Interaction Engineering: Taming of the CSMA

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Introduction

Carrier Sense Multiple Access (CSMA) is an important MAC protocol in today's wireless networks

- Distributed, adapts to topology and traffic
- Complex, not well-understood effects of interference
  - Shared wireless channel, complicated interactions between neighbors
  - Performance penalties like hidden/exposed terminals, packet timeouts, ...

Paper focus: Can we optimize CSMA performance?

Background – MAC interactions

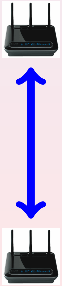
Success of packet reception at MAC depends on interaction between

- Transmitter ↔ Receiver
- And neighboring flows

Simple two-link interactions under CSMA/CA

Discrete number of MAC interaction patterns:

- Unlike continuous PHY interference (e.g. SINR)
- 10 types of interactions



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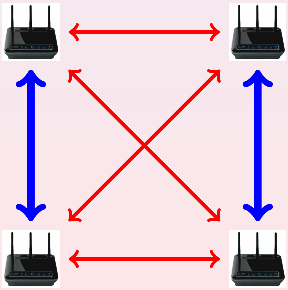

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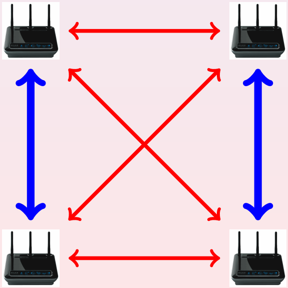
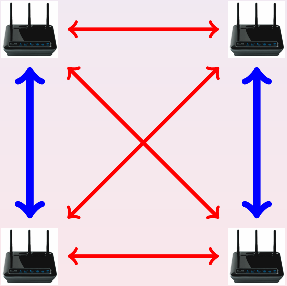


Background – Two-flow problem

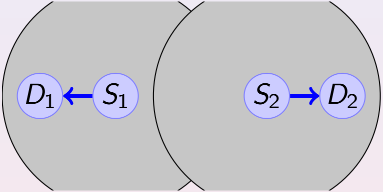
4 promintent categories of link-interactions

- No Interaction
- Sender Connected
- Classical Hidden Terminal
- Capture Effect



Background – 4 MAC interactions

No Interaction – NI



Sender Connected – SC

Hidden Terminal – HT (AIS)

HT with Capture – HTC

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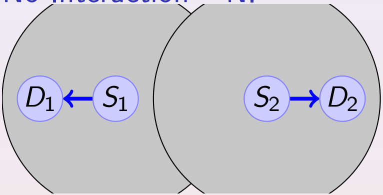

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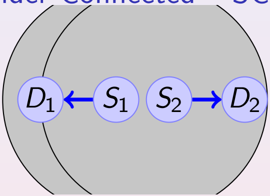

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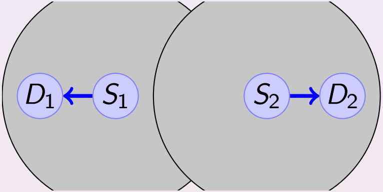

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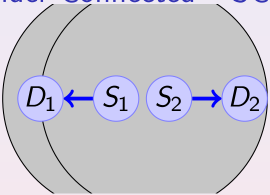

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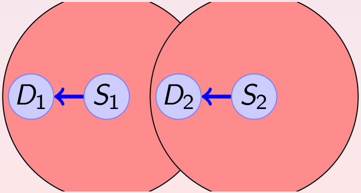

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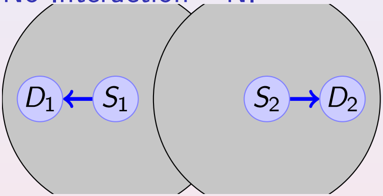

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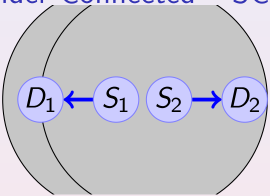

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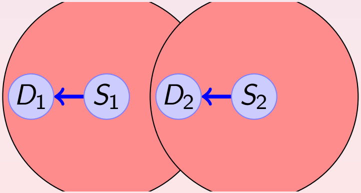

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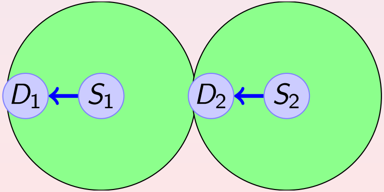


Motivation

Current MAC protocols are grossly inefficient

- 15% of scenarios have timeouts, 40% have exposed terminals.
- AIS=0% channel capacity, SC=50% channel capacity.

Large impact on higher-layers and applications

- Lower capacity, Longer delays, TCP effects, . . .

