ACORN: Managing Interference in 802.11n WLANs

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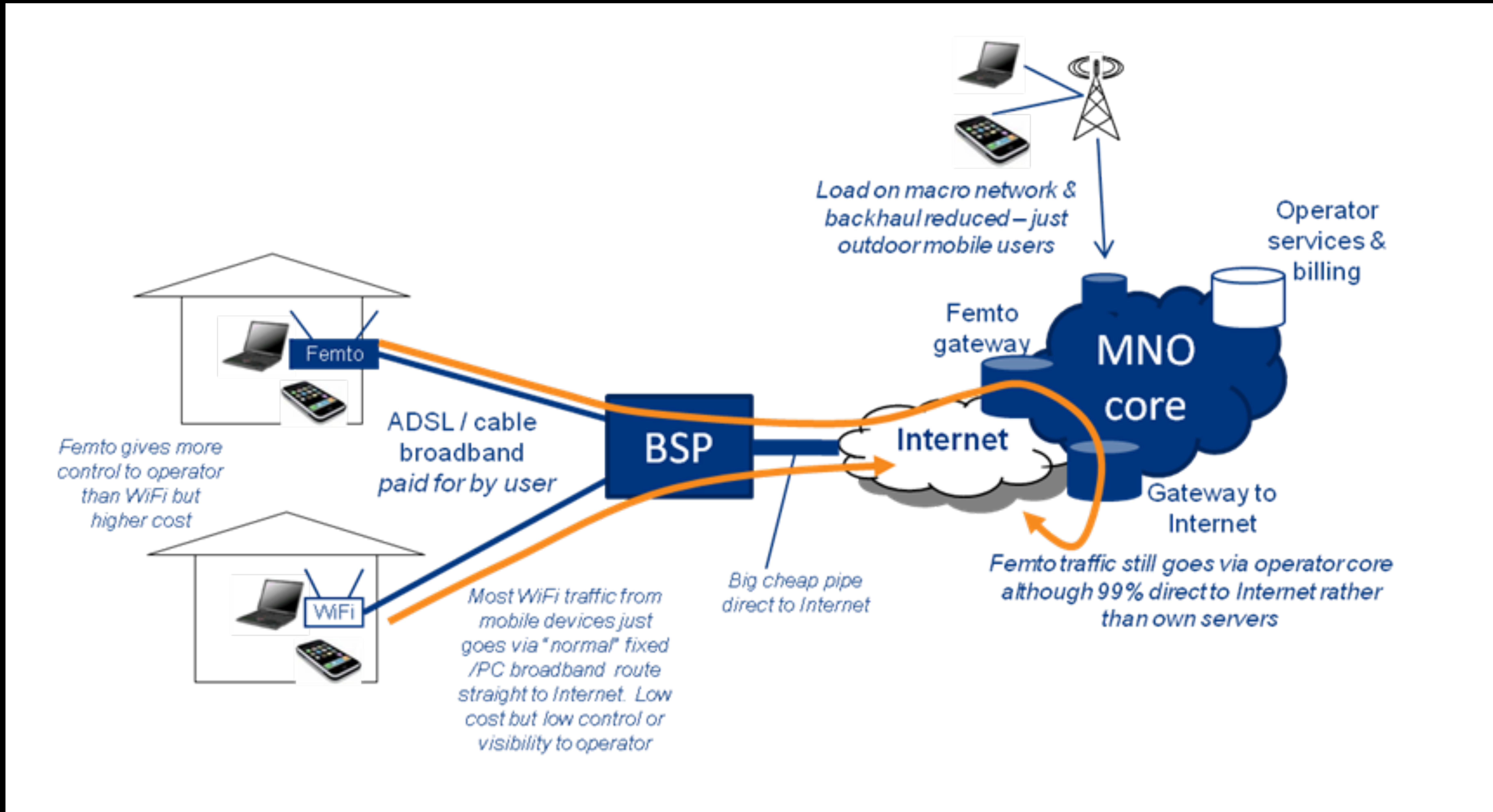
ACM CoNEXT 2010

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



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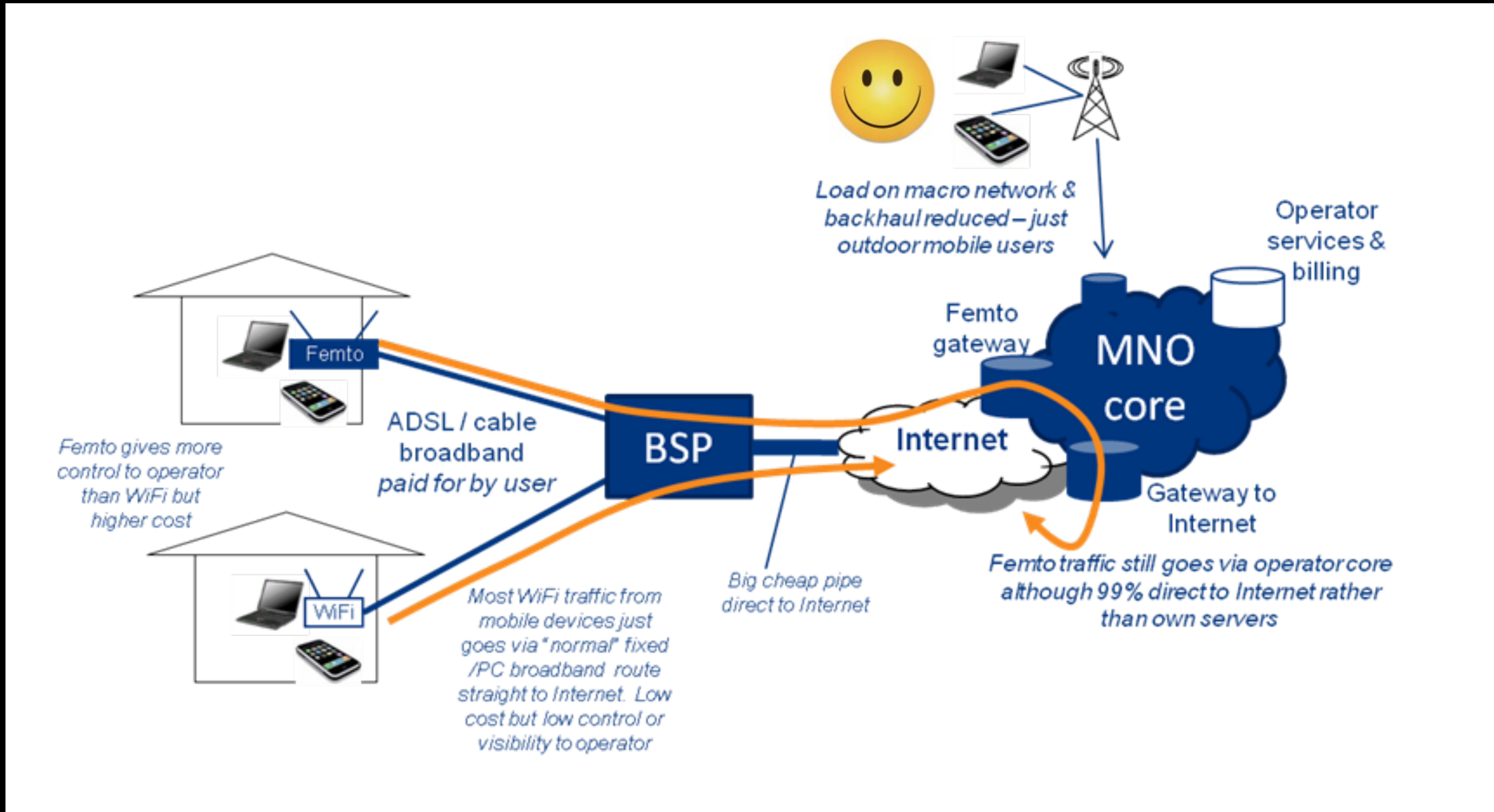

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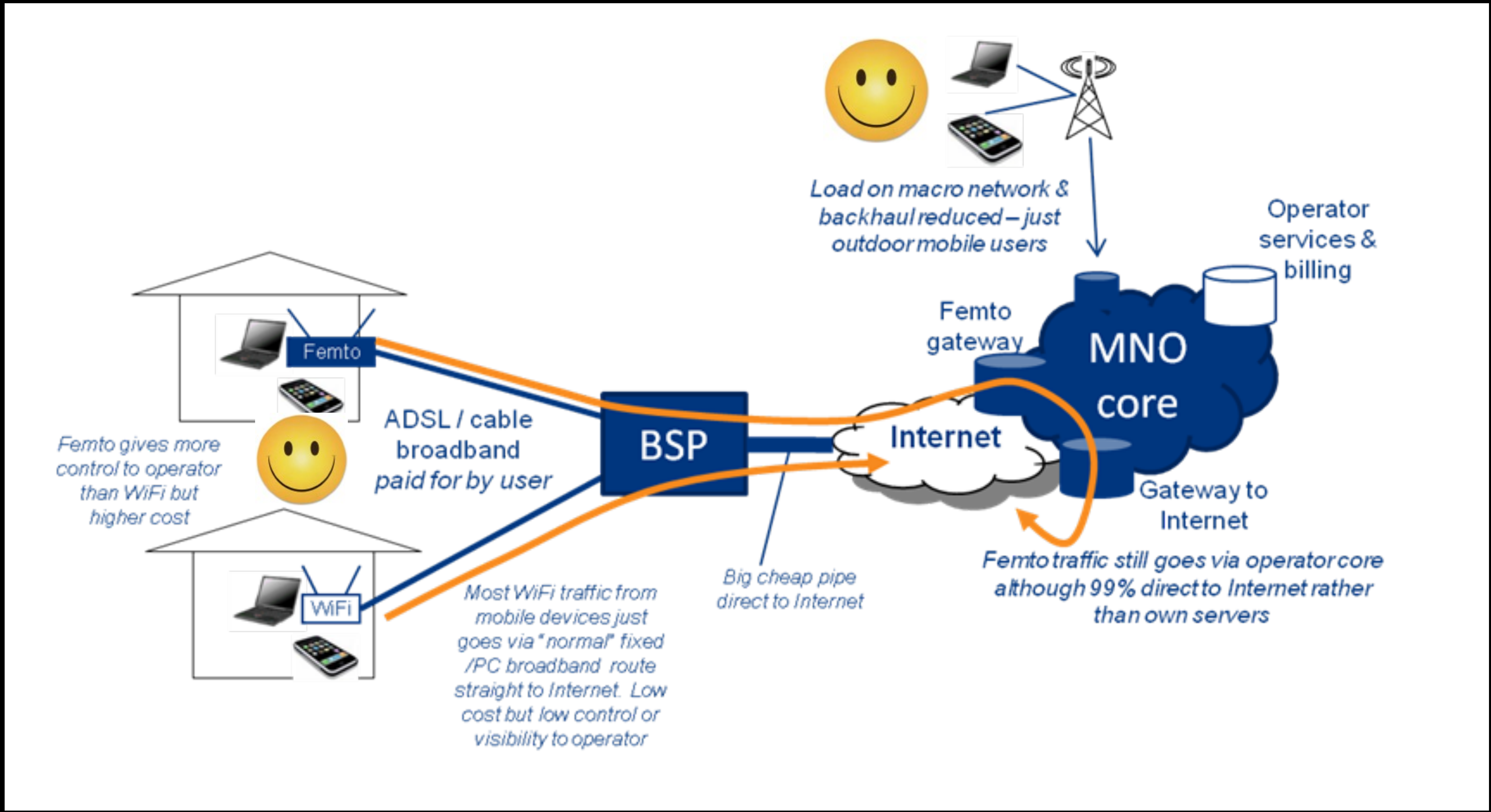

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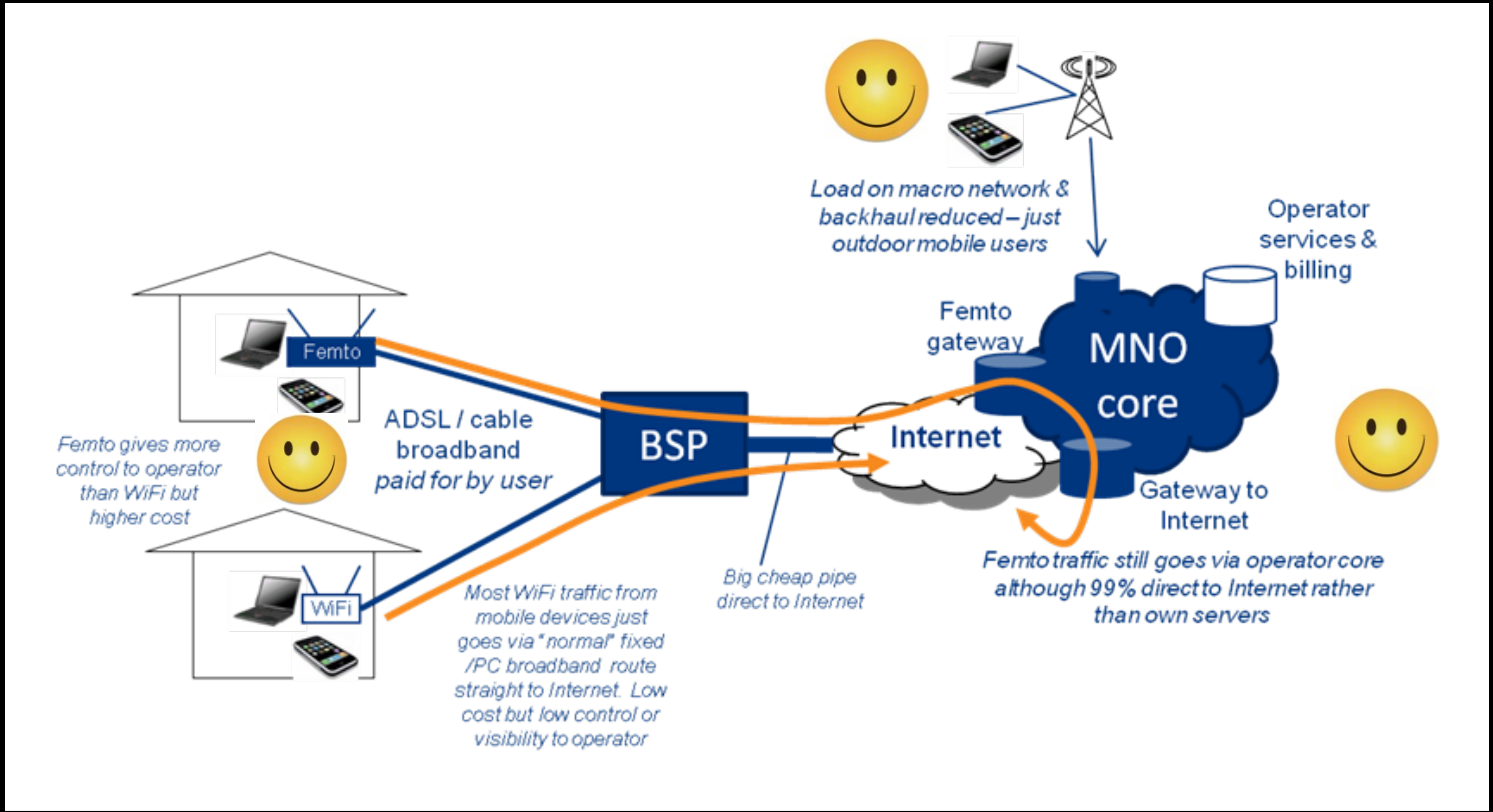

The Case of Noisy Neighbors

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:

