Interference in Multi-hop Wireless Chains

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IEEE WiMob, 2009

Brief Introduction

Multi-Hop Wireless Networks (MHWN) becoming increasingly important:

- Mesh networks, Sensor networks, bluetooth, . . .

But, MHWN performance is unpredictable

- Inefficient and well below analytical limits

Interference has substantial and unpredictable impact at all network layers

- Makes analysis and design of systems difficult

High-level Motivation

Interference in wireless systems are poorly understood

Need better approaches to quantify and avoid interference

- Understand the effect of interference at each layer
- Quantify them
- Redesign protocols or layering schemes

Problem Statement

Recently, a new approach for analyzing interference at the MAC layer from first principles was proposed.

The analysis was extended to model a single multi-hop **chain**.

Our contribution: Extending the analysis to study how multiple chains interfere with each other.

MAC interactions

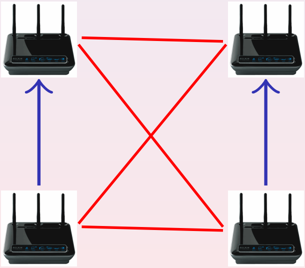
Two-flows under CSMA/CA

Countable number of interaction patterns:

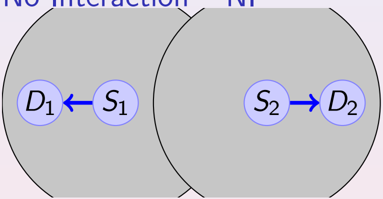
- 10 categories under SINR model [2]

4 promintent categories:

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



No Interaction – NI

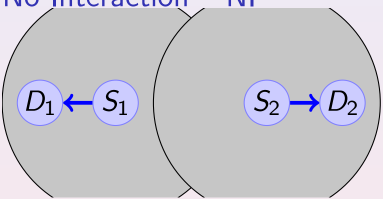


Sender Connected – SC

Hidden Terminal – HT (AIS)

HT with Capture – HTC

No Interaction – NI



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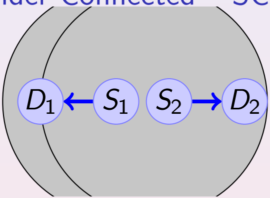

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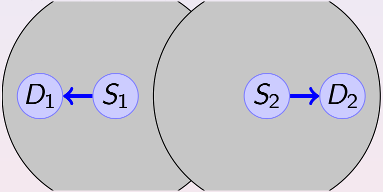

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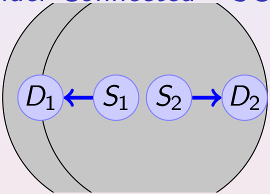

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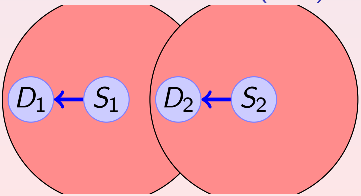

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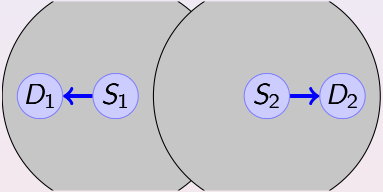

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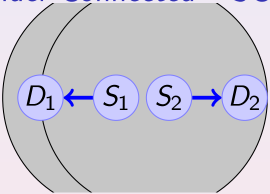

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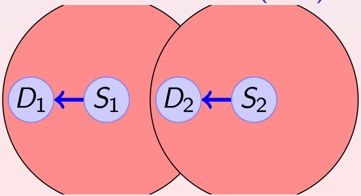

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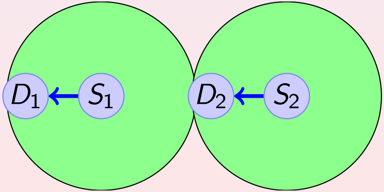
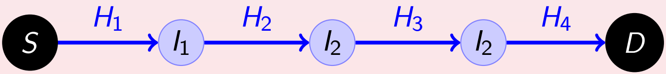


Self-interference in Chains

Interference in chains have significant differences than *free* links.

Chains have strict dependencies.

- Node locality constraint: Nodes lie along src-dest line.
  - Controls node-positions in a chain
- Pipelining effect: Traffic from predecessors feed forward.
  - Controls traffic at each node



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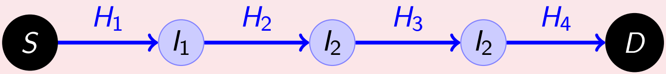

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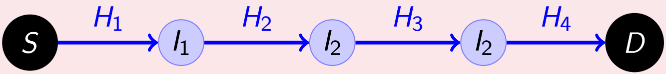
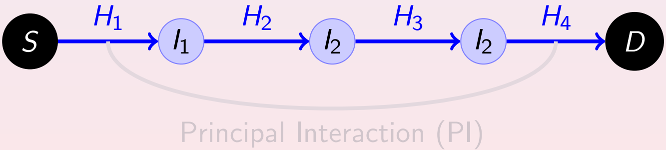


Categories of isolated chains

We consider a 4-hop chain.