Good news: Open device drivers and open radios

- Easy for optimizing and customizing MAC protocols

Contribution

We propose **Interaction Engineering**

- Configure the network such that links have *best* interactions

Approach: Optimize interactions between the links by controlling transceiver parameters

- 3 important parameters: Tx-Power, Carrier sensing threshold, receiver sensitivity
- Resolve interdependency issues: Jointly optimize 3 parameters at all nodes

Optimal model → Centralized algorithm → Distributed protocol

Related work

Large number of studies optimize MAC protocols and radio parameters.

Our work adds to existing knowledge by:

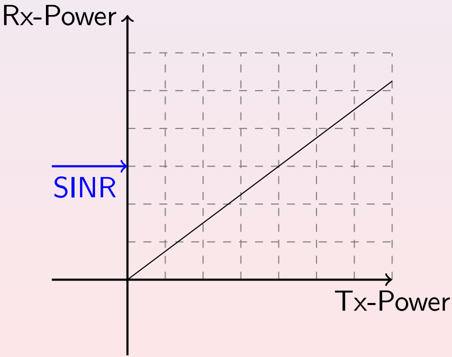
- MAC interaction based: Optimize for effect of interference at MAC.
- Network specific optimization: Tuning any arbitrary network.
- We consider advanced CSMA protocol rules
- Joint consideration of all parameters that affect interactions.

Example 1: Single Link

Relationship: Tx-Power and Rx-Sen

If distance between $S - D$ is constant,

- Rx-Power(D) $\propto$ Tx-Power(S)
- Or other approximations



Packet is received correctly at MAC, if

- Rx-Power > max(SINR, Rx-Sen)

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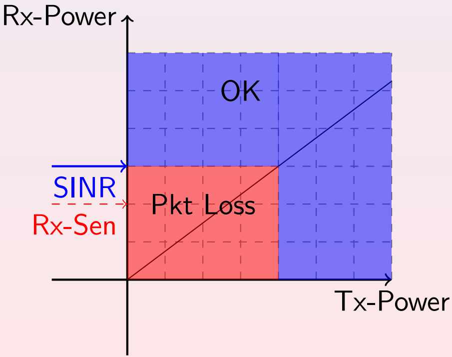

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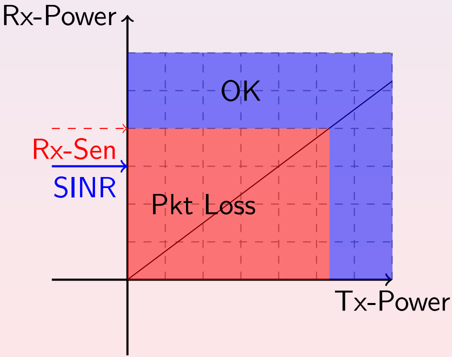

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Example 2: Two Links – NI interaction

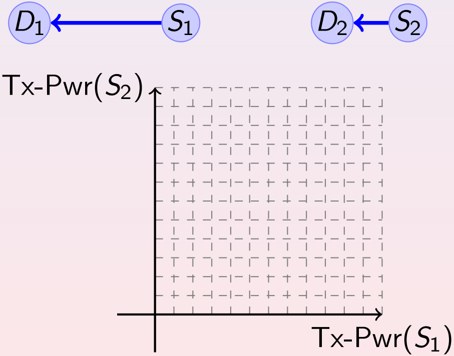
Relationship: Tx-Power(S_1) and Tx-Power(S_2)

Packet is received at D_1, if SINR is strong

- Signal from S_1 is strong
- Interference from S_2 is weak

Similar constraints for $S_2 - D_2$

Feasible region for Tx-Powers for NI.



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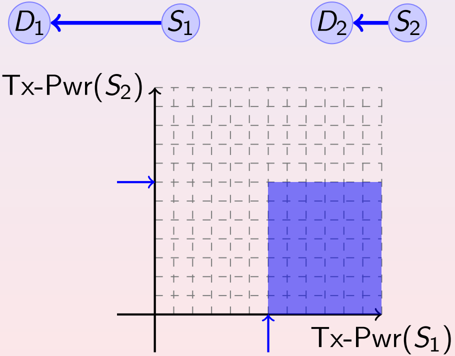

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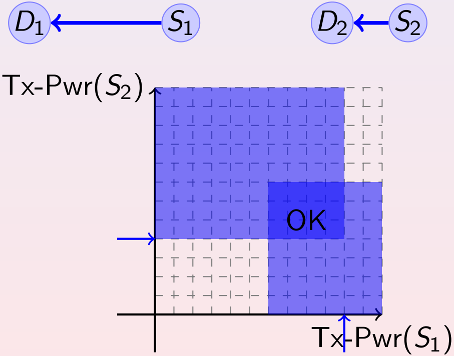
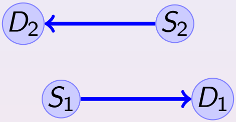