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) ==> higher data rate.
- The effect of interference
  - *Low SINR ==> low modulation ==> 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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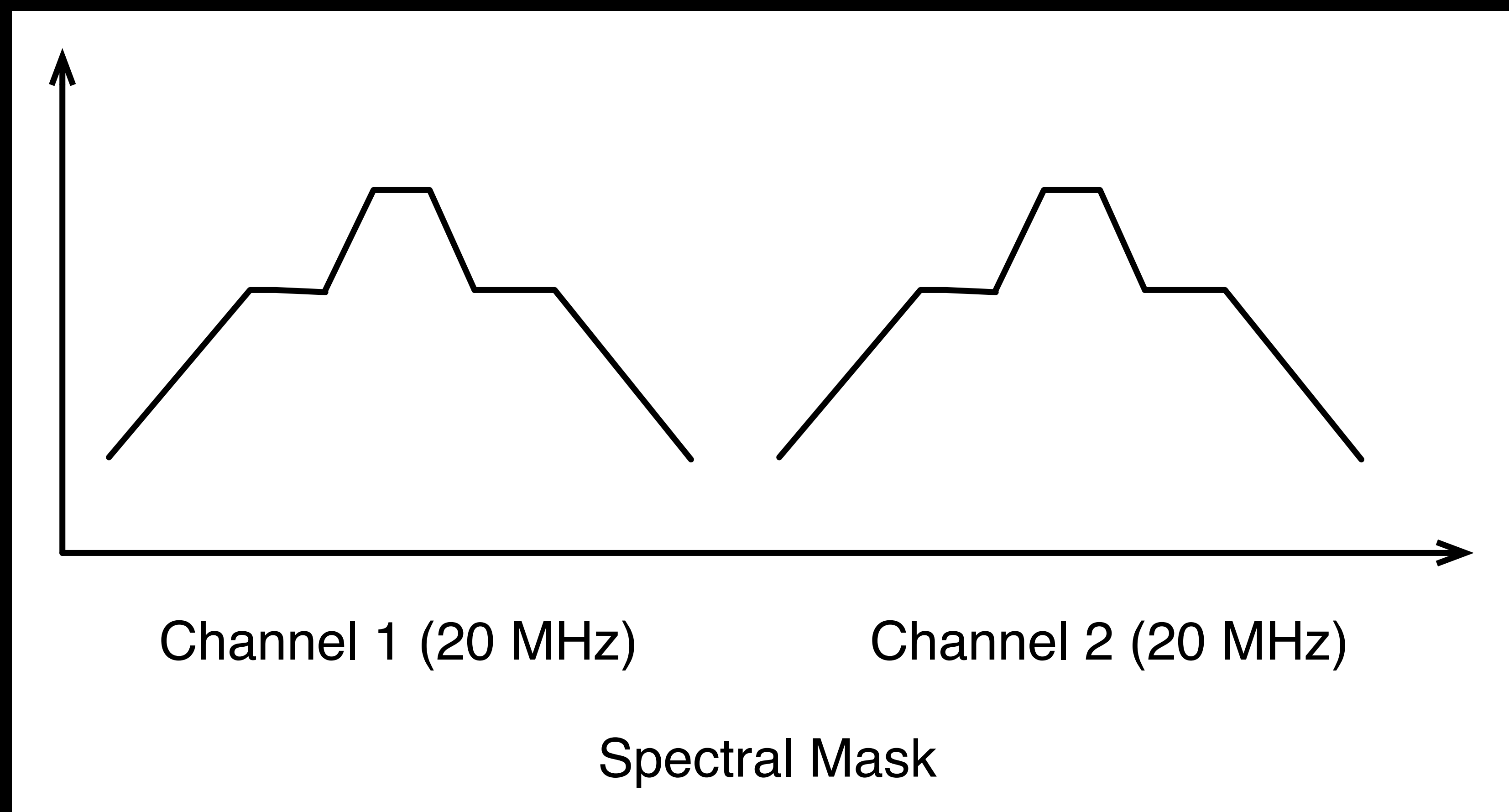

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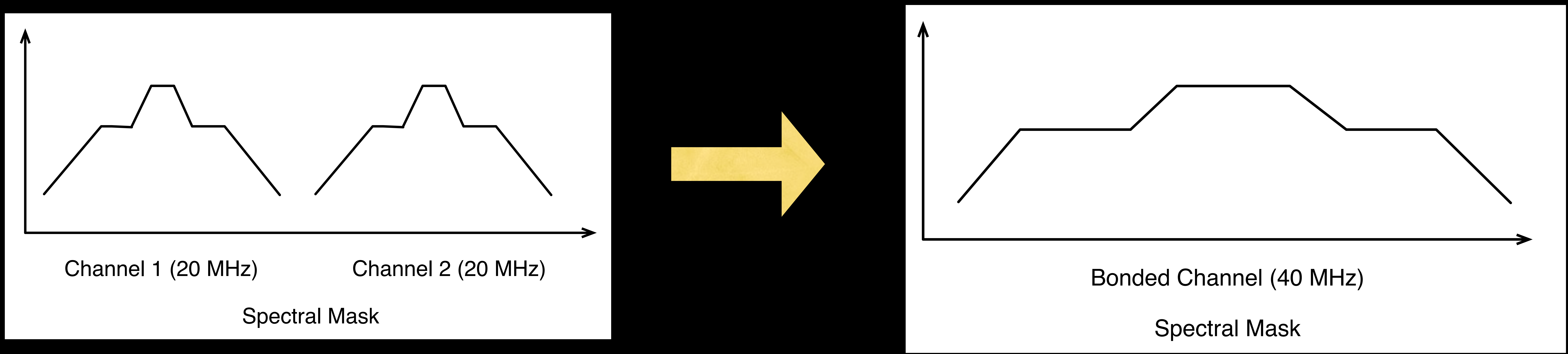

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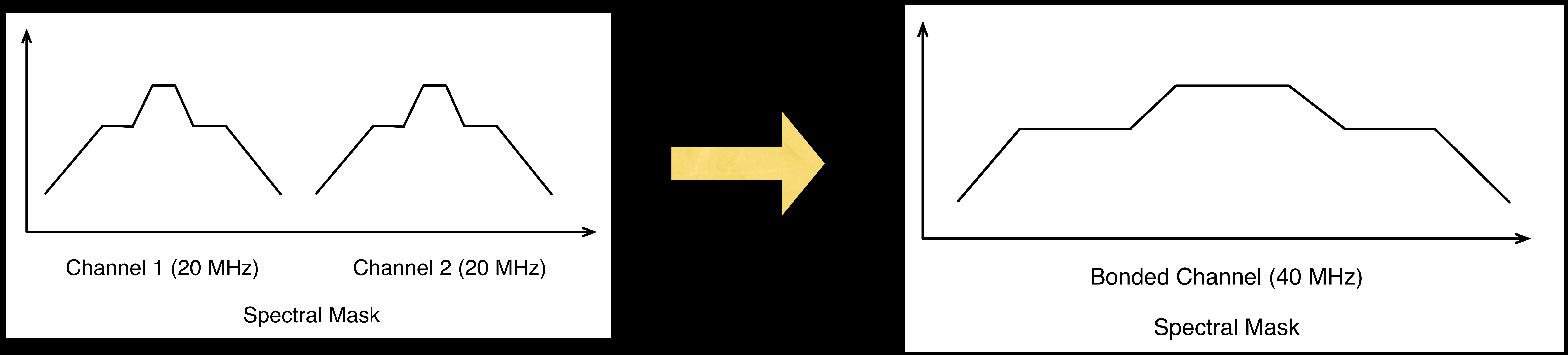

Fact: CB increases interference (Pelechrinis et. al, Shrivastava et. al.)

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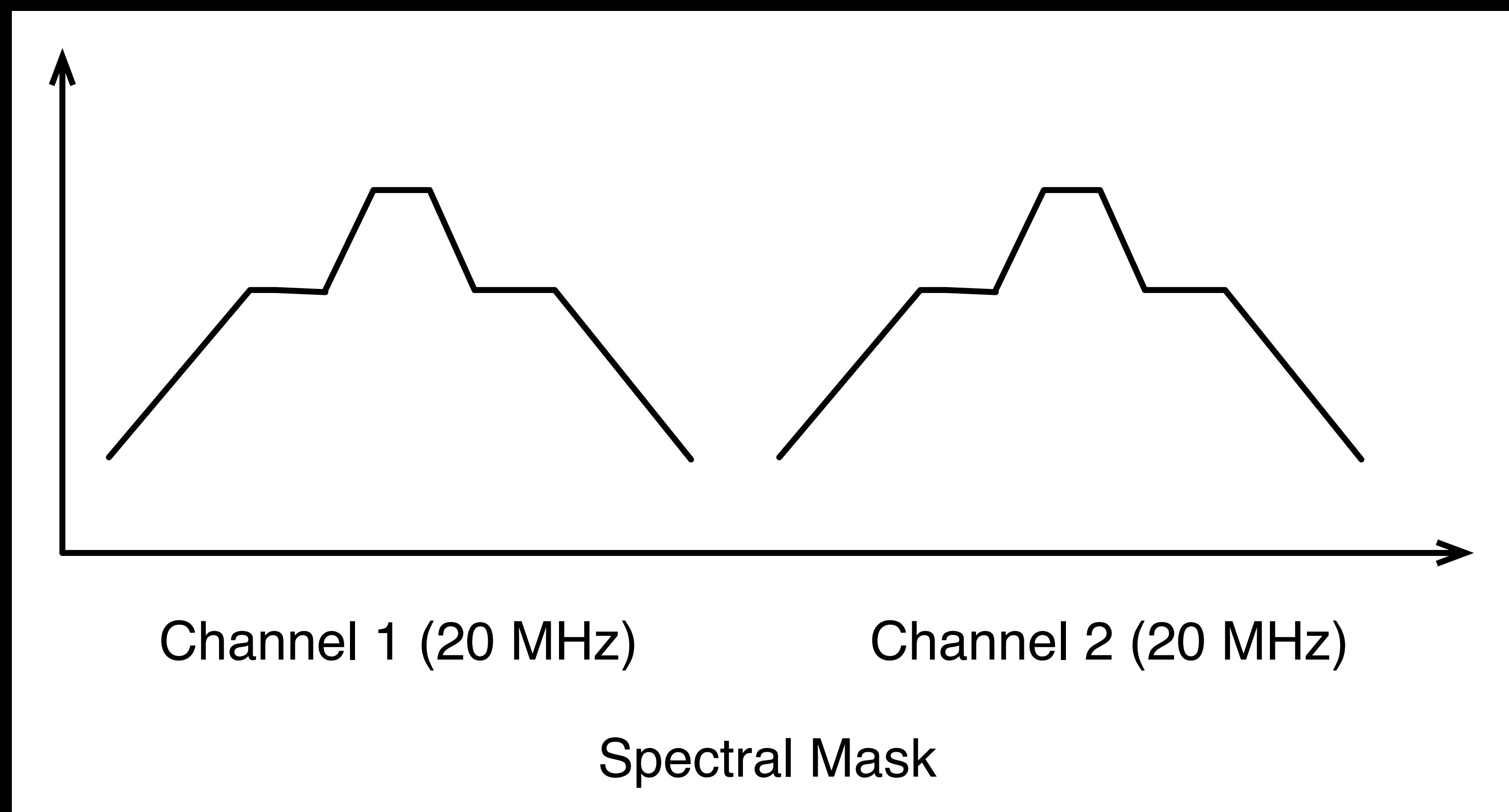

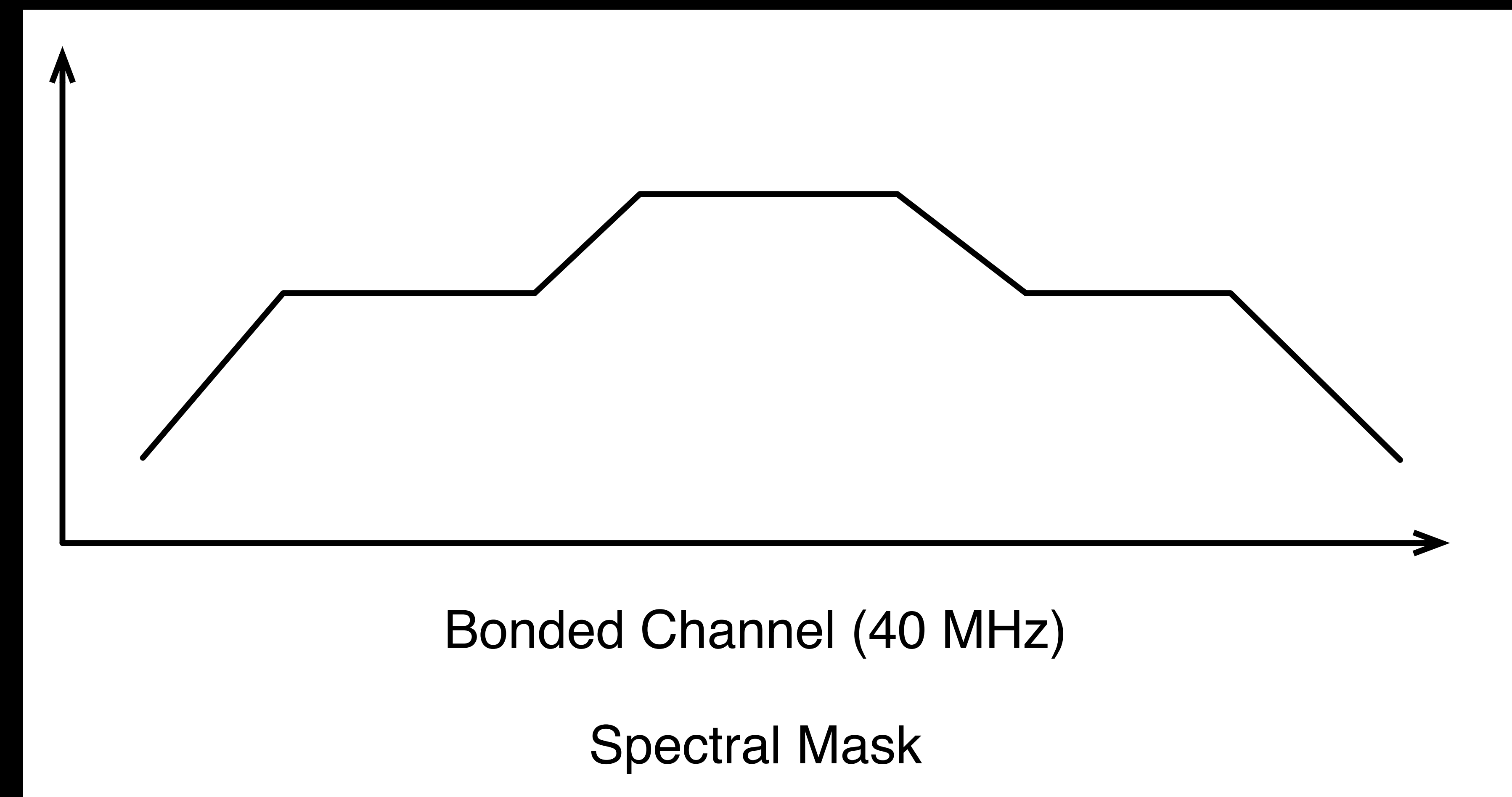

Fact: CB increases interference (Pelechrinis et. al, Shrivastava et. al.)

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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- **A**uto-**CO**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

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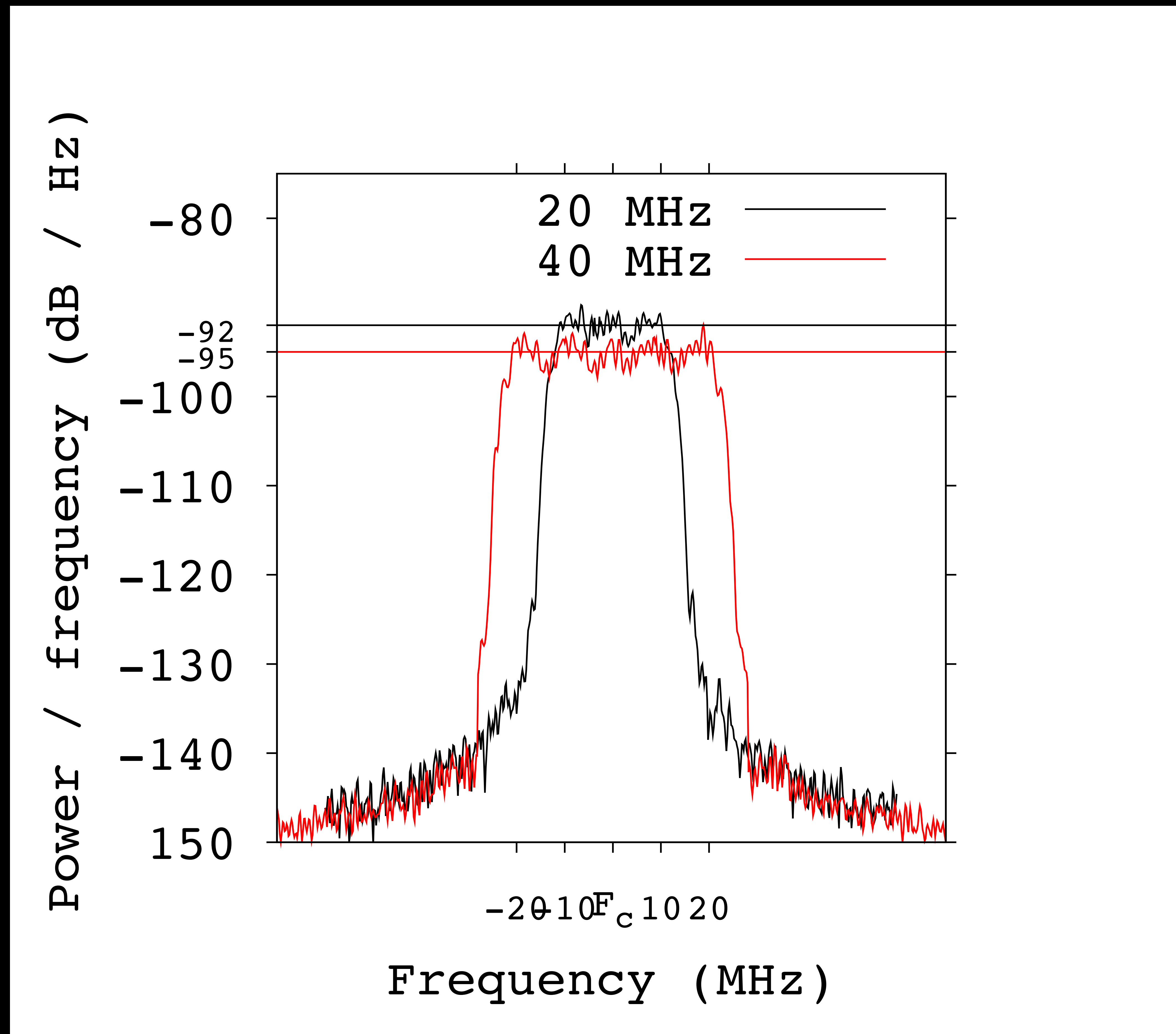
  - For a given TX power, *energy per sub-carrier* is halved.

