (2015-05).*

Different location and load rates (Cont'd)

- Simulation results for different load rates (8 pairs)

	WiFi				LAA			
R = 0.2	0.1678	0.1678	0.1658	0.1668	0.1664	0.1671	0.1673	0.1666
R = 0.5	0.3271	0.2685	0.2883	0.3167	0.3238	0.2796	0.2489	0.3259
R = 0.8	0.3999	0.2753	0.2976	0.3621	0.3874	0.3073	0.2611	0.4034

- Discussion
  - ✓ Low rate (0.2), no competition, all nodes work well
  - ✓ Medium rate (0.5), better than the case of same location
  - ✓ Medium/High rate(0.5/0.8), the nodes in the margin have more opportunities to access the channel than the nodes in the middle

Different location and load rates (Cont'd)

- Simulation results for different density (R=0.5)

	WiFi				LAA			
4 pairs	0.3331		0.3318		0.3326		0.3340	
8 pairs	0.3271	0.2685	0.2883	0.3167	0.3238	0.2796	0.2489	0.3259
16 pairs	0.3179	0.1202	0.1580	0.1416	0.2522	0.1705	0.1897	0.1375
	0.1503	0.1615	0.1750	0.2834	0.1584	0.1326	0.1343	0.2989

- Discussion
  - ✓ LAA may be able to decode WiFi signal? Different CCA level.
  - ✓ 8 pairs are dense enough? Both WiFi and LAA work very well.
  - ✓ 5 GHz will be congested? (There are 24 subchannels in total.)

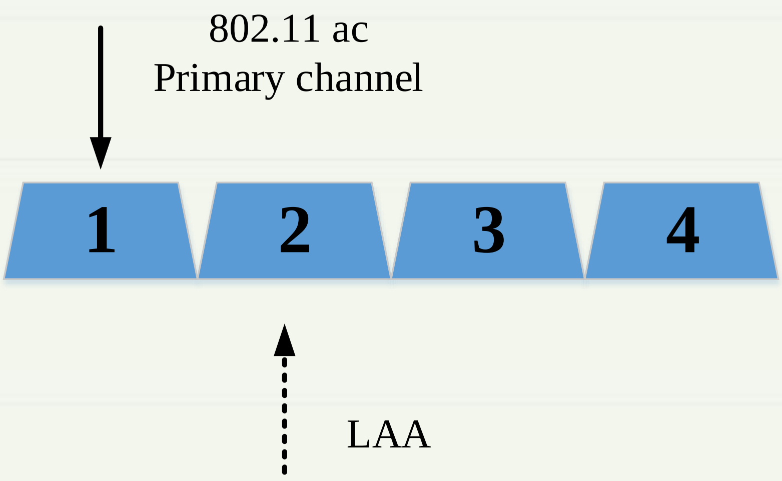
Channel Selection: Review

Scenario:

✓802.11ac with dynamic 80/40/20 MHz (primary channel requires to be included in any bandwidth)

✓LAA works in 20 MHz bandwidth

✓Channel selection depends on load rates (Ignore delay, from probability perspective)



Example 1: 2 pairs, $p_{AC} = p_{LAA} = 0.2$

To achieve the highest effective bandwidth (throughput), both 802.11ac and LAA will choose the same subchannel (e.g. #1).

$EB(1,1) = 0.2 * 80 + 0.2 * 20 = 20$

$EB(1,2) = 0.2 * (0.8 * 80 + 0.2 * 20) + 0.2 * 20 = 17.6$

$EB(1,3) = 0.2 * (0.8 * 80 + 0.2 * 40) + 0.2 * 20 = 18.4$

Example 2: 2 pairs, $p_{AC} = p_{LAA} = 1$

To achieve the highest effective bandwidth (throughput), 802.11ac chooses #1, and LAA choose #3 or #4.

$EB_{max} = EB(1,3) = 1 * 40 + 1 * 20 = 60$

Channel Selection: possible model

Let h_{ij} denote whether the j-th transmitter choose the i-th subchannel. To maximize the total effective bandwidth, one possible model is

Primary 20 MHz

Secondary 20 MHz

Secondary 40 MHz

$$\text{maximize} \quad \sum_{i \in C} \sum_{j \in S_{AC}} p_j h_{ij} \left(1 + \prod_{i \in i_1} \sum_{j \in \bar{j}} (1 - p_j h_{ij}) \left(1 + 2 \prod_{i \in i_2} \sum_{j \in \bar{j}} (1 - p_j h_{ij})\right)\right) + \sum_{i \in C} \sum_{j \in S_{LAA}} p_j h_{ij}$$

$$\text{s.t.} \quad \sum_{i}^{K} h_{ij} = 1, \quad \forall j \in S$$

One transmitter can only choose one subchannel (For AC, it is primary channel)

$$p_j h_{ij} = \min\{p_j h_{ij}, 1/\sum_{j \in S} h_{ij}\} \quad \forall i \in C, \quad \forall j \in S$$

