Auto-configuration of 802.11n WLANs

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Channel Bonding (CB)

- Goal of CB is to combine two adjacent 20 MHz channels to double the bandwidth (raw transmission rate)
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• CB, when blindly applied, hurts throughput!
  ✓ Extensive measurements with WARP and off-the-shelf 802.11n
  ✓ PHY and MAC observations

• User association + frequency selection
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• **Auto-Configuation** of 802.11n WLANs
  ✓ First system custom built for 802.11n
  ✓ 1.5x - 6x throughput gain per AP

• Public belief: CB always gives throughput benefits.
Roadmap

• CB - why and when does it fail?
  ✓ Effect on the PHY
  ✓ MAC and application layer observations

• Designing ACORN
  ✓ User association, channel selection

• Evaluation
CB at the PHY
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• 20 MHz vs 40 MHz (twice OFDM subcarriers in a symbol with CB)
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- Thermal Noise
  - $N \text{ (dBm)} = -174 + 10\log(B)$
  - 3 dB higher (twice) noise - *noise per subcarrier* is the same
CB at the PHY

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  ✓ For a given TX power, *energy per subcarrier* is halved (3 dB loss)
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- SNR per subcarrier is 3 dB less with CB
CB at the PHY
CB at the PHY

a) without CB

b) with CB
CB at the PHY

a) without CB

b) with CB
CB at the PHY

a) without CB

b) with CB
CB at the PHY

a) without CB

b) with CB
CB at the PHY

CB increases baud error rate → increase in BER
CB at the PHY

Graph 1:
- Bit Error Ratio vs. SNR (dB)
- BER-20Mhz
- BER-40Mhz
- Theory

Graph 2:
- Bit Error Ratio vs. Transmit Power [0:63]
- BER-20Mhz
- BER-40Mhz
CB at the PHY

- For a given TX power, BER is higher when CB is employed
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CB at the MAC

- PHY observations with CB may not be exported to MAC
  ✓ Coding (FEC)
  ✓ What is the impact on PDR?

- Throughput \( (T) = \text{Rate} \ (R) \times \text{PDR} \)
  ✓ \( T_{20} = R_{20} \times PDR_{20} \)
  ✓ \( T_{40} = R_{40} \times PDR_{40} = 2 \times R_{20} \times PDR_{40} \)
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Throughput ($T$) = Rate ($R$) * PDR

- $T_{20} = R_{20} * PDR_{20}$
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$$\sigma = \frac{PDR_{20}}{PDR_{40}}$$
CB at the MAC

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$$\sigma = \frac{PDR_{20}}{PDR_{40}}$$

- $T_{20} > T_{40}$ if
  $$\sigma > 2$$
CB at the MAC

\[ \sigma = \frac{PDR_{20}}{PDR_{40}} \]

- \( T_{20} > T_{40} \) if \( \sigma > 2 \)

<table>
<thead>
<tr>
<th>( \sigma \geq 2 )</th>
<th>QPSK(^{3/4})</th>
<th>16QAM(^{3/4})</th>
<th>64QAM(^{3/4})</th>
<th>64QAM(^{5/6})</th>
</tr>
</thead>
<tbody>
<tr>
<td>-7dB</td>
<td>3dB</td>
<td>5dB</td>
<td>8dB</td>
<td></td>
</tr>
<tr>
<td>-4dB</td>
<td>5dB</td>
<td>7dB</td>
<td>11dB</td>
<td></td>
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</table>

2 - 3 dB of critical region
CB at the end-user

Throughput-20Mhz (Mbits/s)

Throughput-40Mhz (Mbits/s)

UDP

TCP
CB at the end-user
CB at the end-user

CB hurts for poor links!
Summary

• CB does not always benefit
  ✓ SNR decrease
  ✓ Increased BER
  ✓ Increased PER

• Culprit for poor links
Roadmap

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ACORN

- User association
  - Group similar quality clients in a cell
ACORN

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Diagram:
- AP
- Poor Client
- Good Client
ACORN