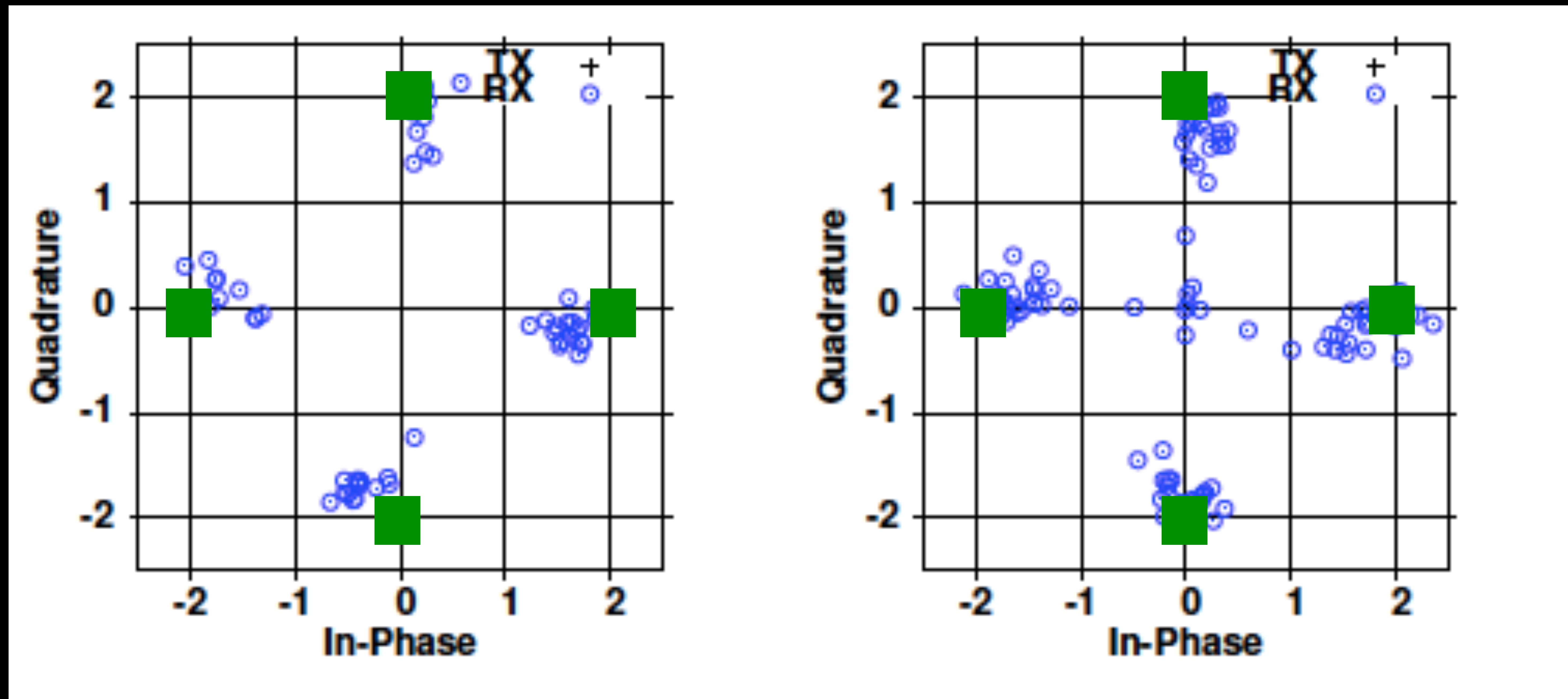
CB at the PHY

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



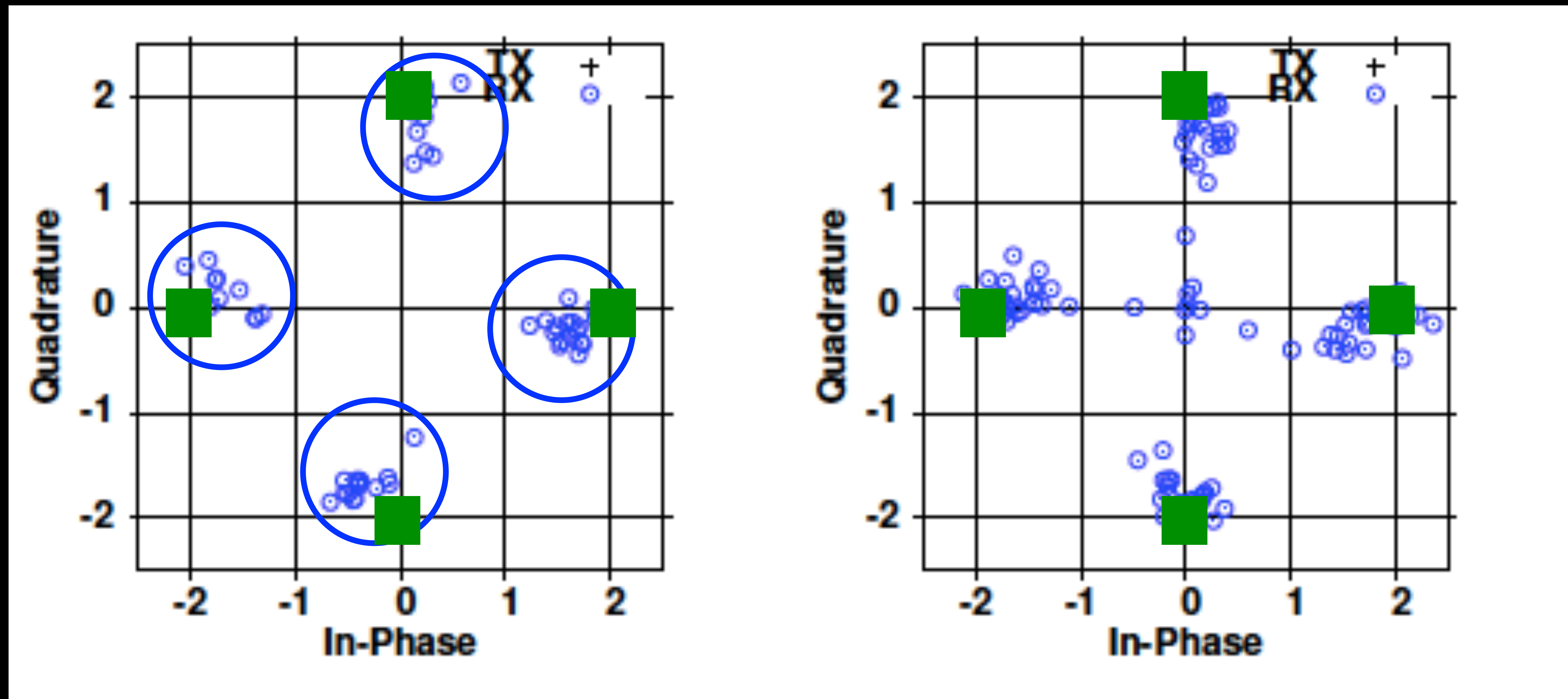
Measured impact on received signals



a) without CB

b) with CB

Measured impact on received signals



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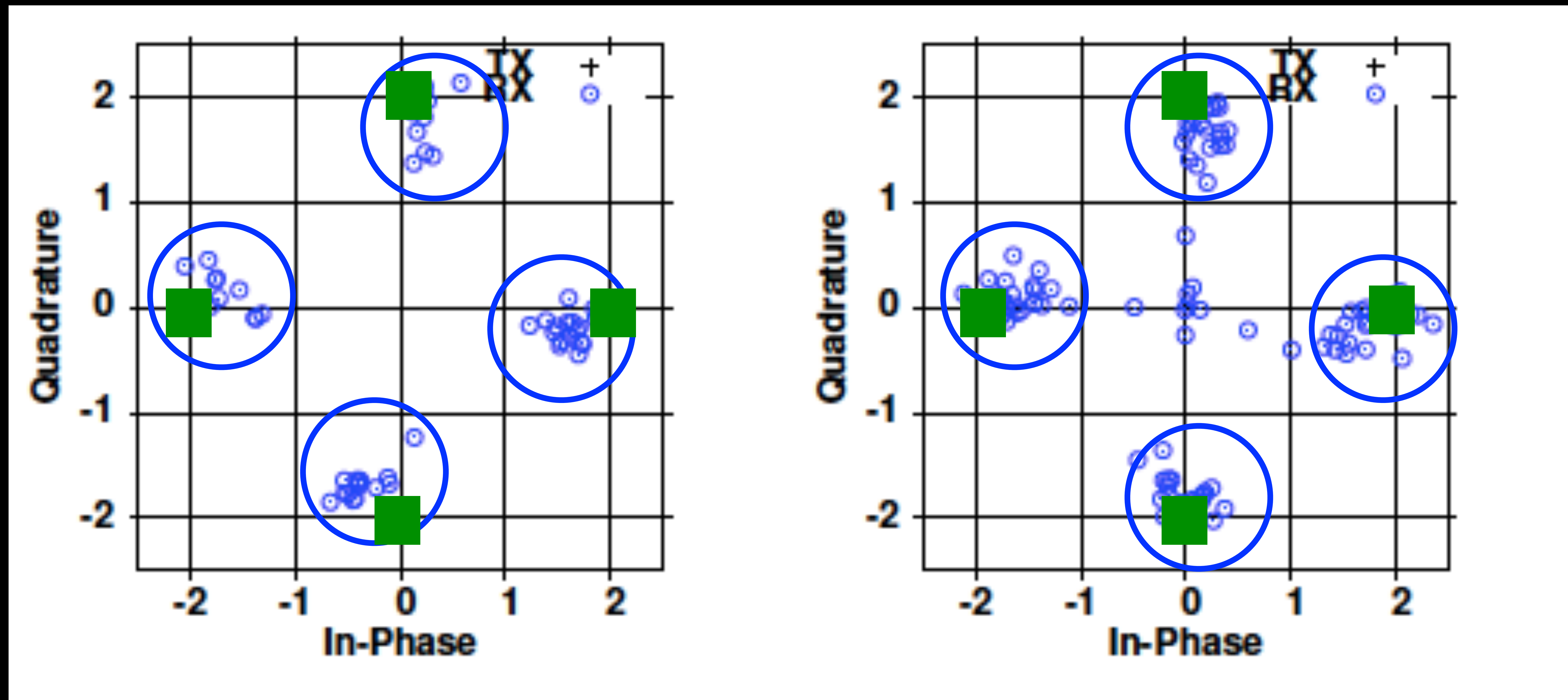

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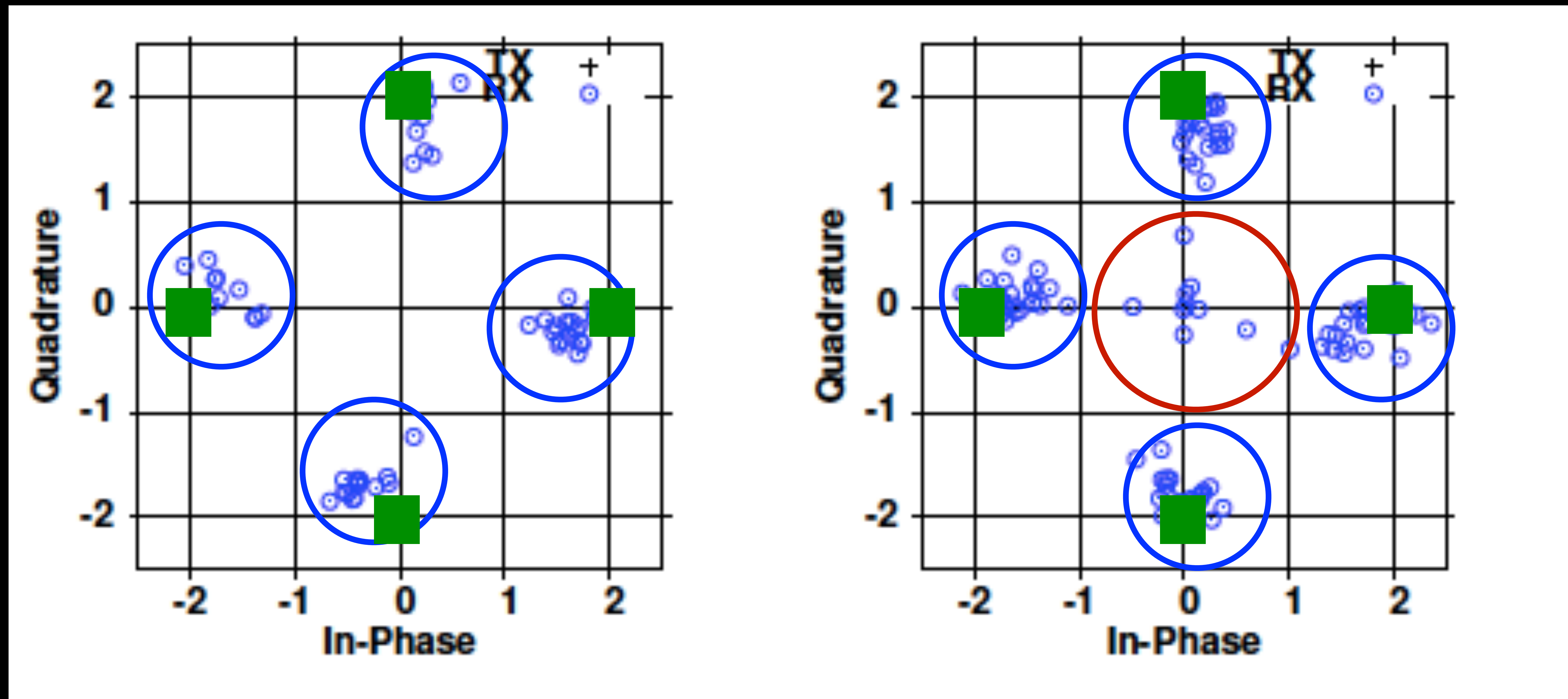
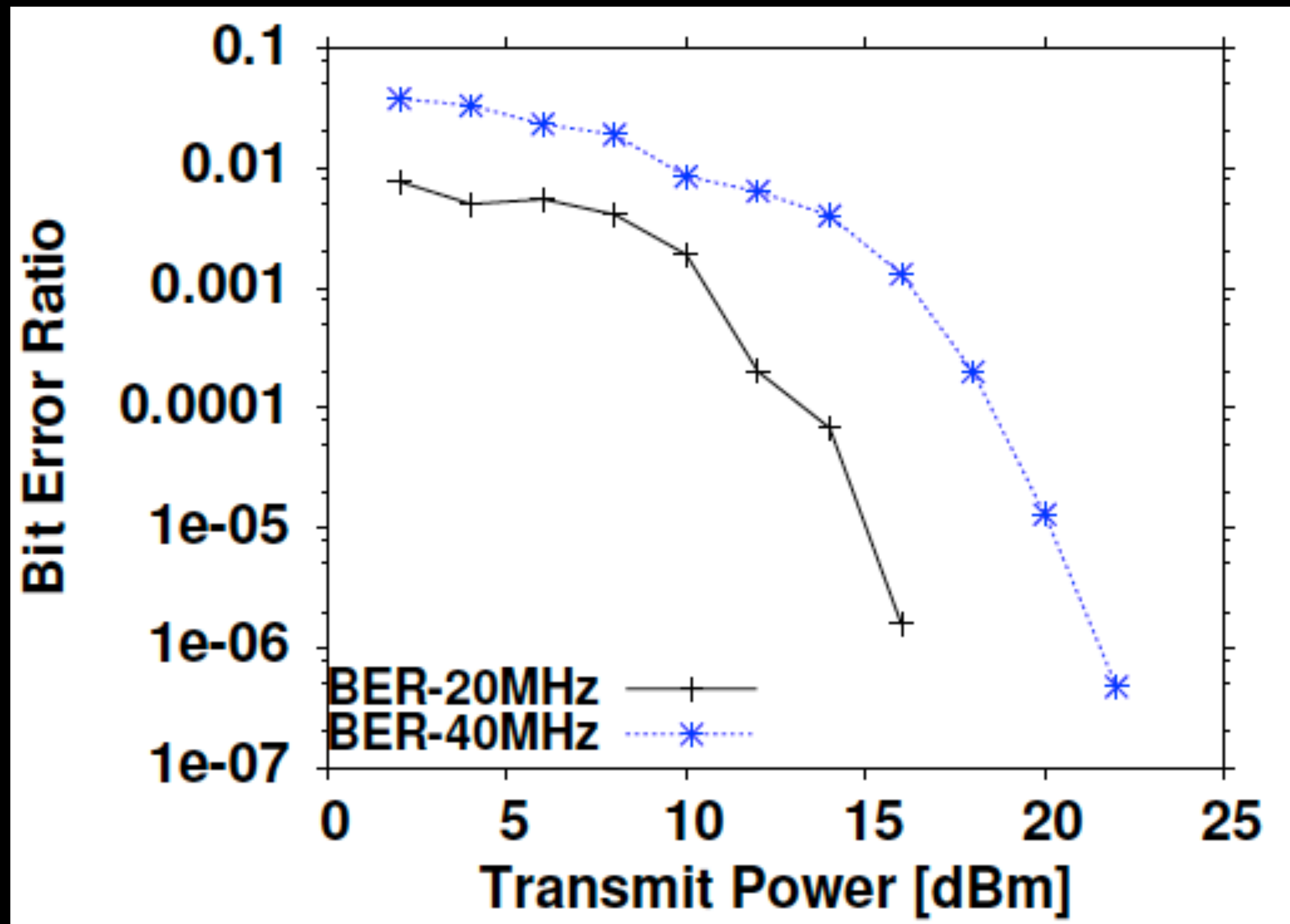