Multiple transmitters have the same opportunity to win the channel access

$$j \cup \bar{j} = S$$

$$h_{ij} \in \{0, 1\}$$

$$i_1 = \begin{cases} 2 & i = 1 \\ 1 & i = 2 \\ 4 & i = 3 \\ 3 & i = 4 \end{cases} \qquad i_2 = \begin{cases} \{3,4\} & i = 1 \\ \{3,4\} & i = 2 \\ \{1,2\} & i = 3 \\ \{1,2\} & i = 4 \end{cases}$$

Channel Selection: possible model

However, this model is difficult to be solved, and I am currently using exhaustive search.

Case I: $N_{\mathrm{AC}} = 2, N_{LAA} = 2, p_j = 0.1$

$$H = \begin{bmatrix} 1 & 1 & 1 & 1 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix}$$

Case II: $N_{\mathrm{AC}} = 2, N_{LAA} = 2, p_j = 0.5$

$$H = \begin{bmatrix} 1 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Case III: $N_{\mathrm{AC}} = 2, N_{LAA} = 2, p_j = 0.9$

$$H = \begin{bmatrix} 1 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Case IV: $N_{\mathrm{AC}} = 3, N_{LAA} = 3, p_j = 0.9$

$$H = \begin{bmatrix} 1 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 1 \end{bmatrix}$$