- User association
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Diagram:
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User Association

\( \text{ATD}_i \): aggregate transmission delay of AP i
\( \text{Mi} \): channel access time of AP i (\( = 1 \) with no contention, saturated traffic)
\( \frac{\text{Mi}}{\text{ATD}_i} \): long term per-client throughput of AP i
\( K_i \): number of clients of AP i (including u)
User Association

\[ \text{max. } U_{\text{asoc}}(u, i) = K_i \cdot X_{w,u}^i + \sum_{j \in A_u, j \neq i} (K_j - 1) \cdot X_{wo,u}^j \]

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$M_i$ : channel access time of AP i ( = 1 with no contention, saturated traffic)

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aggregate throughput of AP i

max. $\mathcal{U}_{asoc}(u, i) = K_i \cdot X_{w,u}^i + \sum_{j \in A_{u,j \neq i}} (K_j - 1) \cdot X_{w_0,u}^j$
User Association

\[ \text{aggregate transmission delay of AP } i \]
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\[ \frac{M_i}{ATD_i} : \text{long term per-client throughput of AP } i \]
\[ K_i : \text{number of clients of AP } i \text{ (including } u) \]

aggregate throughput of AP \( i \) aggregate throughput of other APs

\[
\max. \quad U_{assoc}(u, i) = K_i \cdot X_{w,u}^i + \sum_{j \in A_u, j \neq i} (K_j - 1) \cdot X_{w_0,u}^j
\]
Channel Selection

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<td>( F : V \rightarrow Ch )</td>
<td>Channel assignment mapping</td>
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\max_{F} \quad Y = \sum_{i \in V} X_i(F)
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$\max_{F} Y = \sum_{i \in V} X_i(F)$

The problem reduces to graph coloring and is NP-complete

- In every iteration:
  - AP with the max. increase in aggregate throughput picks a new channel

- When there is no improvement, terminate
Channel Selection

20 MHz  40 MHz
Channel Selection

-3 dB

20 MHz ➔ 40 MHz
Channel Selection

-3 dB

20 MHz ➔ 40 MHz ➔ +3 dB
Channel Selection

-3 dB

20 MHz → 40 MHz

+3 dB

Theoretical BER

BER
Channel Selection

-3 dB

20 MHz

40 MHz

+3 dB

Theoretical BER

1 - (1 - BER)^L

BER

PER
Channel Selection

20 MHz → -3 dB → Theoretical BER → BER → I - (1 - BER)^L → PER

40 MHz ← +3 dB ←

Set of Interferers
Channel Selection

-3 dB  
20 MHz  
40 MHz  
+3 dB

Theoretical BER  
1 - (1 - BER)^L

Set of Interferers  
Scale down channel access ratio by (# Interferers + 1)
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Evaluation

• 18 node 802.11n testbed - Ralink chipset

• Comparison with a legacy auto-configuration system
  ✓ Kauffmann et. al. - Infocom’07

• Legacy user association
  ✓ Minimize total ATD of all users

• Legacy channel selection
  ✓ Minimize total interference between APs
  ✓ Modified to aggressively pick 40 MHz channels
Pictorial representation of actual testbed deployment
Evaluation

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Evaluation

Mid-quality client group - AP3 serves one good client
Evaluation

![Diagram showing network with AP2, AP3, AP4, AP5, and API connections]

![Throughput (Mbps) bar chart comparing Legacy and ACORN for API and AP3]
Evaluation

With ACORN, higher congestion at API

*Aggregate throughput* does not change!
Conclusion

• CB can hurt throughput even in isolation
  ✓ User association becomes critical

• CB increases interference
  ✓ Addressing channel selection

• ACORN performs both functions in tandem
  ✓ Trade off fairness for aggregate throughput

• Implementation on a testbed and evaluations show:
  ✓ ACORN outperforms legacy approaches agnostic to CB
THANK YOU!