a) without CB

b) with CB

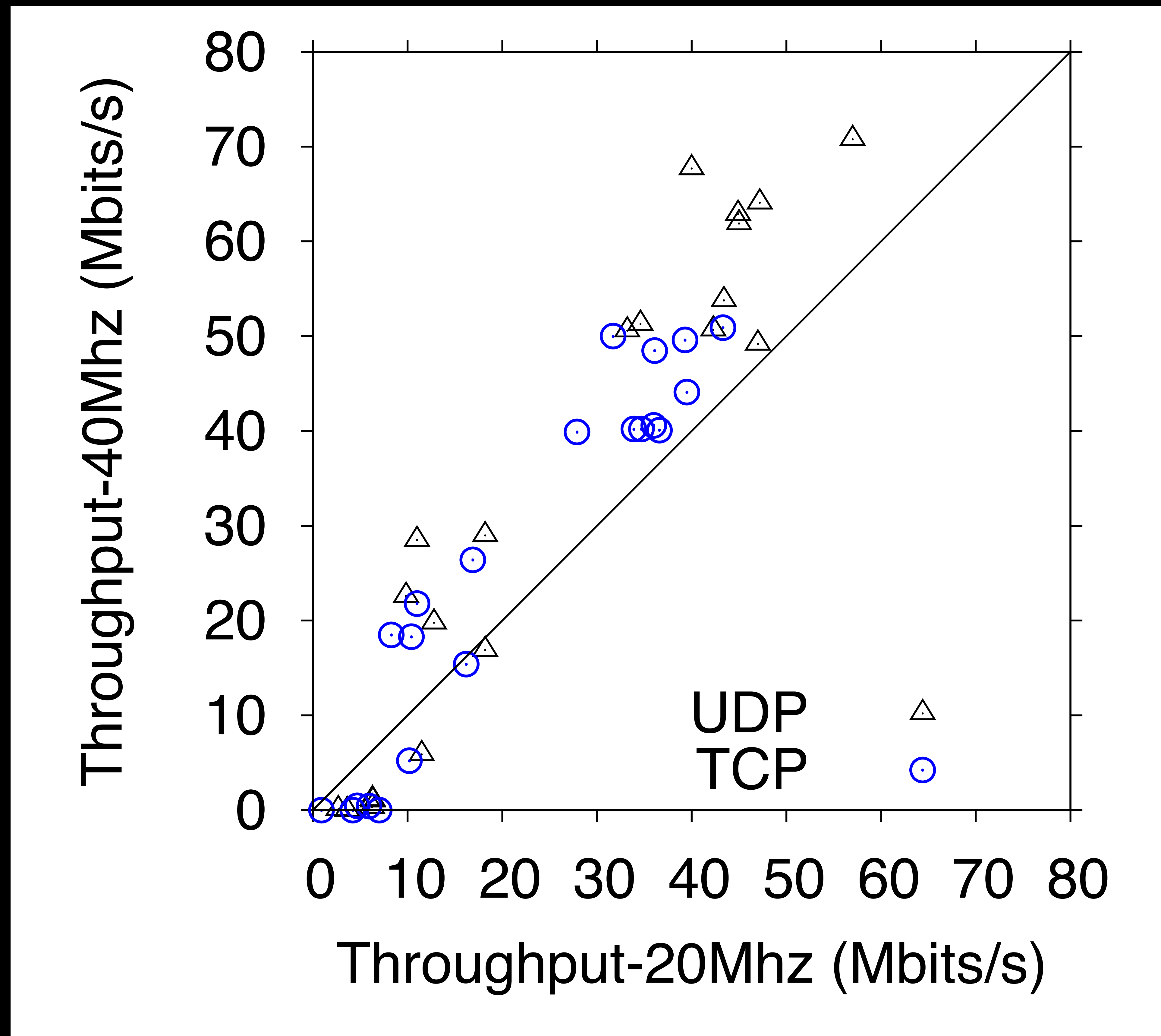
CB increases baud error rate → increase in BER

Measured Bit Error Rates with CB



- For a given TX power, BER is higher when CB is employed.

CB effect as seen by the user: lower thruput



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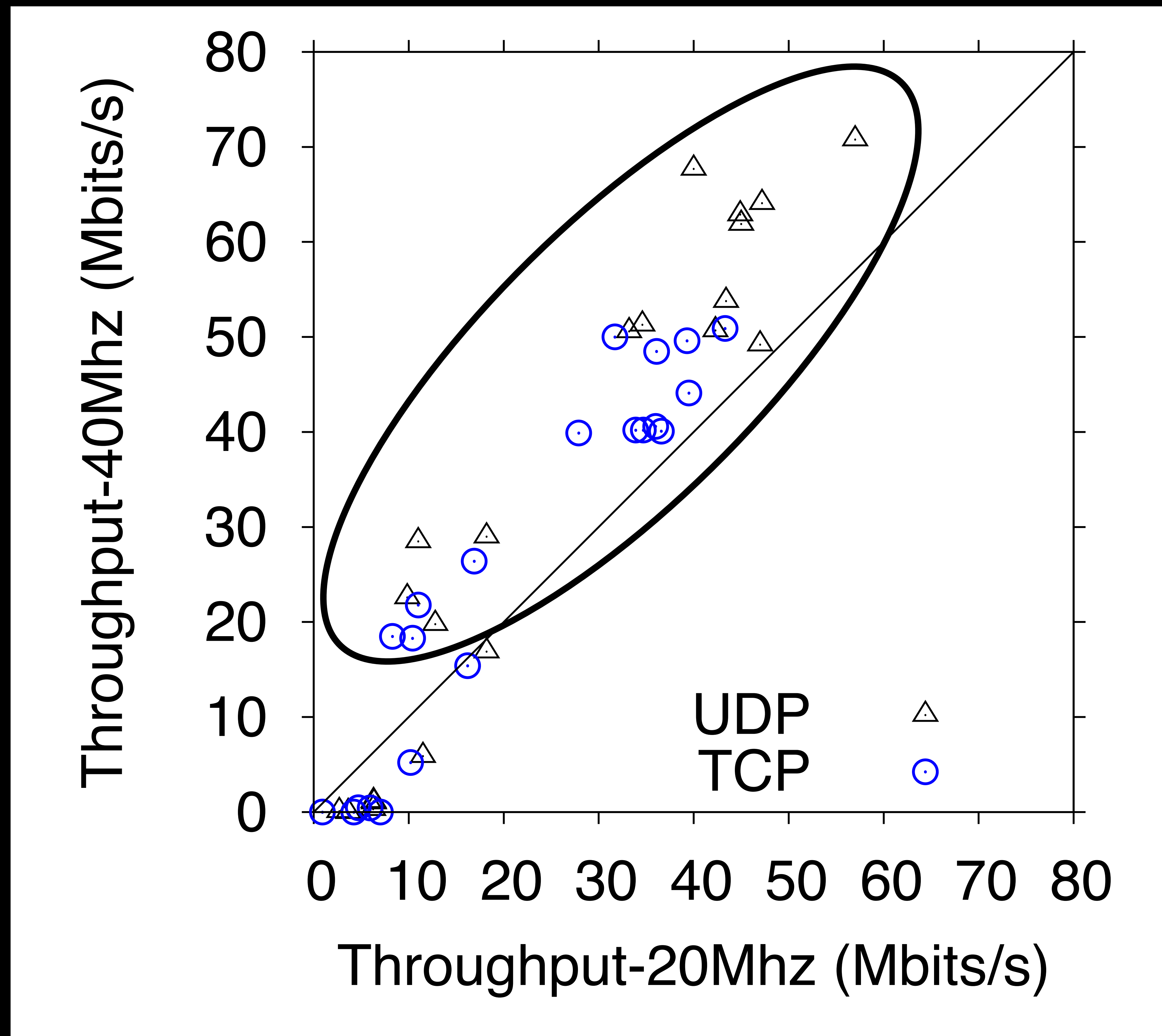

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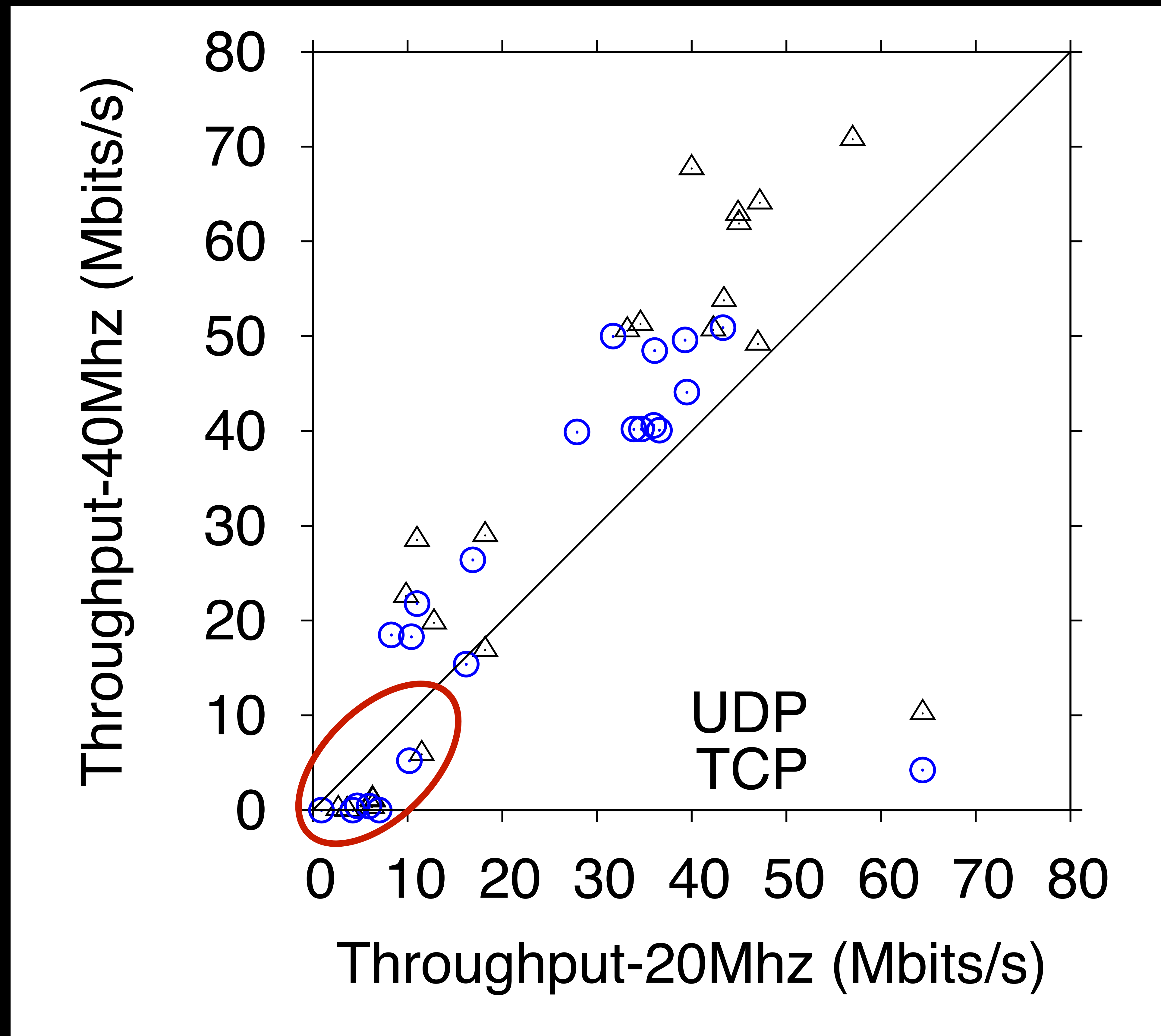


CB reduces throughput for low-SINR links!

A “bad” node affects everybody’s performance

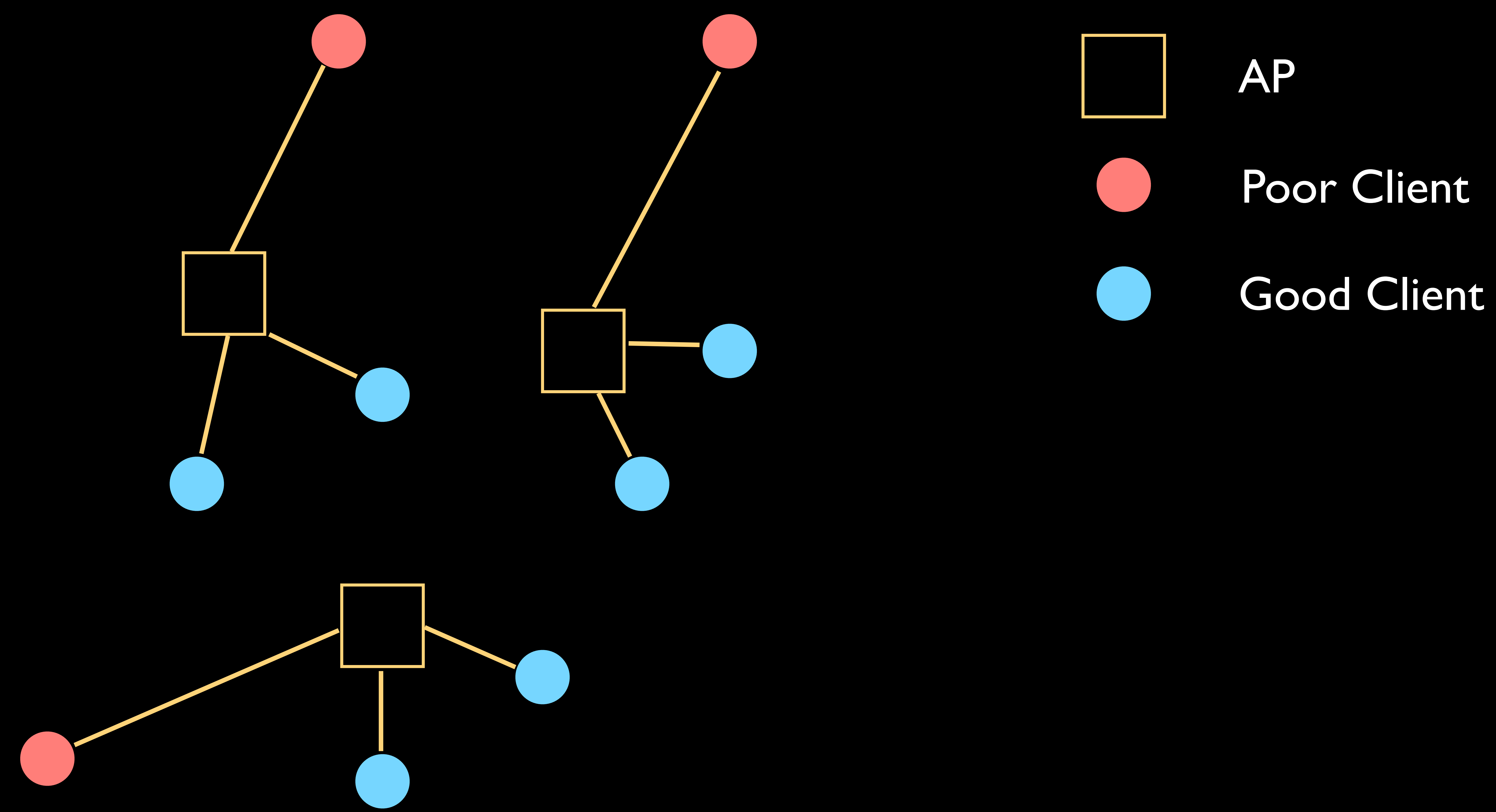
- Assume one AP and multiple clients connected to it.
  - AP serves each client in a fair manner in the long term (equal opportunities for access).
- A low data rate client (i.e. low SINR) has high service time.
  - Reduces the long-term throughput of other clients of the AP.
- How can we address this?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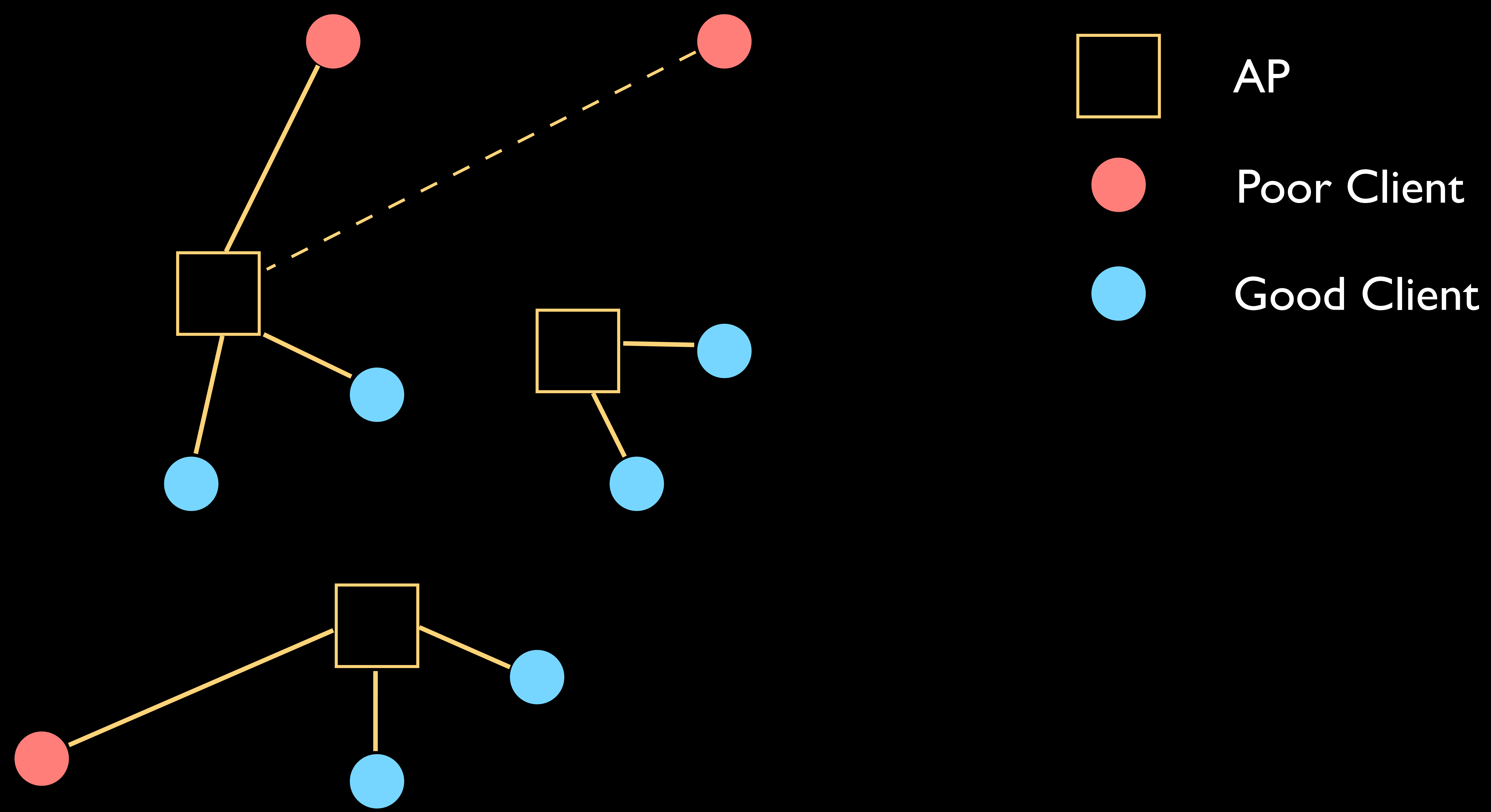