Example 3: Two Links – SC interaction



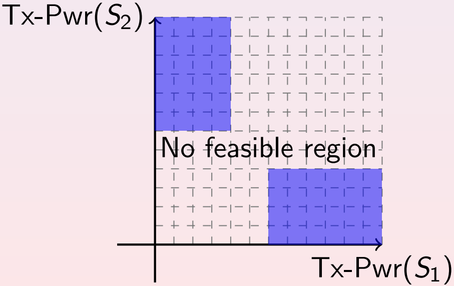
Relationship: Tx-Power(S_1) and Cx-Sense(S_2)

NI is best interaction for 2 links. But, not always feasible

Optimize for the next best interaction

- SC – good in handshake and network utilization

Set Cx-Sense threshold such that the sources sense each other.



Optimal Link-Pair (OLP) Model

Given two links, jointly optimize all three parameters of all nodes

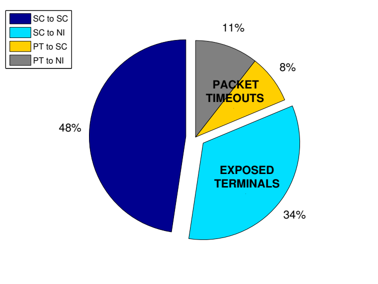
Approach: 2-phased model

- Test for NI interaction
  - Compute feasible region of Tx-Power, Cx-Sense, and Rx-Sen for S_1, S_2, D_1, D_2
- If feasible, configure for NI interactions
- Else, configure for SC (Example 3)

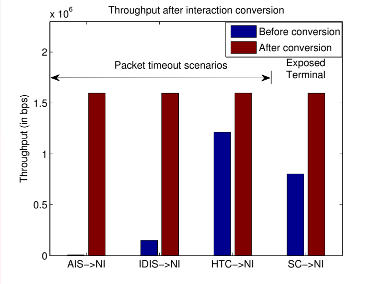
Optimized Link-Pair (OLP) Model

400 link-pairs

- Optimal conversion: No packet timeouts, maximized NI
- Large savings in throughput
- Efficient network usage



Interaction Conversions



Impact on throughput

Centralized Link-Pair (CLP) Algorithm

Extend OLP model to approximate n-link topologies

Approach:

1. Run OLP between all-link pairs
2. If feasible region is found → Optimum
3. Else approximate
   - Maintain lower bounds on Tx-power and interaction type (NI/SC) for each node
   - Choose best Tx-Power
   - Compute Cx-Sense and Rx-Sen thresholds

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Interaction based MAC (I-MAC) protocol

Idea: I-MAC extends centralized and non-adaptive CLP to a distributed protocol

Approach:

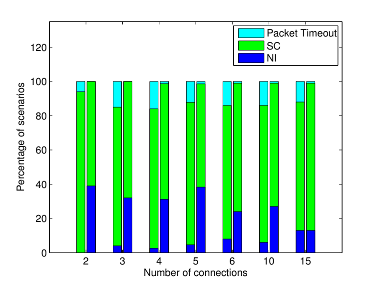
- Sources exchange link parameters in neighborhood
- Maintain table of links, tx-power, interaction type
- Act locally (similar to CLP)

Issue: Dissemination of information between neighboring links

- Reliable vs. unreliable broadcast

Performance of I-MAC

- Completely removes packet timeouts.
- Reduces exposed terminals
- Overall improvement in application throughput and network usage



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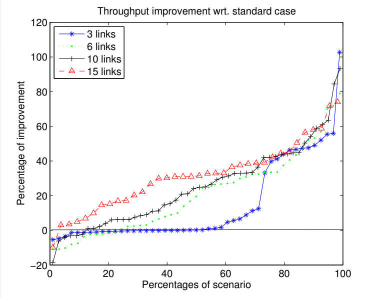

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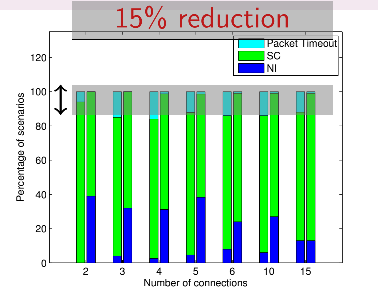

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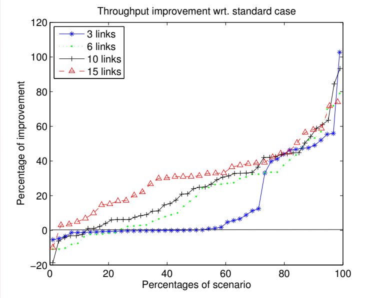