- Min number of hops needed for non-trivial interactions.

Any two links on a chain have SC-interaction except H1-H4.



Three prominent categories based on PI:
SC-Chain, HT-Chain, HTC-Chain

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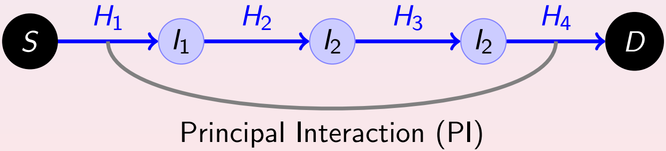

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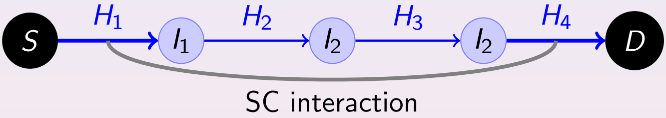
SC-Chain

HT-Chain

HTC-Chain

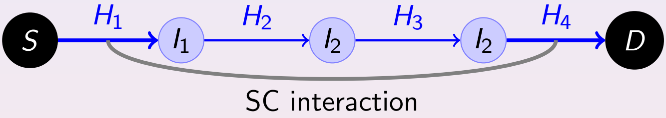
SC-Chain



HT-Chain

HTC-Chain

SC-Chain



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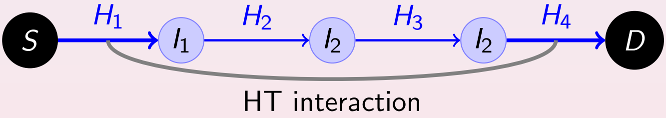
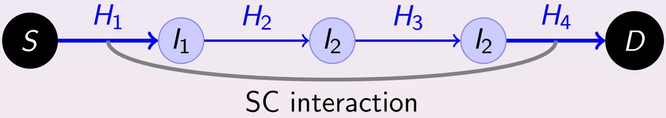


HTC-Chain

SC-Chain



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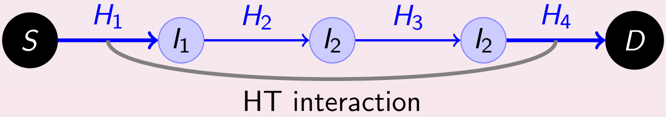

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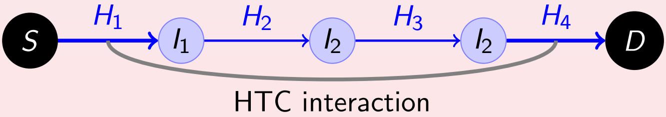


Recap and Problem refinement

4 prominent MAC interactions under two-flows

- NI, SC, HT and HTC

3 prominent isolated chain categories

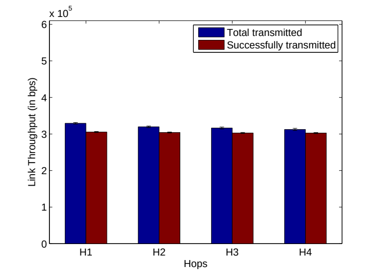
- SC-, HT- and HTC-Chains

Terms

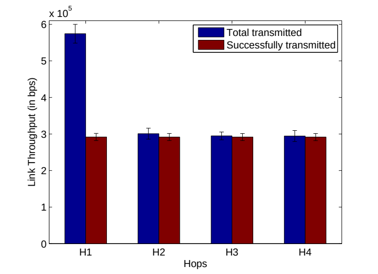
- Connected, Pipelining, X interaction vs. X-Chain, Variability

Contributions:

- Isolated chain analysis
  - *Performance variability, Hop-distance distribution*
- Cross-chain interaction analysis
  - *Vulnerability of chains/links to collisions*
  - *Performance variability, Effect of pipelining*



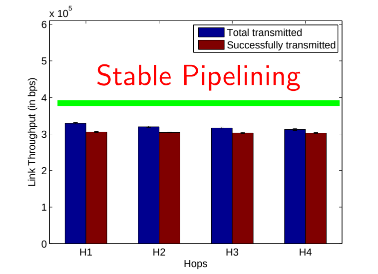
SC-Chain



HT-Chain

Summary

- Pipelining:
  - Smooth in SC
  - *Noise* at H_1 of HT- and HTC-Chains
- Variability: Highly predictable behavior



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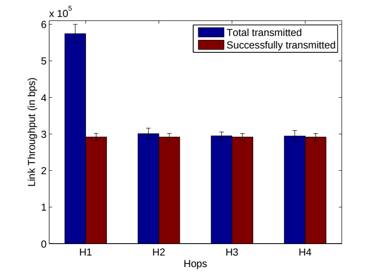