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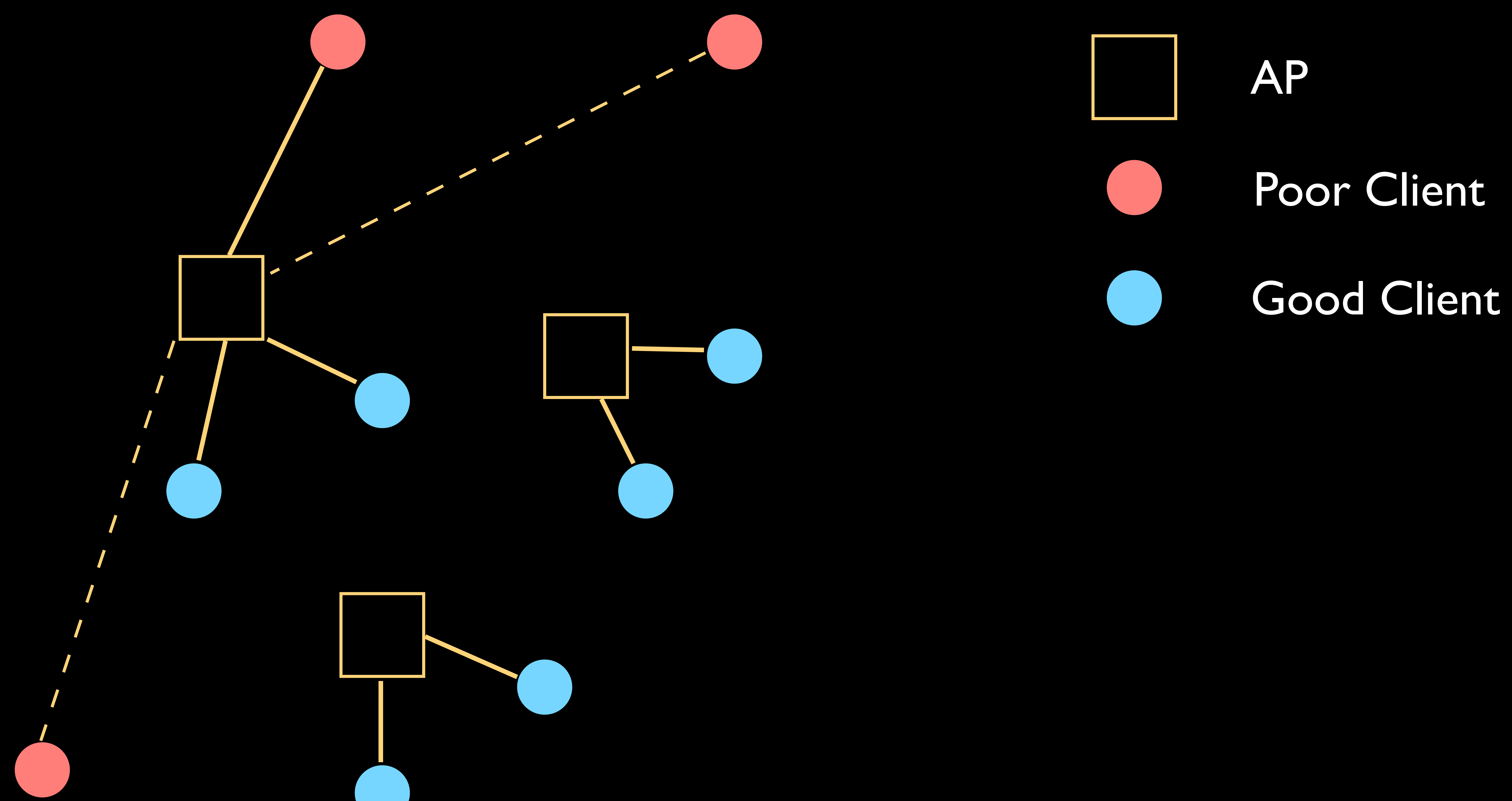

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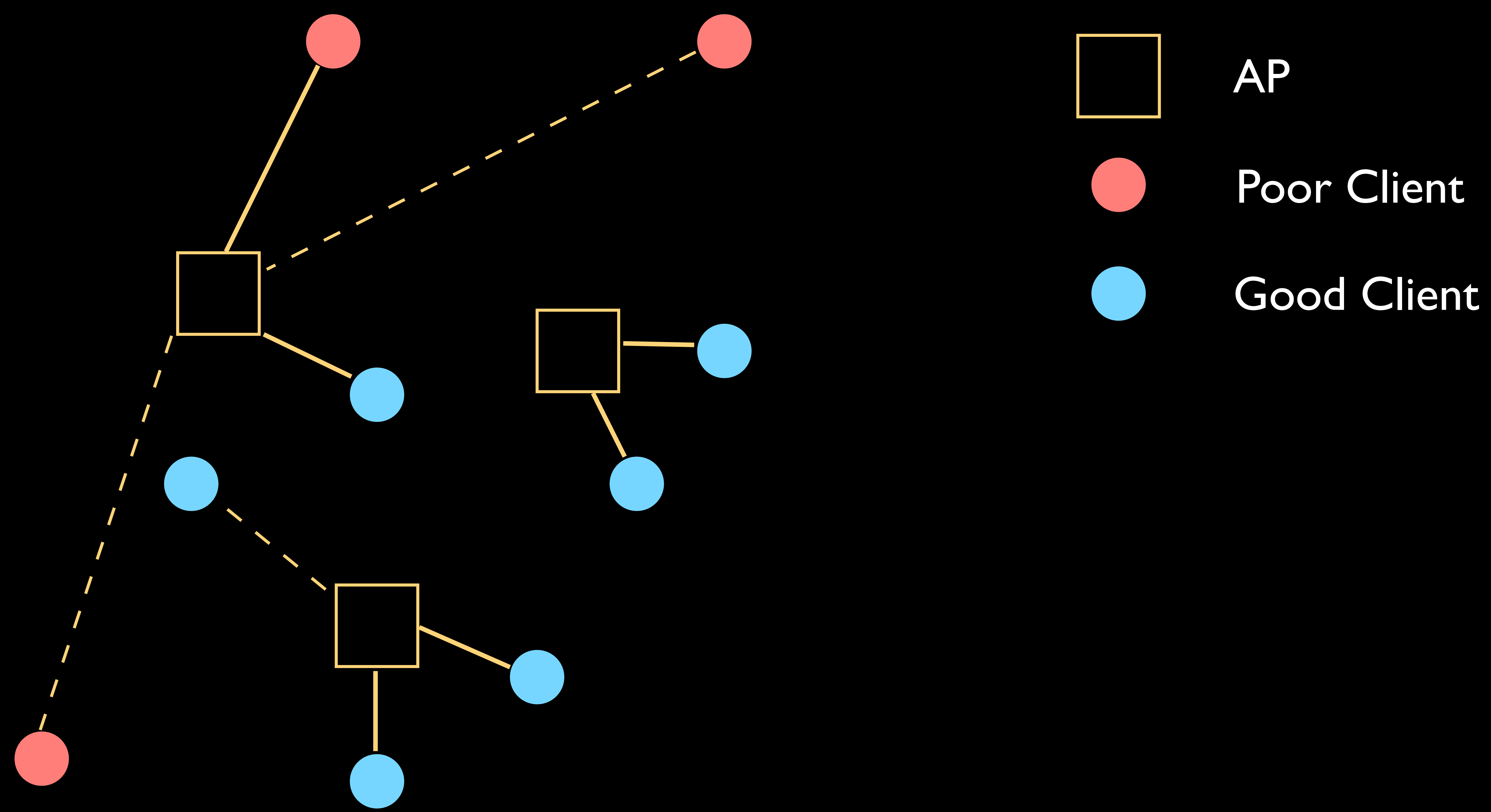

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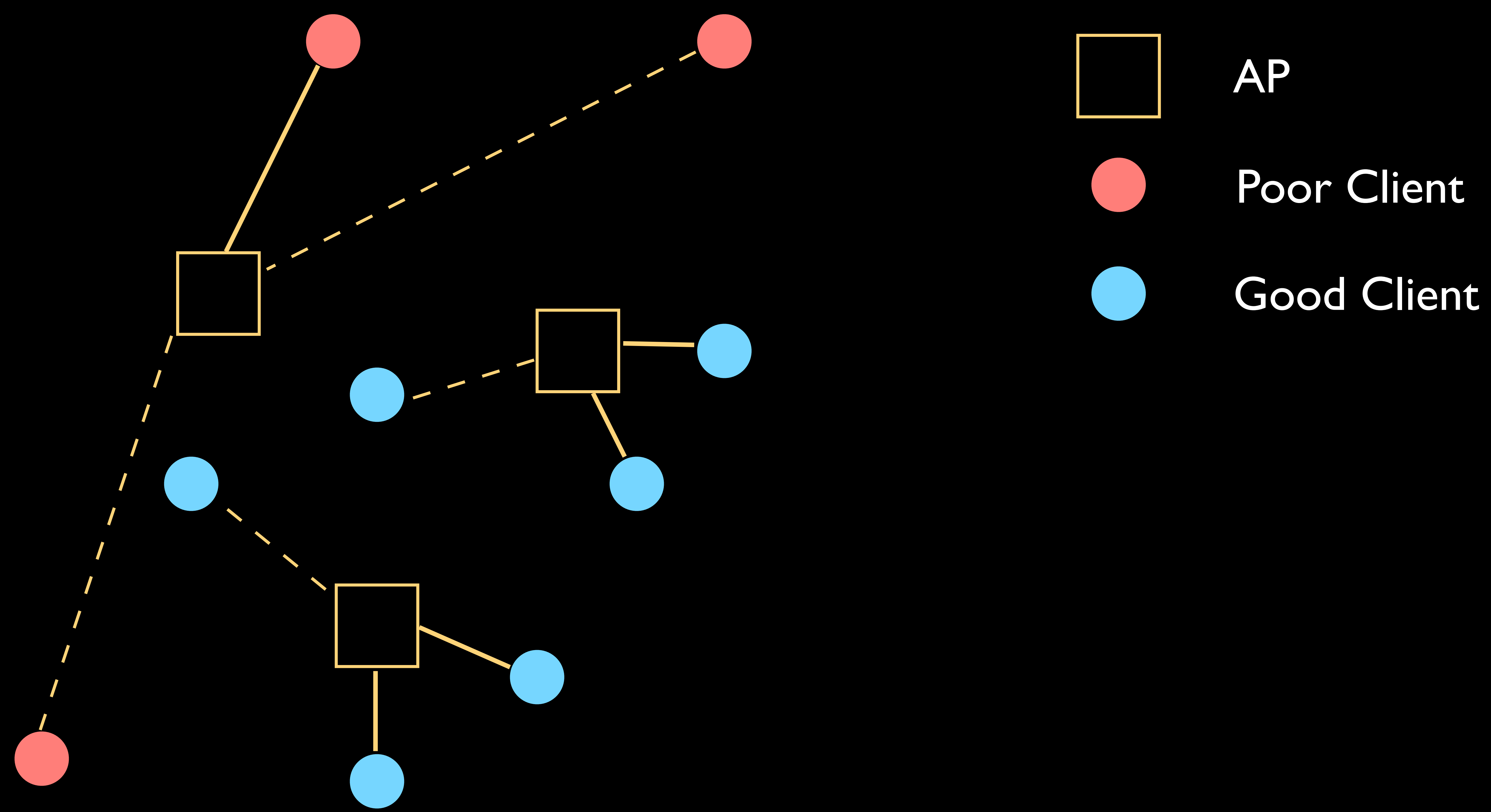

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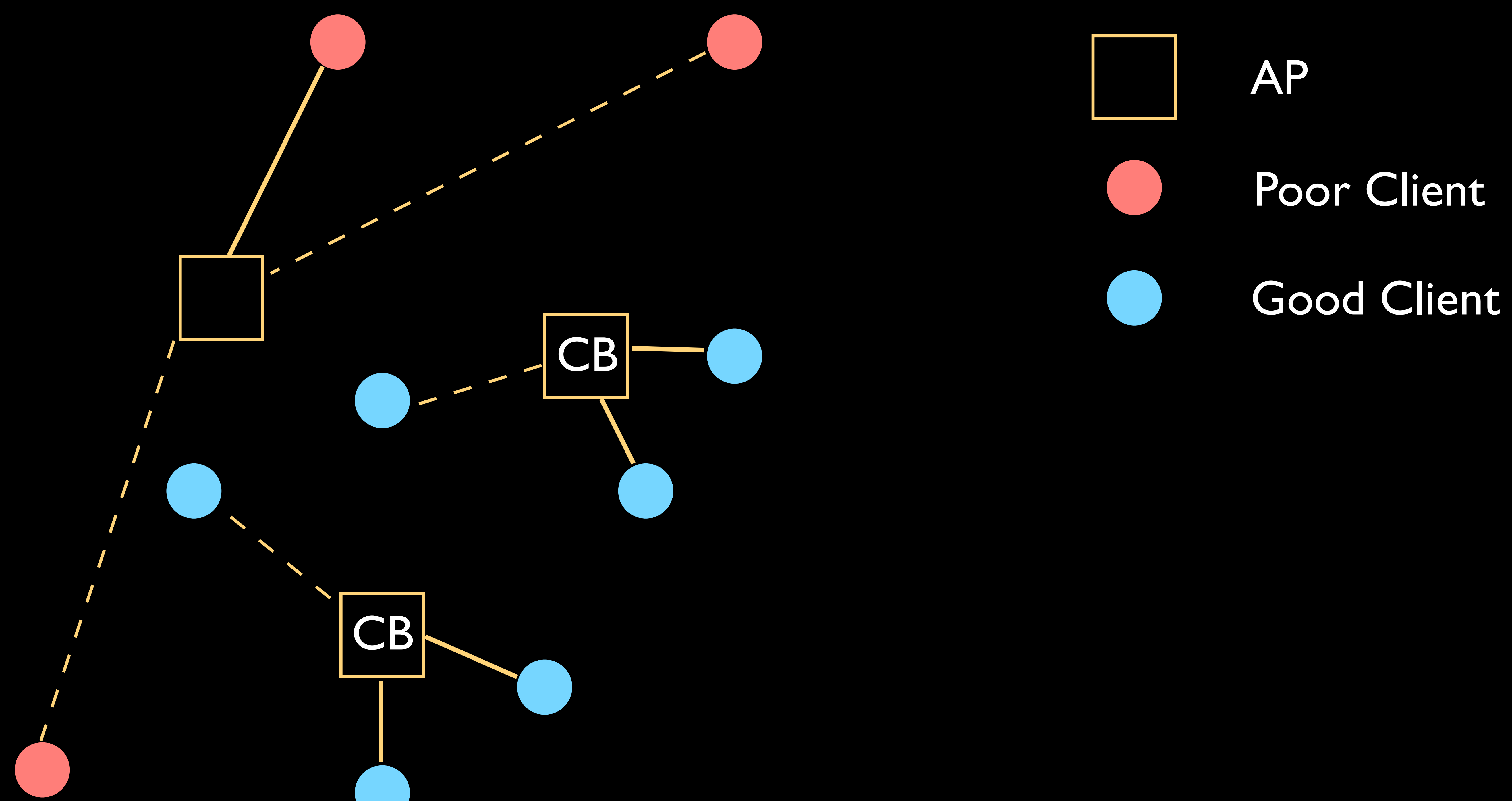

