Cisco Cooperative Project

Channel Access for LAA

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Outline

- Multi-carrier LBT
- Channel selection
Multi-carrier LBT

- **802.11ac’s channel bonding**

  - The backoff procedure is only performed on the primary channel, secondary channel(s) perform a one-shot CCA.
  - Only certain channel bonding configurations are allowed.
  - The designated primary channel should always be part of the channel bonding configurations.
Multi-carrier LBT

- Channel bonding patterns

- Detection threshold

<table>
<thead>
<tr>
<th>Channel Width</th>
<th>CCA-CS (primary)</th>
<th>CCA-CS (secondary)</th>
<th>CCA-ED</th>
</tr>
</thead>
<tbody>
<tr>
<td>20 MHz</td>
<td>-82</td>
<td>-72</td>
<td>-62</td>
</tr>
<tr>
<td>40 MHz</td>
<td>-79</td>
<td>-72</td>
<td>-59</td>
</tr>
<tr>
<td>80 MHz</td>
<td>-76</td>
<td>-69</td>
<td>-56</td>
</tr>
</tbody>
</table>

20/40/80 MHz contiguous channel widths

- Coverage
Multi-carrier LBT

- Multi-carrier LBT, Alt 1: eNB performs LBT Cat 4 on only one unlicensed carrier (Wi-Fi like) [1]

  - The eNB shall choose the carrier requiring LBT uniformly randomly before each transmission burst or fix the carrier at least for 1 sec
  - The energy detection threshold used on channels not performing LBT is same as the one used on channel performing LBT
  - A single backoff counter should be used for the carrier on which LBT is performed.

Multi-carrier LBT

- Multi-carrier LBT, Alt 2: eNB performs LBT Cat 4 on more than one unlicensed carriers
  - The eNB can transmit on the carriers that has completed LBT with potential self-deferral to align transmission over multiple carriers.

Work to do

- Evaluate the performance for LAA with Alt 1 and Alt 2
  - LAA with carrier aggregation for any idle channels
  - LAA with channel bonding as Wi-Fi does
  - LAA with carrier aggregation for every four contiguous channels
Channel Selection

- Maximize area spectral efficiency\(^2\)

```
S_e(x, c) = \log_2 \left( 1 + \frac{P_L l(x^a_n, x)}{\sum_{i \in S^n_c, i \neq n} P_L l(x^a_i, x) + \sum_{m \in S^w_c} P_W l(x^w_m, x) + N} \right)
```

Channel Selection

- Maximize area spectral efficiency\textsuperscript{[2]}
  - Area Spectral efficiency

\[ S(A_n, c) = \frac{1}{A_n} \int_{A_n} S_e(x, c)dx, \]

- Optimization problem

\[
\max_{I(n,c)} \sum_{n=1}^{N_A} S(A_n, c)I(n, c) \\
\sum_{c=1}^{C} I(n, c) \leq 1 \\
I \in 0, 1.
\]

- Integer linear program (NP complete). Simulated annealing algorithm: check whether a neighbor solution is better or not in each iteration.

\[ I(n,c) = 1, \text{ if eNB } A_n \text{ transmit data on channel } c; \]
\[ I(n,c) = 0, \text{ otherwise.} \]
Channel Selection

- Maximize area spectral efficiency\[^2\]

![Graph showing channel selection performance](image)

SA: simulated annealing
LP: least interference power channel selection

1) Both SA & LP outperform random selection
2) SA has advantage over LP in congested cases, for a lower number of channels
Channel Selection

- Maximize number of LAA-UEs sharing $M$ channels

  - For uplink transmissions, assuming the probability of interference energy from Wi-Fi sensed to exceed a threshold at each channel is $p$.
  - Randomly choose the channel to transmit

$$I_{m,i} = \begin{cases} 
1, & \text{i-th LAA-UE selects the m-th resource batch,} \\
0, & \text{otherwise,}
\end{cases}$$

- The probability that the $m$-th channel is selected without collisions

$$\Pr \left\{ \sum_{i=1}^{N} I_{m,i} = 1 \right\} = N \left( \frac{1 - p^M}{M} \right) \left( 1 - \frac{1 - p^M}{M} \right)^{N-1}$$

Channel Selection

- Maximize number of LAA-UEs sharing $M$ channels\textsuperscript{[3]}
  - Optimization problem

\[
N^* = \arg \max_N \left\{ N \left( \frac{1 - p^M}{M} \right) \left( 1 - \frac{1 - p^M}{M} \right)^{N-1} \right\}
\]

- Solution

\[
N^* = \begin{cases} 
\frac{M}{1 - p^M}, & \text{if } \frac{M}{1 - p^M} \text{ is an integer,} \\
\left\lfloor \frac{M}{1 - p^M} \right\rfloor, & \text{otherwise,}
\end{cases}
\]

\[
N^* = \left\lfloor \frac{M}{1 - p^M} \right\rfloor \geq M
\]
Previous work

✓ 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).

$EB(1,1) = 0.2 \times 80 + 0.2 \times 20 = 20$

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

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

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.

$EB_{max} = EB(1,3) = 1 \times 40 + 1 \times 20 = 60$
Channel Selection

Previous work

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

$$\begin{align*}
\text{maximize} & \quad \sum_{i \in C} \sum_{j \in S_{\text{AC}}} p_j h_{ij} \left( 1 + \prod_{i \in i_1} \sum_{j \in j} (1 - p_j h_{ij}) \left( 1 + 2 \prod_{i \in i_2} \sum_{j \in j} (1 - p_j h_{ij}) \right) \right) + \sum_{i \in C} \sum_{j \in S_{\text{LAA}}} p_j h_{ij} \\
\text{s.t.} & \quad \sum_i h_{ij} = 1, \quad \forall j \in S \\
& \quad p_j h_{ij} = \min\{p_j h_{ij}, 1 / \sum_j h_{ij}\}, \quad \forall i \in C, \forall j \in S \\
& \quad j \cup j = S \\
& \quad h_{ij} \in \{0, 1\}
\end{align*}$$

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

Multiple transmitters have the same opportunity to win the channel access

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Work to do

- To do optimization, a lot of assumptions are required: ignore the procedure of CSMA/LBT, using probability instead of traffic model, and so on.
- Simplify the model, sub-optimal solutions.
- For 3GPP scenario, work on selecting channel based on measurements.