ACORN: Managing Interference in 802.11n WLANs

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Interference Problem

• Delivering high data rates in wireless networks is challenging.

• Interference: Degradation in wireless network performance due to the noise generated by other devices in the spectrum.
Indoor Wireless Networks

Source: telco2research.com

Femto gives more control to operator than WiFi but higher cost.

Most WiFi traffic from mobile devices just goes via "normal" fixed line broadband route straight to Internet. Low cost but low control or visibility to operator.

Femto traffic still goes via operator core although 99% direct to Internet rather than own servers.
Indoor Wireless Networks

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The Case of Noisy Neighbors

CNET:

9:37 a.m.: Google is asking attendees to turn off their cell phones, as the interference has ground this demonstration to a halt. Awkward.
The Case of Noisy Neighbors

CNET: Coping with Wi-Fi's biggest problem: interference

PCWorld: Networking & Wireless
1. Public Enemy Number One: Your Neighbors' Wi-Fi Networks

"I'd say the biggest source of interference today for most people is their neighbors' Wi-Fi networks," says Kale. The problem is that most existing Wi-Fi equipment operates on the crowded 2.4GHz band. "There are basically three nonoverlapping channels. I always describe it as a three-lane road that's really, really busy," Kale adds.
The Case of Noisy Neighbors

How can we deal with interference in indoor wireless networks?

- **Using resource allocation to manage the spectrum.**

- The goal is to restore the true potential of indoor wireless networks by mitigating interference and hence, enabling high data rates.
Wireless 101

- SINR: Signal to Interference + Noise Ratio:
  - How strong is your received signal?
    - Noise + interference results in poor reception.
      - *Interference is generated by other transmissions.*
  - Modulation: the rate at which you encode and transmit bits
    - Higher mod (higher SINR required) $\Rightarrow$ higher data rate.
  - The effect of interference
    - *Low SINR $\Rightarrow$ low modulation $\Rightarrow$ low data rate on the link.*
802.11n 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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**Fact:** CB increases interference (Pelechrinis et. al, Shrivastava et. al.)
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Fact: CB increases interference (Pelechrinis et. al, Shrivastava et. al.)

Public belief: CB always gives throughput benefits in isolation.
Common Belief About CB

- CB is advertised to be “just great”!
Contributions

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  • Extensive measurements led to PHY and MAC observations.
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• Extensive measurements led to PHY and MAC observations.

• Auto-**C**O**nfigu**R**ation of 802.11**N** WLANs
  ✓ First system targeted for 802.11n
  ✓ 1.5x - 6x throughput gain per AP
Roadmap

- CB - why and when does it fail?
  - Experiments to reveal fine-grained observations.

- Designing ACORN
  - User association, channel selection

- Key evaluation results
CB at the PHY
CB at the PHY

- 20 MHz vs 40 MHz (twice the sub-carriers in a symbol with CB)
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- Sub-carrier energy
  - For a given TX power, \textit{energy per sub-carrier} is halved.
CB at the PHY

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- Sub-carrier energy
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- $P_1$: energy with 20 MHz and $P_2$: energy with 40 MHz.
  - $10\log_{10}(P_1/P_2) = 3$ dB loss in transmitted energy.
Measured Power Spectral Density

![Graph of Measured Power Spectral Density](image)

- Power / frequency (dB / Hz)
- Frequency (MHz)

- 20 MHz
- 40 MHz
Measured impact on received signals

a) without CB

b) with CB
Measured impact on received signals

a) without CB

b) with CB
Measured impact on received signals

- a) without CB
- b) with CB
Measured impact on received signals

CB increases baud error rate

increase in BER
For a given TX power, BER is higher when CB is employed.
CB effect as seen by the user: lower throughput
CB effect as seen by the user: lower throughput
CB effect as seen by the user: lower throughput

CB reduces throughput for low-SINR links!
A “bad” node affects everybody’s performance

• Assume one AP and multiple clients connected to it.
  • AP serves each client in a fair manner in the long term (equal opportunities for access).
  • A low data rate client (i.e. low SINR) has high service time.
    • Reduces the long-term throughput of other clients of the AP.

• How can we address this?
  • Use ACORN!
What is ACORN?

- ACORN manages interference in IEEE 802.11n WLANs.
- It assigns 20 MHz or 40 MHz bands to base stations intelligently.
- It performs intelligent user-association
  - wherein clients are assigned to appropriate cells to aid frequency band allocation (as above).
- ACORN’s key idea:
  - *Prevent low SINR clients from joining APs with 40 MHz*
ACORN’s User Association

- Key idea: group similar quality clients in a cell
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ACORN’s Channel Selection

• Problem: given a network of APs, assign channels s.t. the aggregate network throughput is maximized.

• reduces to graph coloring ==> NP-hard

• Iteratively assign each channel to the AP that has the best throughput increase with that channel.
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20 MHz  →  40 MHz
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\[\text{20 MHz} \rightarrow \text{40 MHz} \rightarrow \text{BER}\]

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Evaluation through implementation

• 18 node 802.11n testbed.

• Comparison with a legacy auto-configuration system
  • Kauffmann et. al. - Infocom’07
    • Legacy user association
      • Minimize total transmission delay.
    • Legacy channel selection
      • Each AP selects a channel with the least interference.
      • Pick 40 MHz channels all the time (mimic public belief).
Evaluation

[Diagram showing connections between AP2, AP3, AP1, AP4, and AP5]
Evaluation

AP2

AP3

AP4

AP1

AP5
Evaluation

CB avoided due to low-SINR clients.
Evaluation
Evaluation
Evaluation

Mid-quality client group - AP3 serves one good client
Evaluation
With ACORN, higher congestion at API (per-client throughput is reduced) but aggregate throughput does not change!
Conclusion

• Demonstrated that CB may hurt throughput even in isolation.
  • User association becomes critical and is coupled with channel width selection.
• ACORN performs both functions in tandem
  • the goal is to maximize network throughput (NP-hard).
• outperforms state-of-the-art by as much as 6x via careful selection of channel width.