ACORN's Channel Selection

- 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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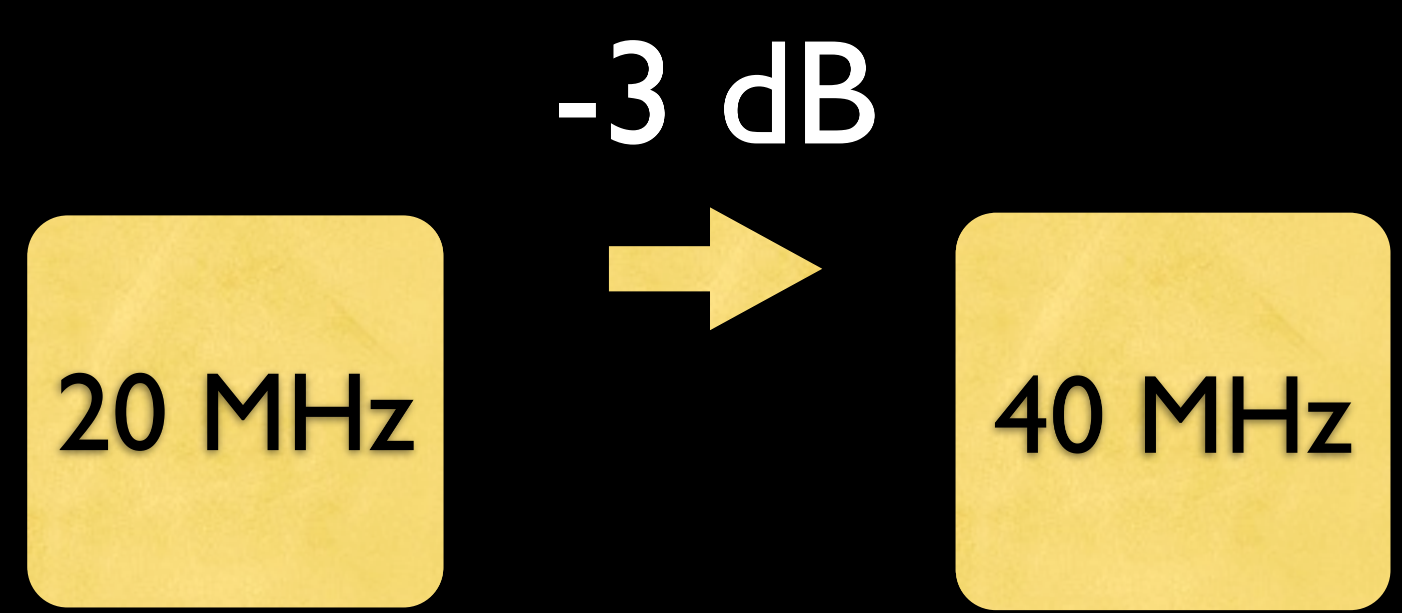

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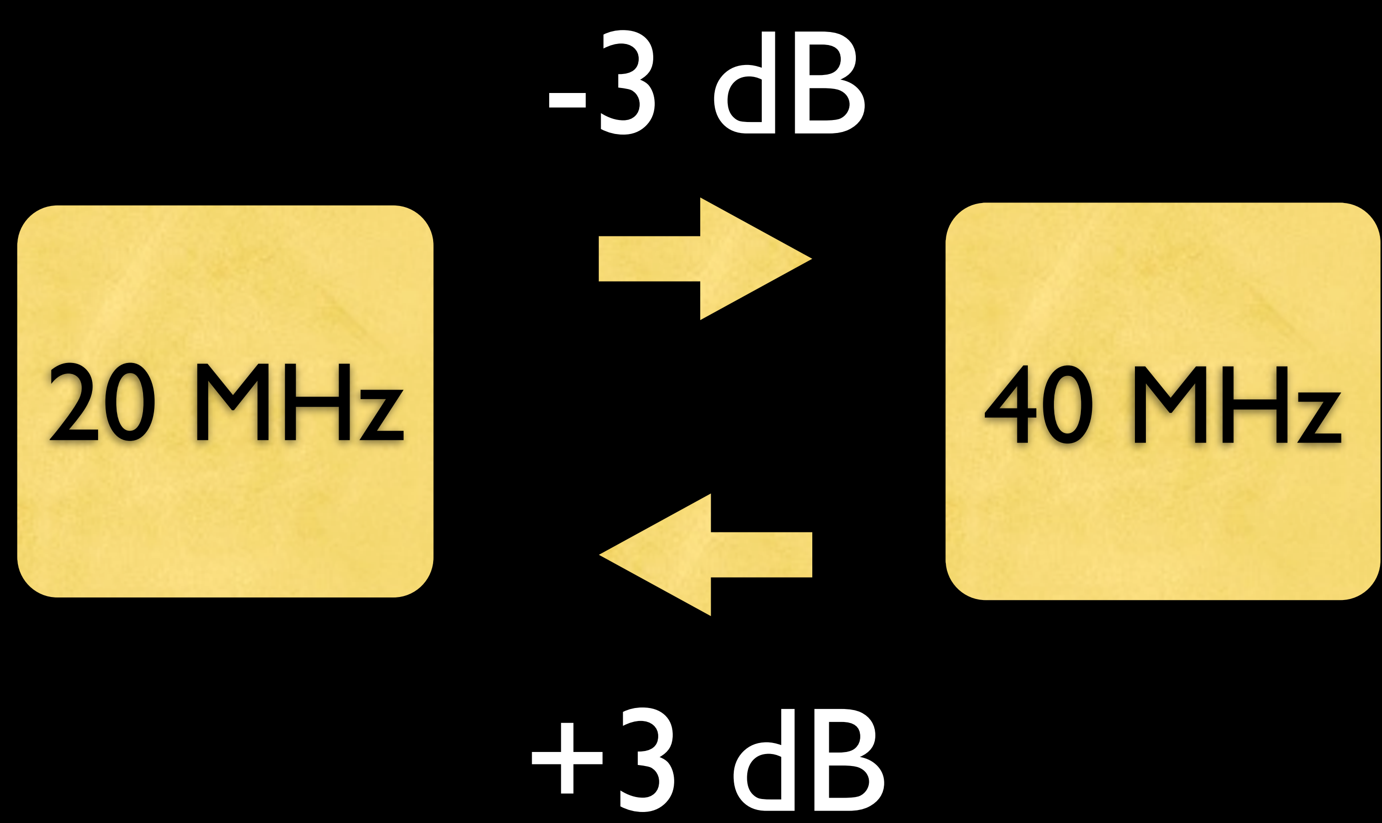

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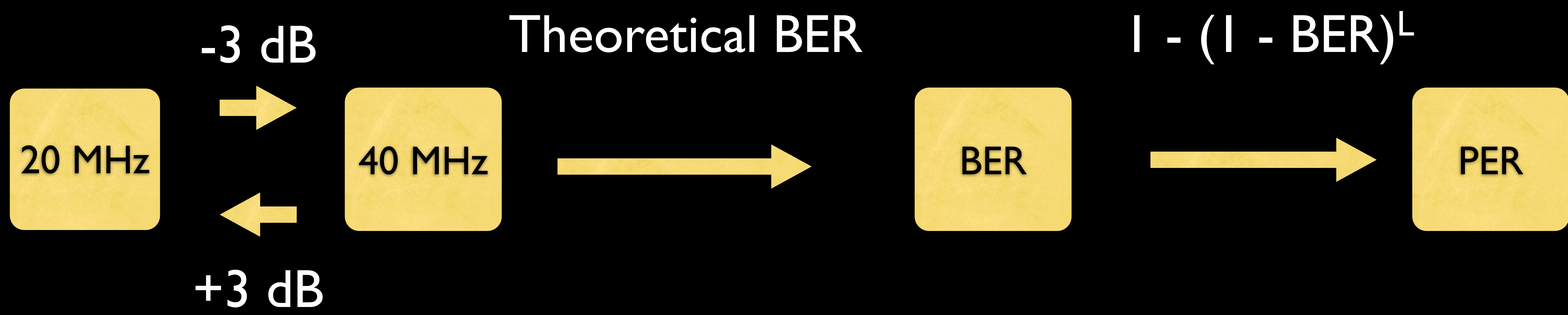
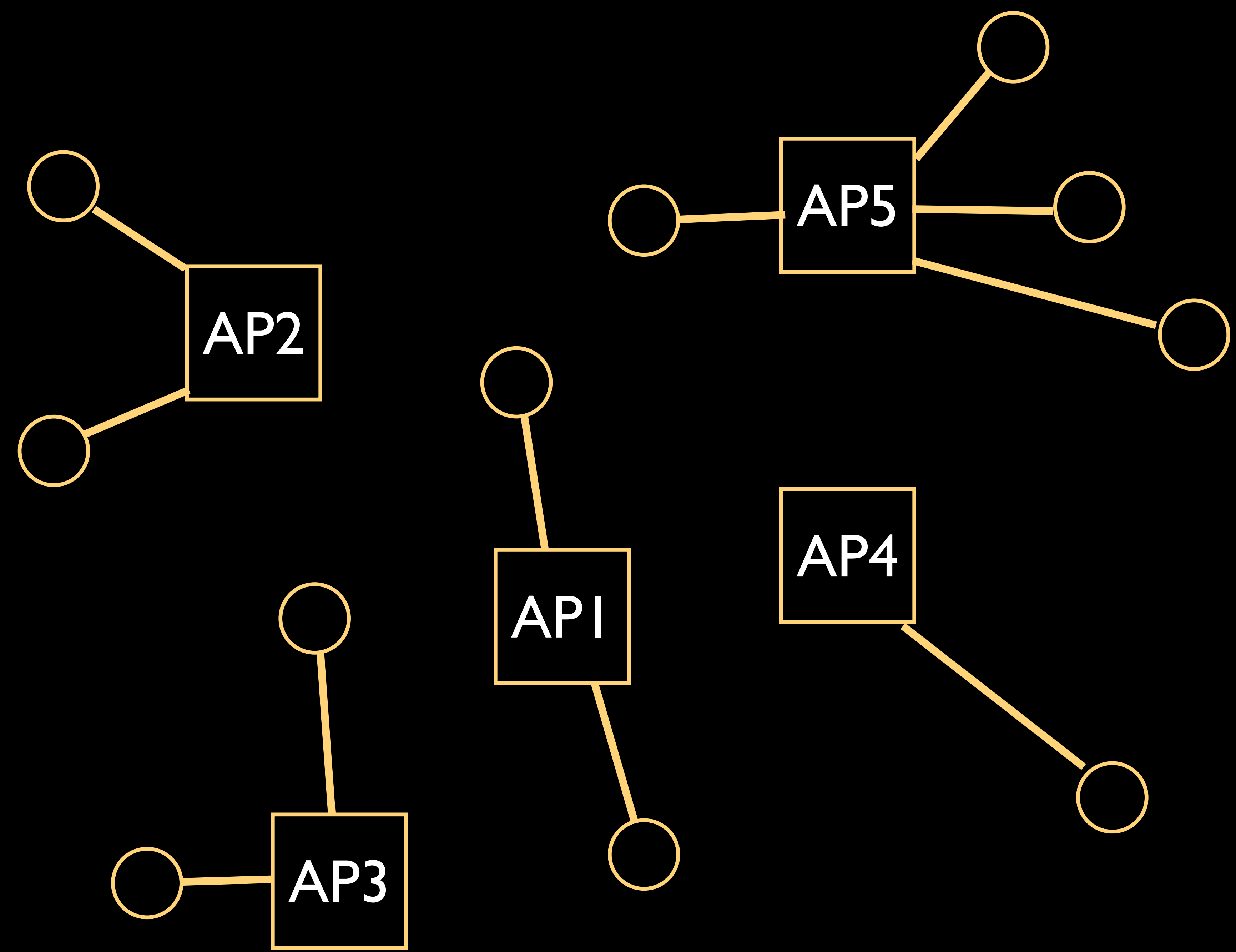


Evaluation through implementation

- 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



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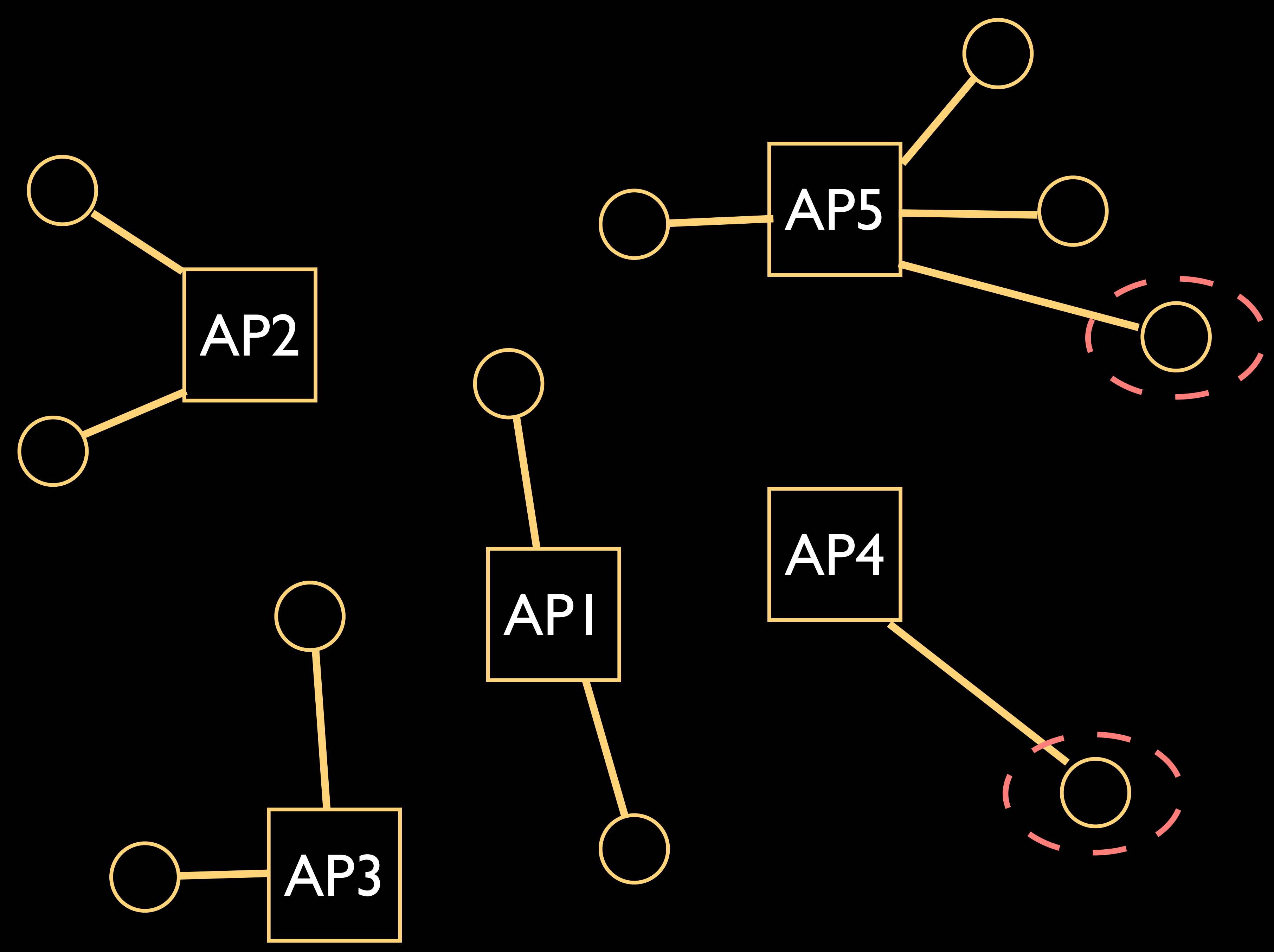