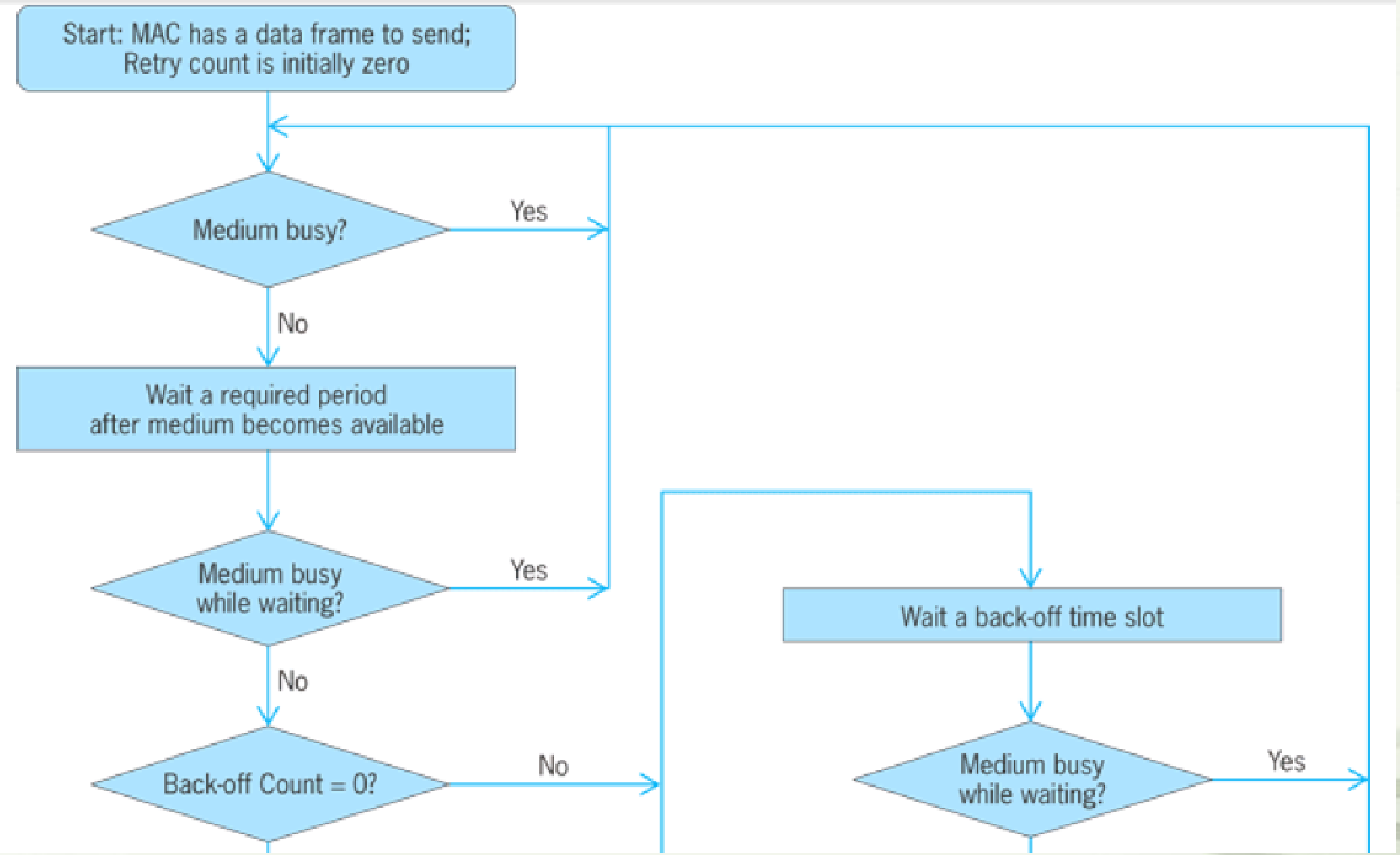
Channel Selection: Discussion

- Need to find a solution or a better model;
- WiFi does not take part in the optimization, only LAA can do channel selection.
- Need to consider competition loss and impact of delay, otherwise, the nodes will prefer to sharing one subchannel.

Next steps

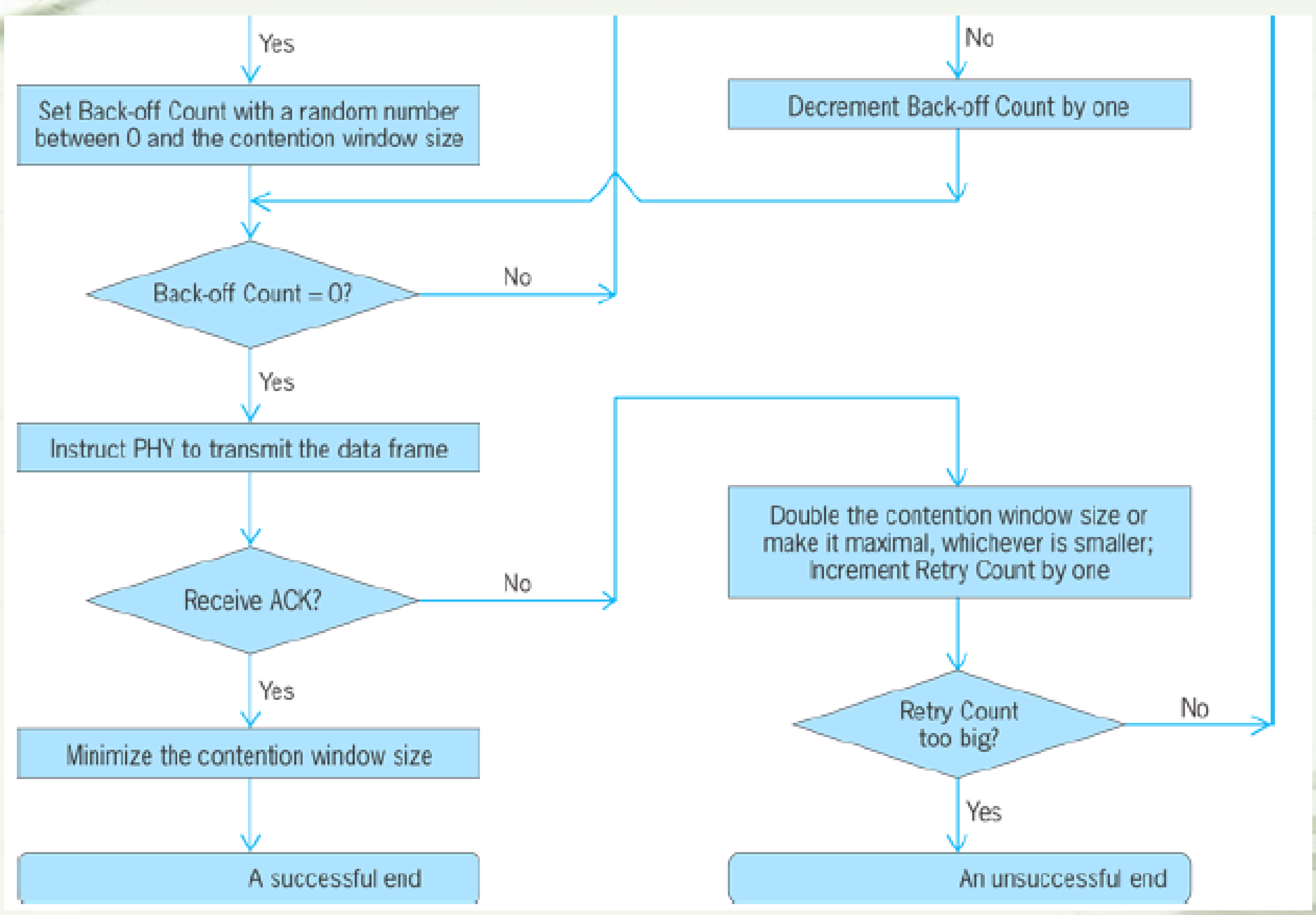
- Consider more realistic simulations, like multiple UEs and clients
- Continue to study channel selection algorithms
- Study LAA with CB, CA or something between
- Consider the effect of multi-user beamforming, which leads to less interference

CSMA/CA



[1] *CompTIA Network + Exam Guide, 4 th ed., Chapter 15*.