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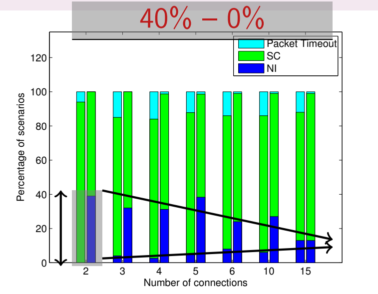

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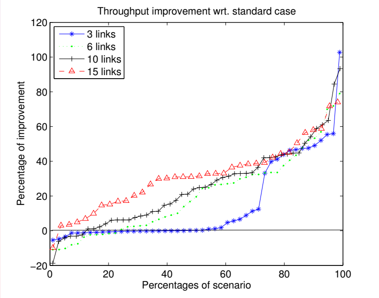

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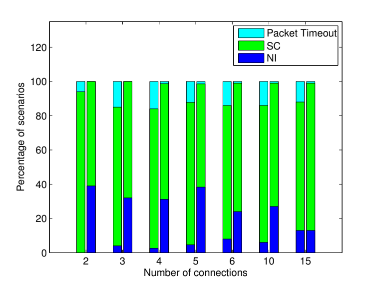

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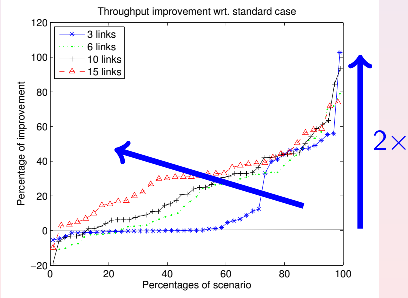


Impact on throughput

Conclusions and Future work

Interaction Engineering methodology: Interference avoidance at MAC

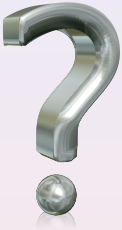
- Increases spatial reuse, eliminates packet timeouts

Three progressive layers of solutions

- Optimal OLP Model $\rightarrow$ Centralized CLP algorithm $\rightarrow$ Distributed I-MAC protocol

Future work

- Optimal n-link model
- Evaluation on testbed with Software Defined Radios
- Interaction Engineering in Multi-radio, Multi-Channel, Multi-rate networks



Thank you.

For further information, please contact:
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Saquib Razak: srazak@cmu.edu

Related work – Details

Overlap in 3 general segmented areas:

- Toplogy control: Gao et al. INFOCOM 2008, Muqattash et al. Mobihoc 2004, Halperin et al. Mobicom 2008.
- Effective carrier sensing: Kim et al. Mobicom 2006, Vutukuru et al. NSDI 2008, Brodsky et al. SIGCOMM 2009, Yang et al. Mobicom 2005
- Capture effect: Whitehouse et al. EmNets 2005

We present a holistic solution at MAC layer including all parameters.

Related work – Details

Issue 1: Toplogy assumptions [Yang2005, Kim2006]

- Above studies concentrate on random topology, but not on arbitrary topology
- We observe large difference in interactions for each topology

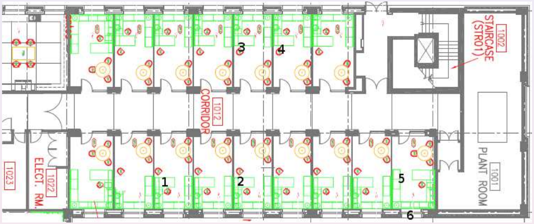
Issue 2: Complete parameter space (tx-power, rx-sen, cx-sense)

- Constant carrier sensing threshold [Gao2008,Muqattash2004,Halperin2008].
- Constant tx-power [Jamieson2005,Vutukuru2008,Yang2005,Brodsky2004].
- None of the above work consider capture effect

Issue 3: Complete CSMA rules

- 2-way handshake
- Carrier sensing

Performance of CLP on testbed



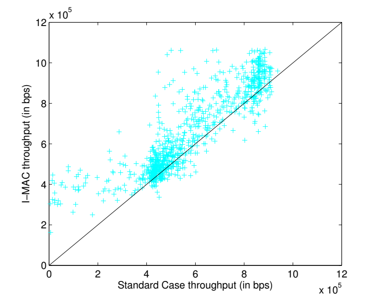
- 6 Soekris boards with Atheros chipsets running modified MadWifi
- Tx-Power changes only. Cx-Sense and Rx-Sen cant be changed on Atheros
- 4 possible two way links: 1-2, 3-4, 5-6, 3-2

13 possible link-pair scenarios

- 5 scenarios: Perfect interaction engineering
- 4 scenarios: Partially successful. Channel asymmetry
- 4 scenarios: Weak links → Current CLP is ineffective

Performance of I-MAC in Chains

Two 4-hop chains. 1000 scenarios
Max improvement= 60×



Throughput improvement in chains