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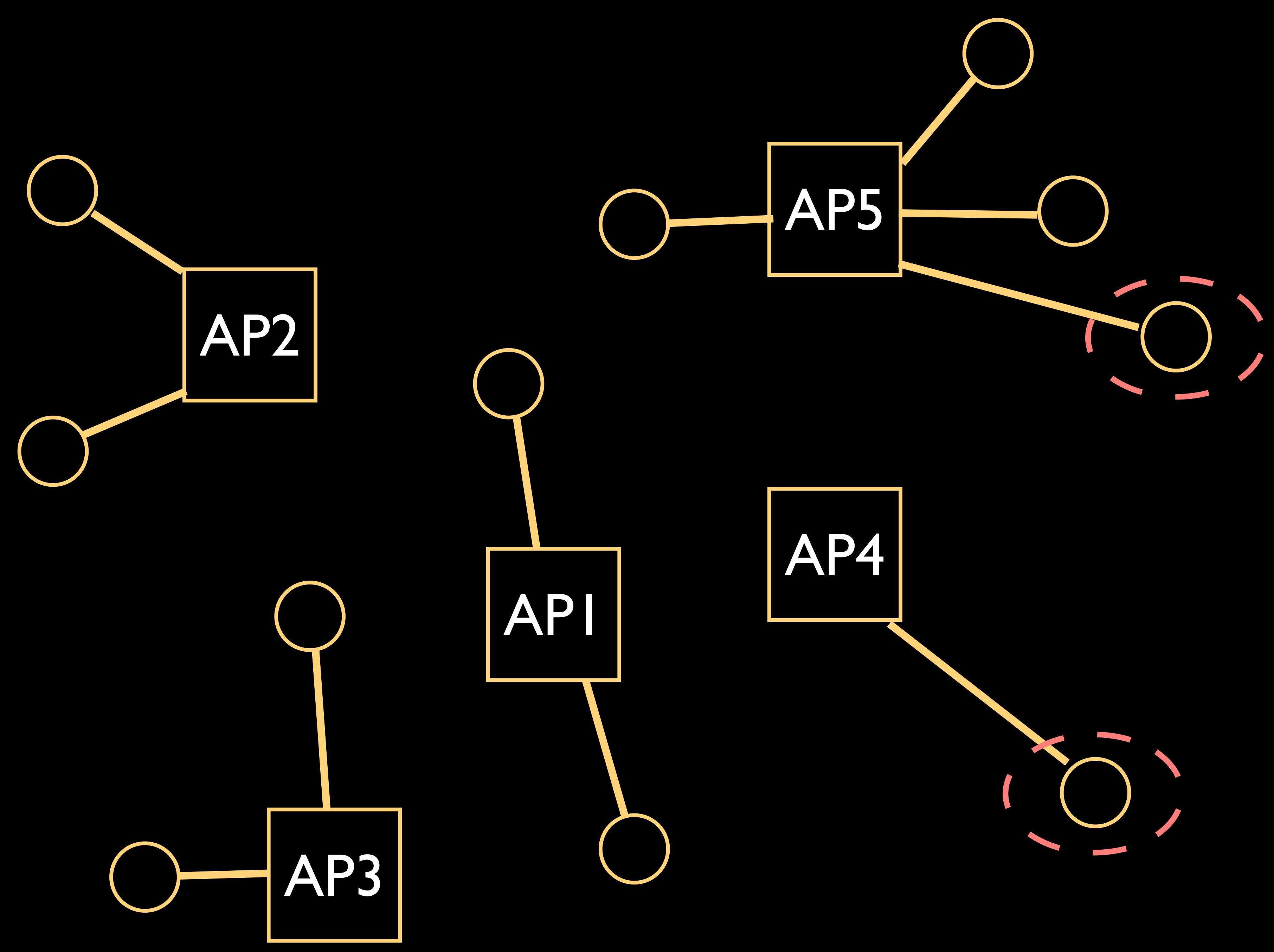

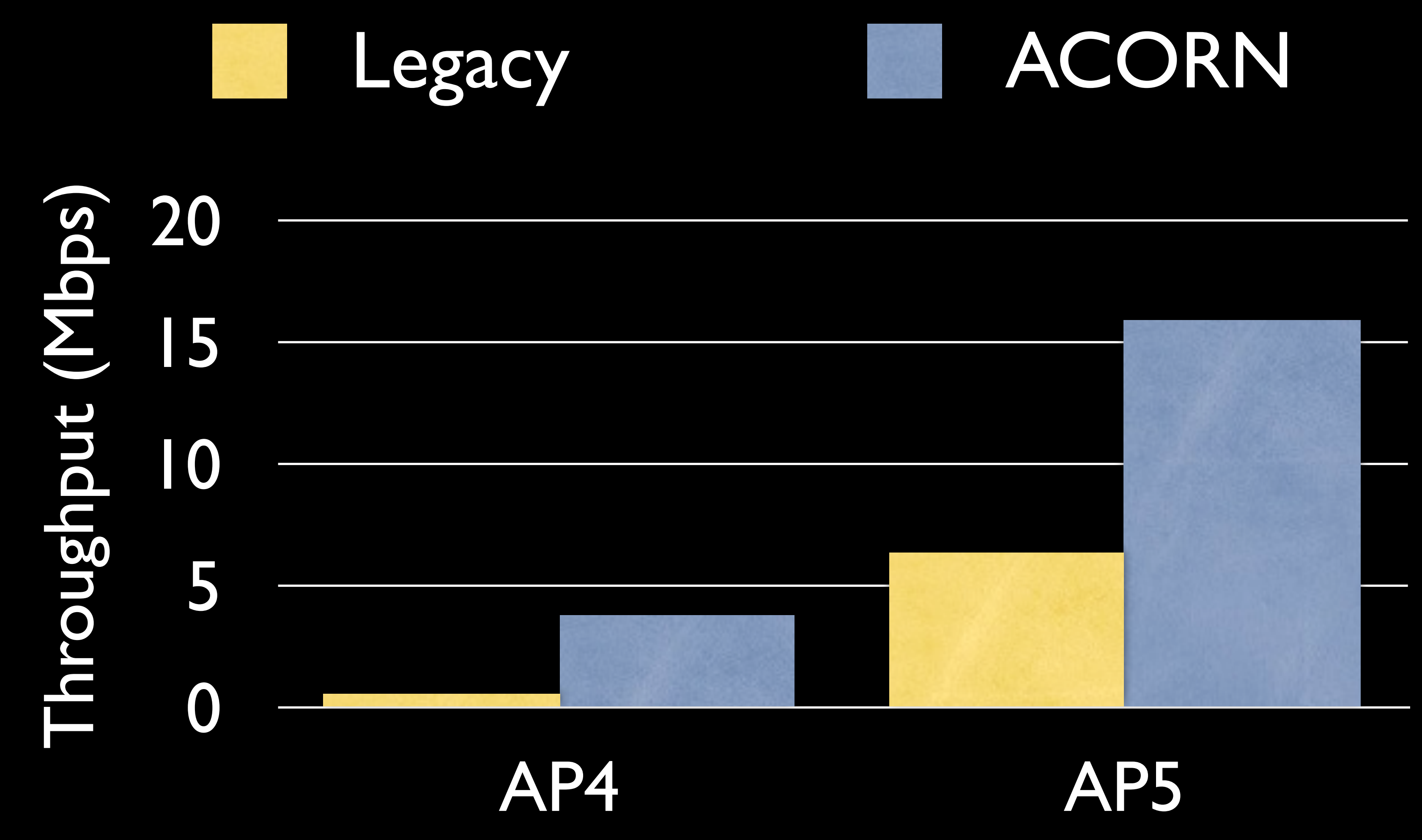

CB avoided due to low-SINR clients.

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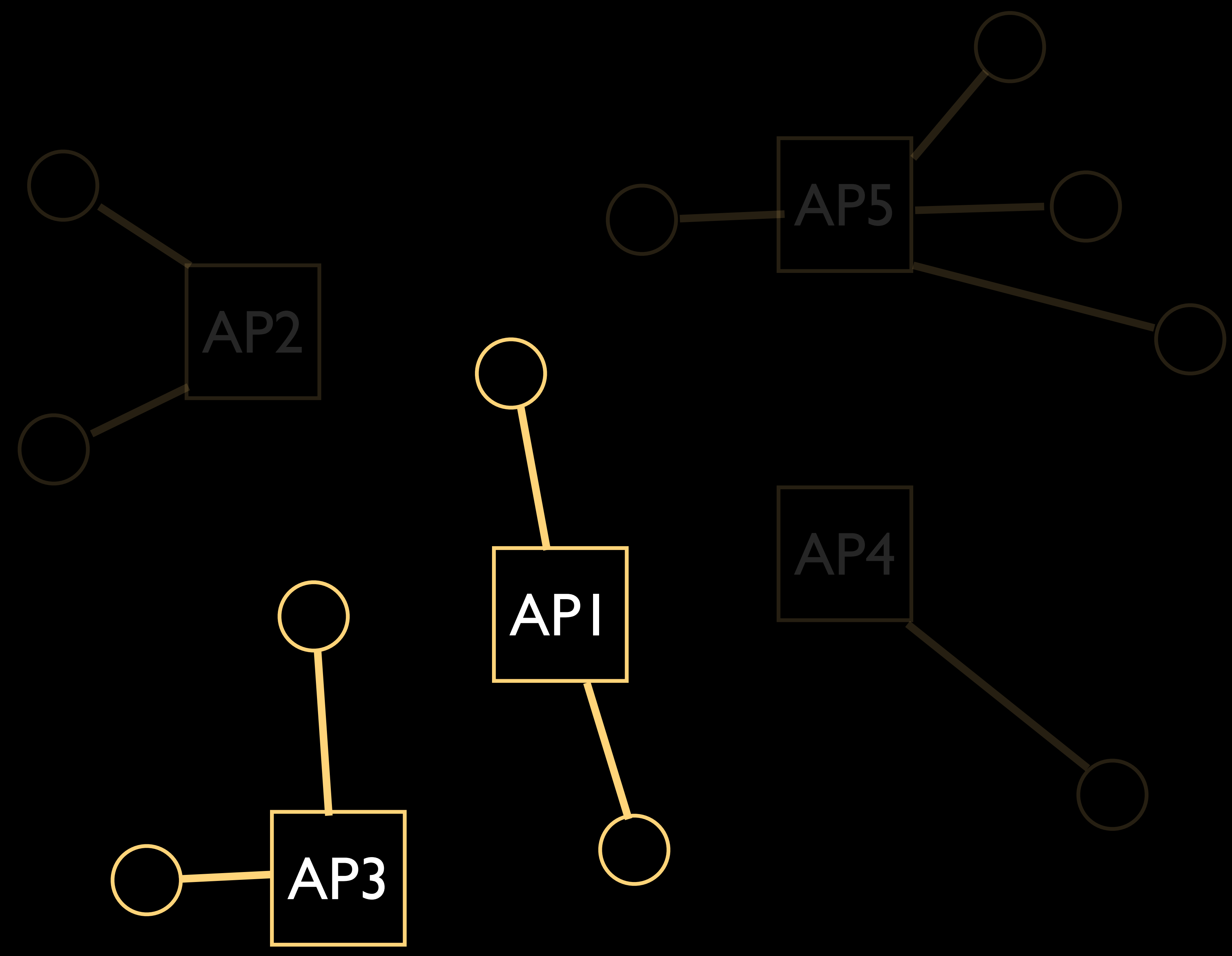

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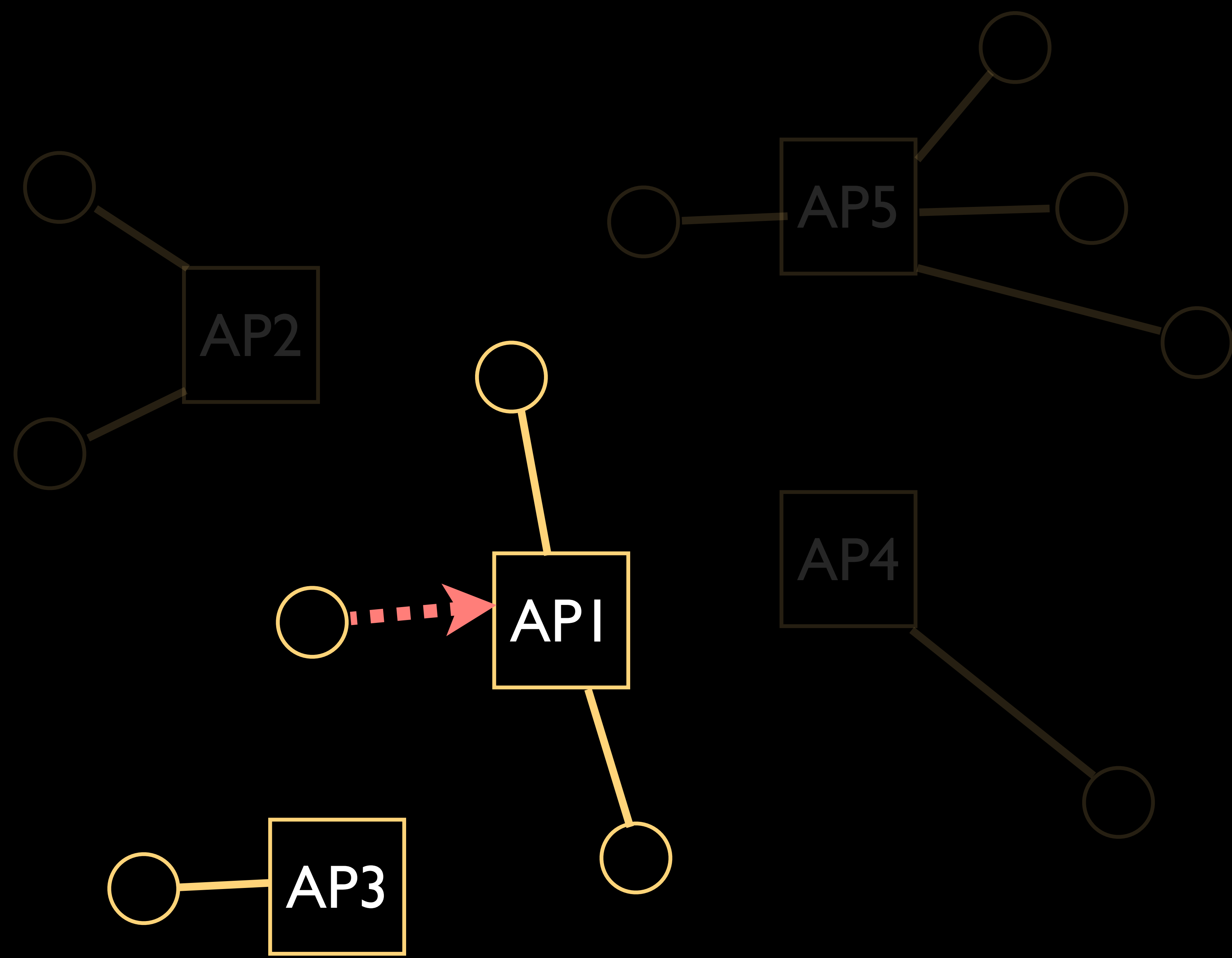