CSMA/CA (cont'd)



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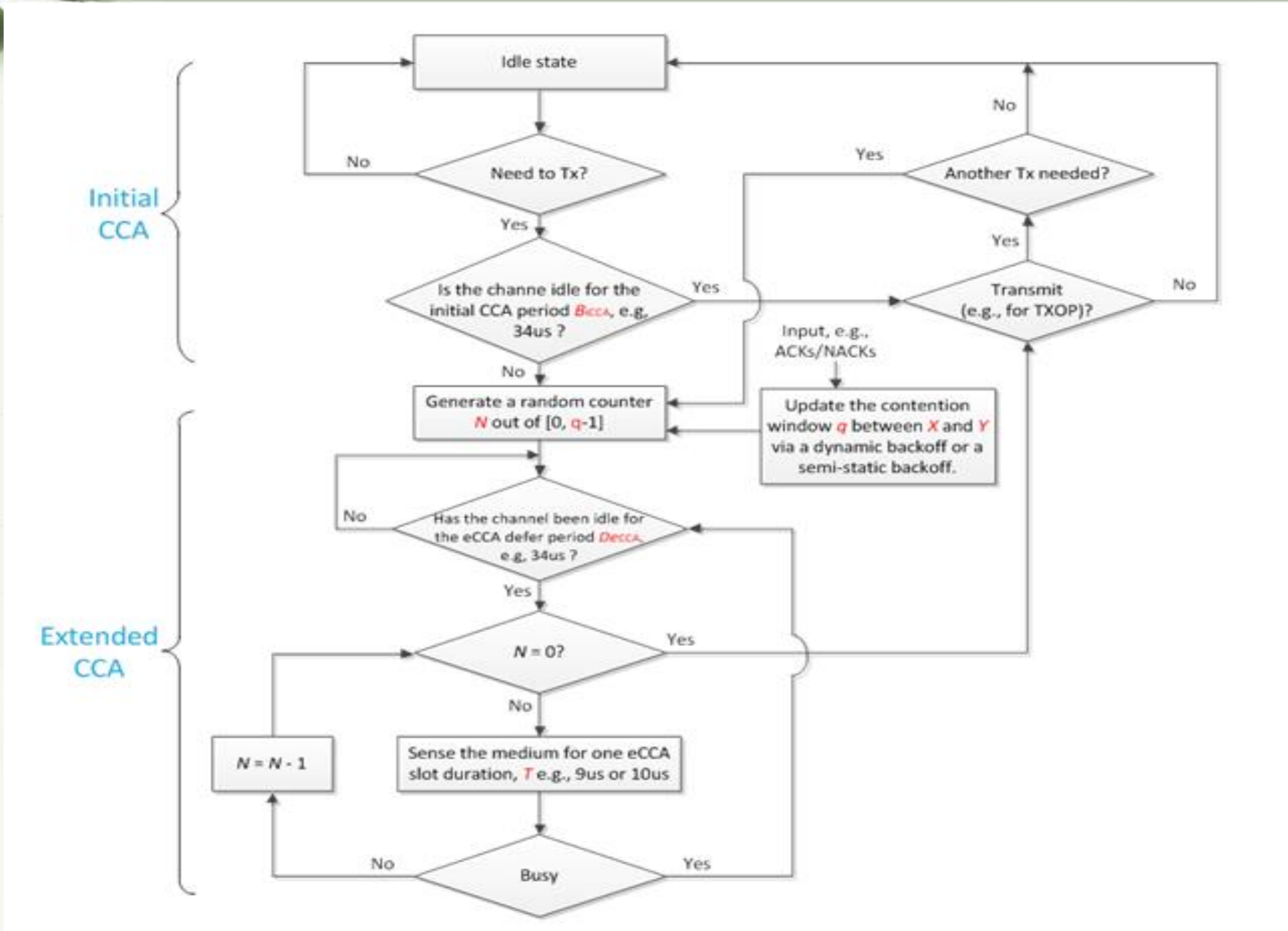
LBT CAT 4



[1] *3GPP TR 36.889 V1.0.0 (2015-05)*.