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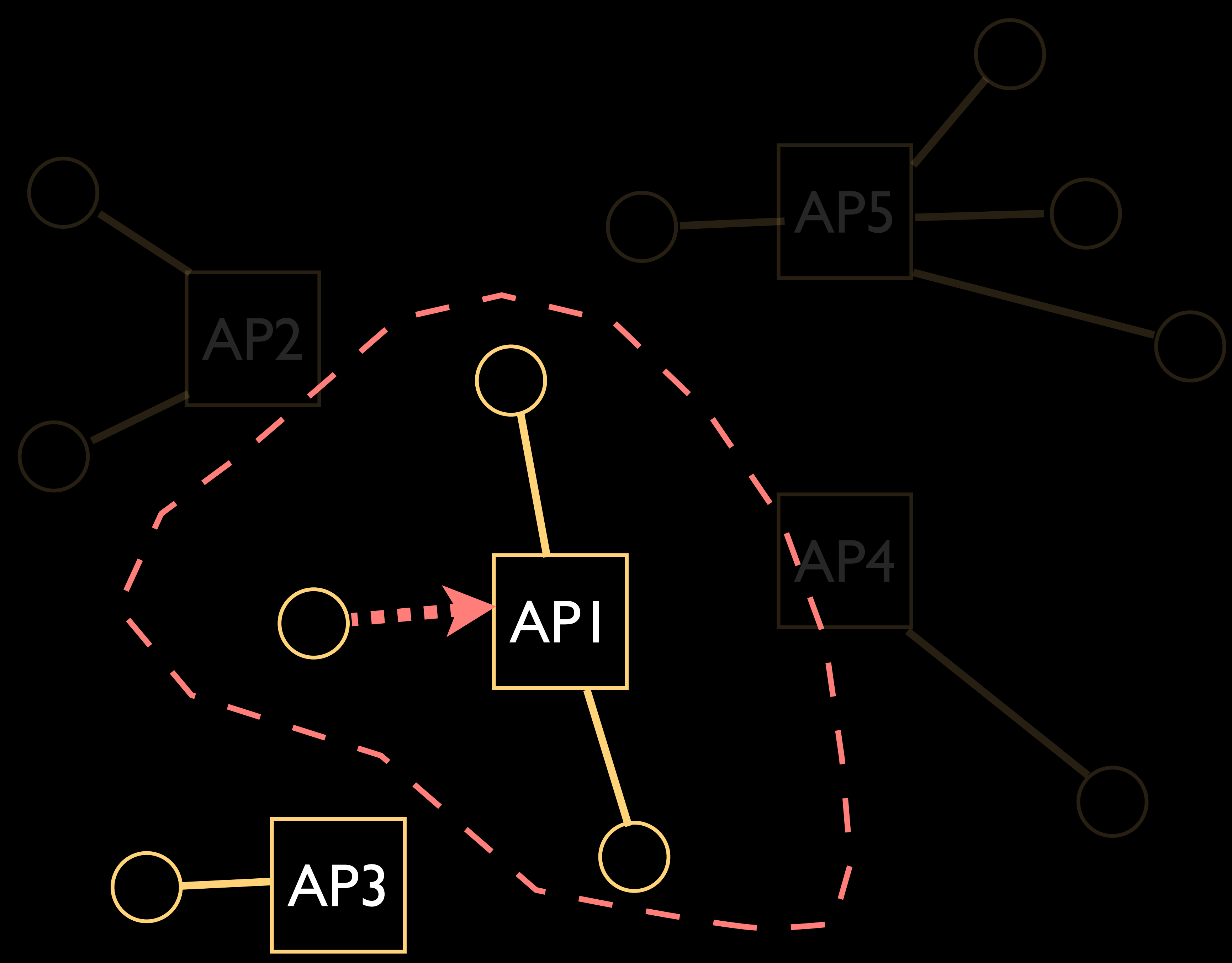
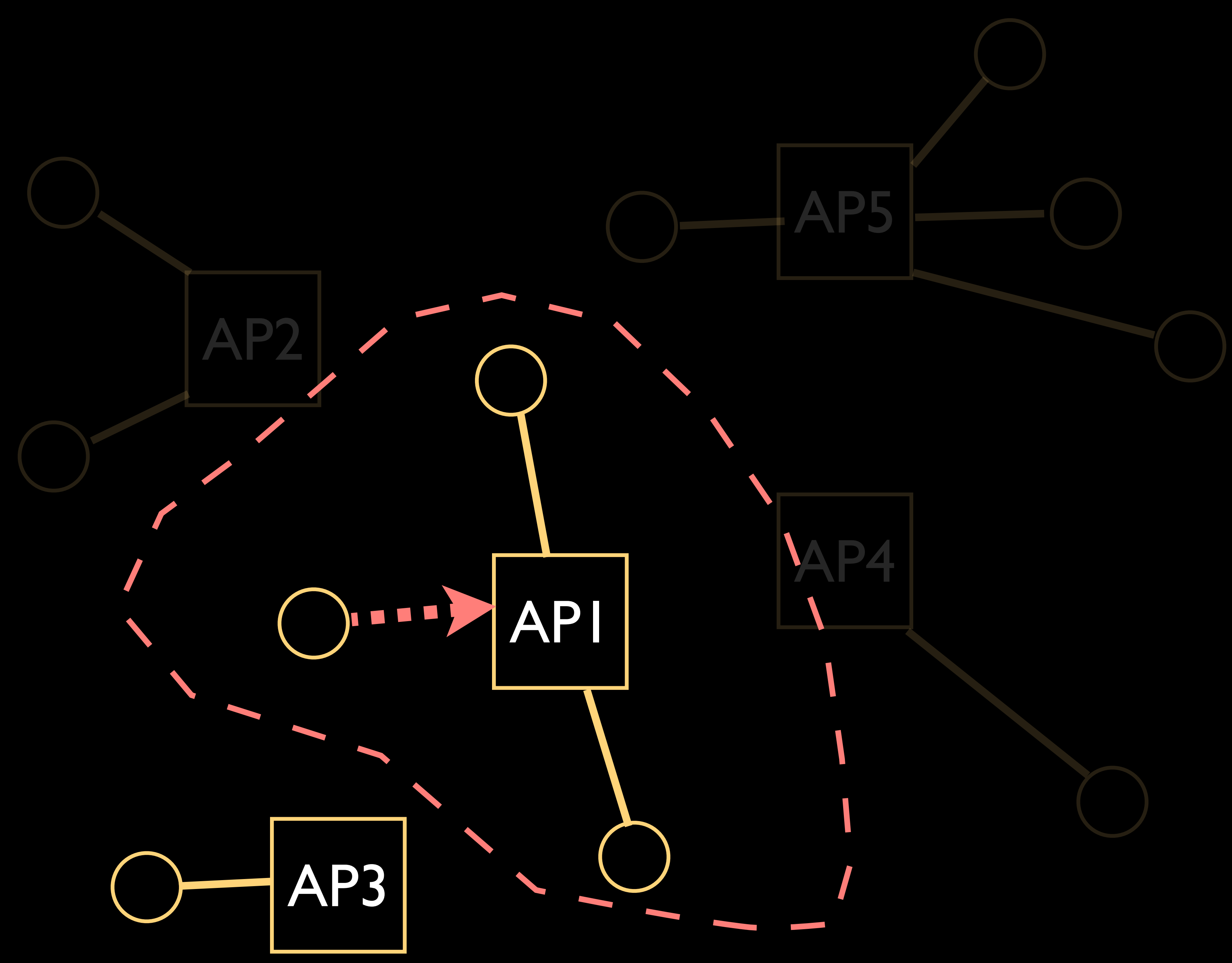
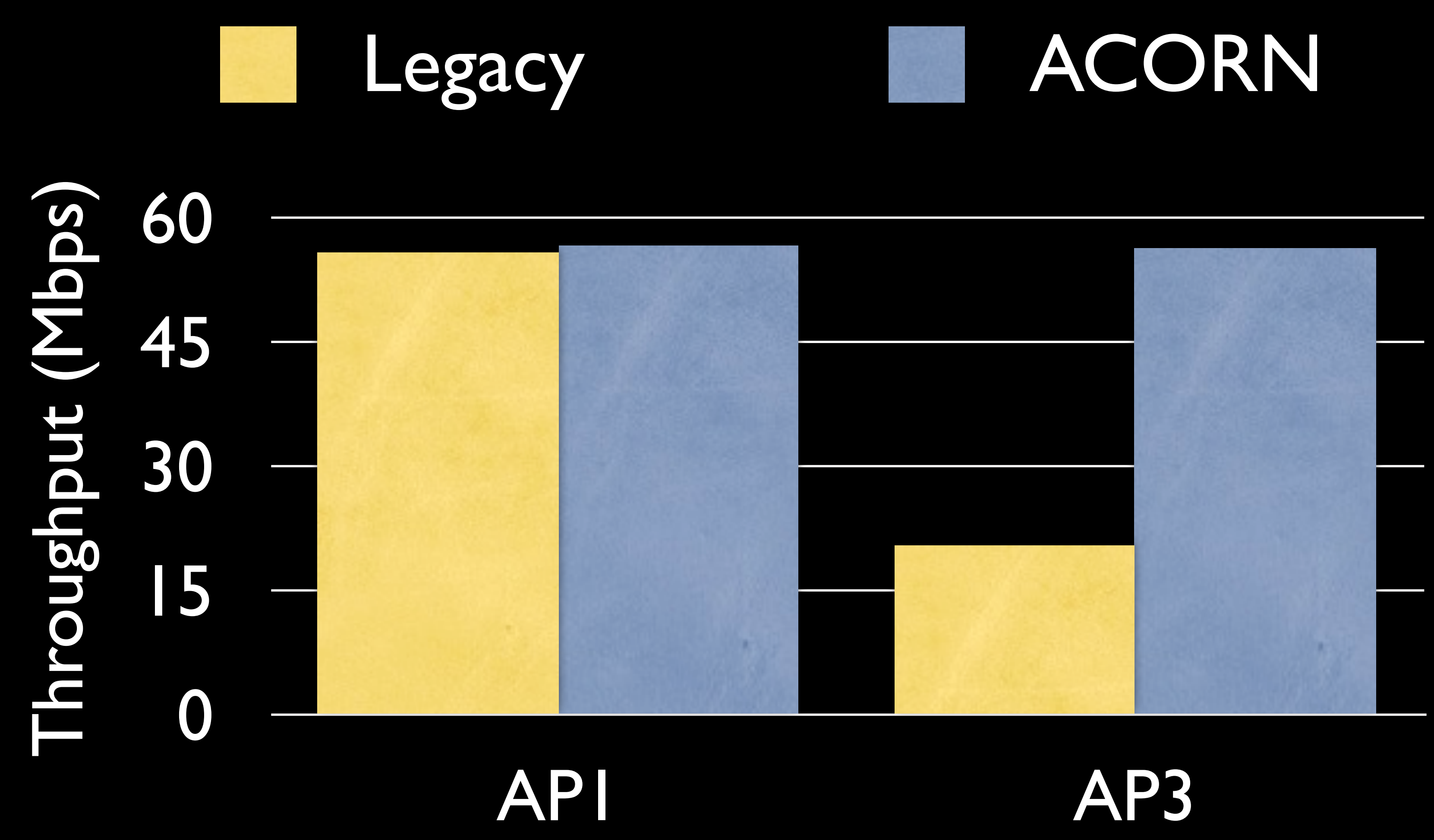


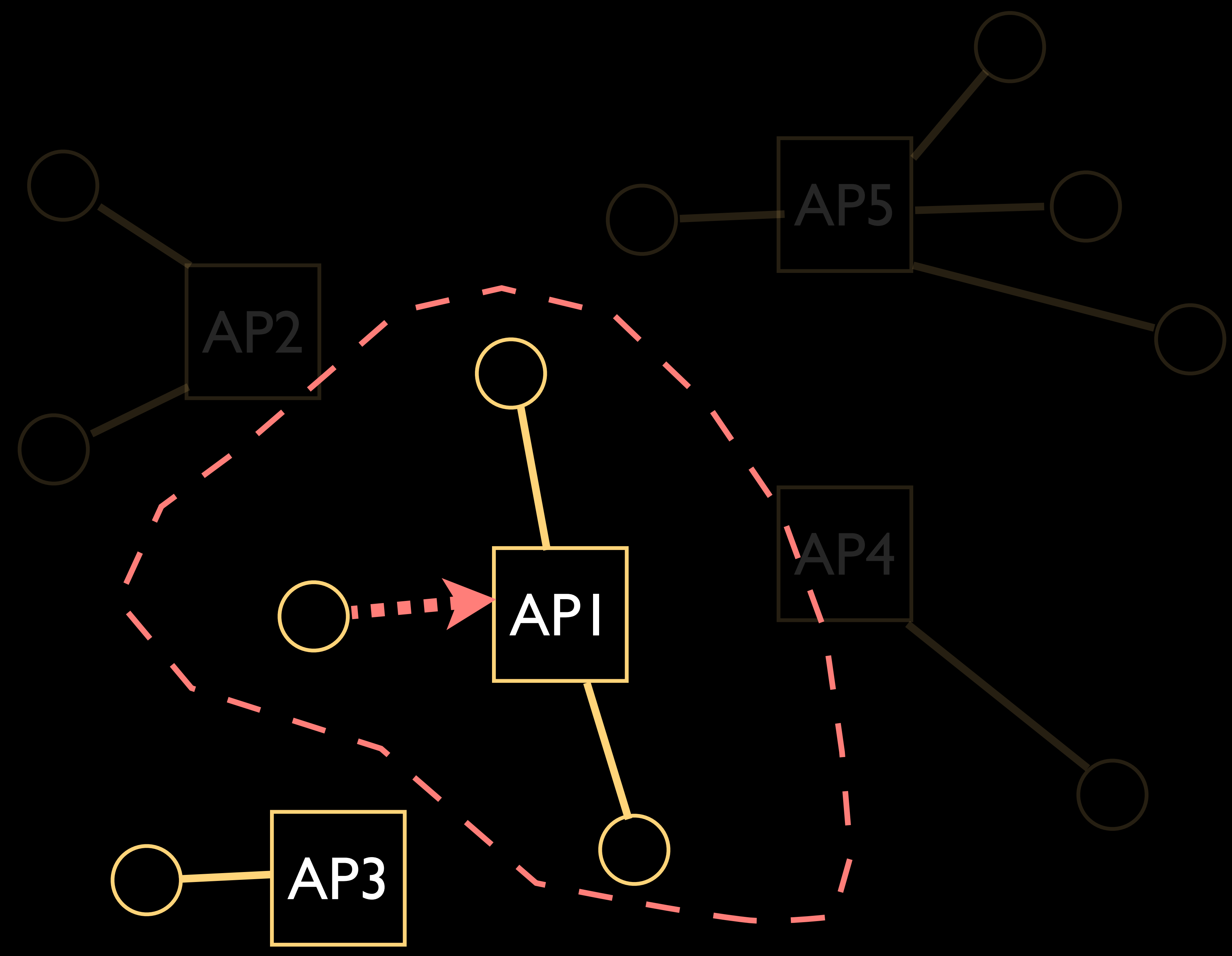
Mid-quality client group - AP3 serves one good client

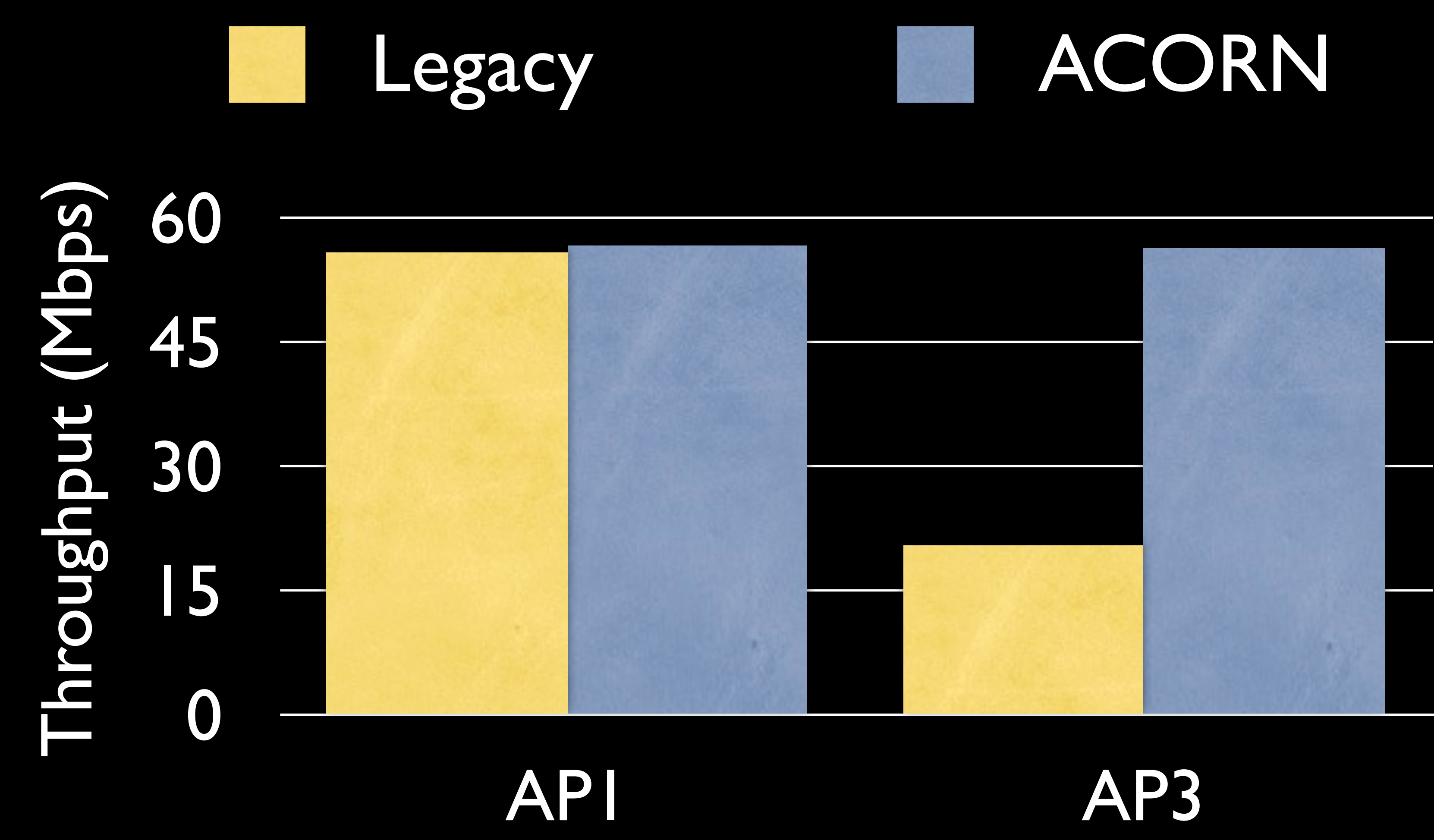
Evaluation


AP5
AP2
AP4
AP1
AP3


Legacy
ACORN
Throughput (Mbps)
60
45
30
15
0
AP1
AP3

Evaluation





With ACORN, higher congestion at AP1 (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.