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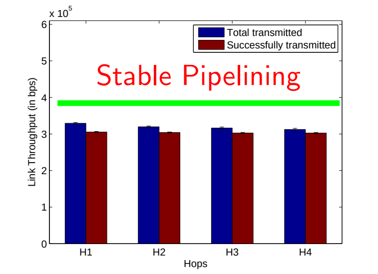

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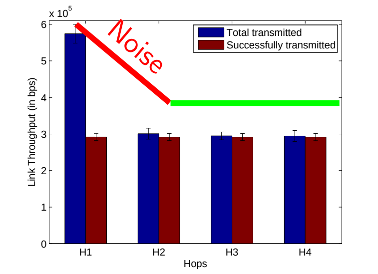

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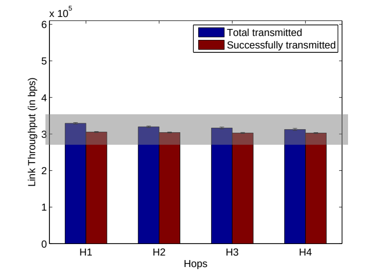

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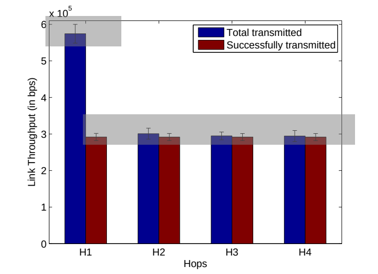

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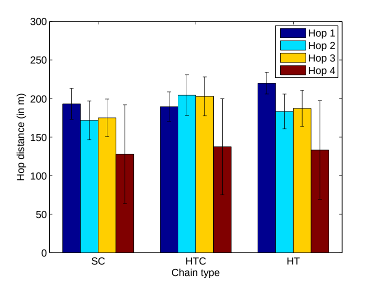
Hop-distance distribution

- Last hop has large variance
- HT interaction: Large distance between $S - R$
- HTC interaction: Less distance between $I - R$, reasonable hop-distance



Hop-distance

Cross-chain interaction characteristics

MAC interactions: Independent links.

- Collisions possible at any node.

Isolated chain interactions: Constrained.

- Node-locality and Pipelining.

Cross-chain interactions:

- Independent cross-chain interactions.
- Constrained self-interference interactions.

Characterizing cross-chain scenarios are harder.

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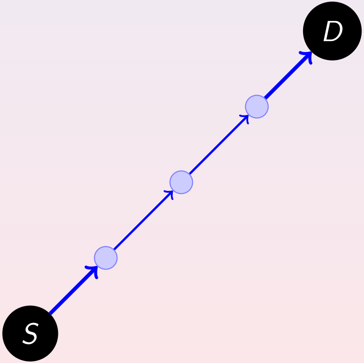

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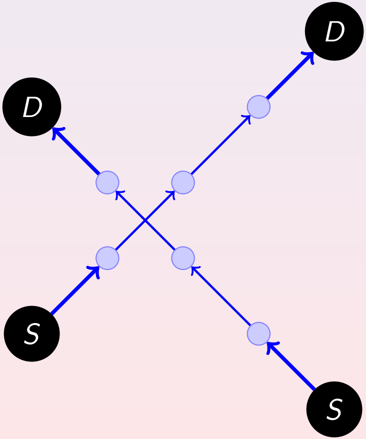

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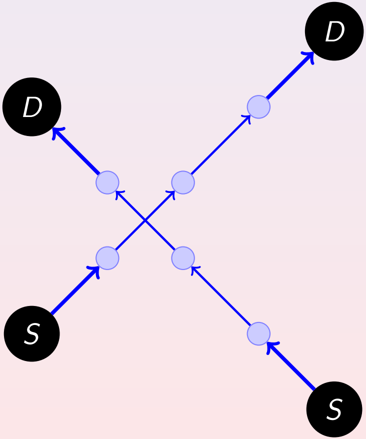

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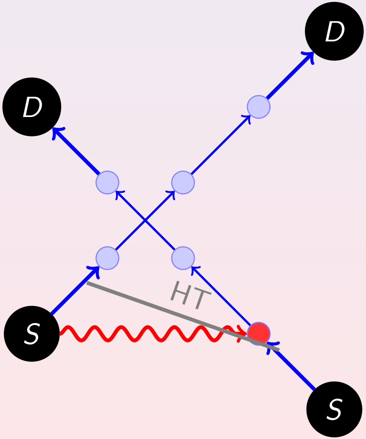

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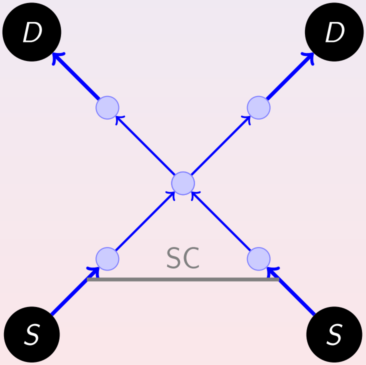
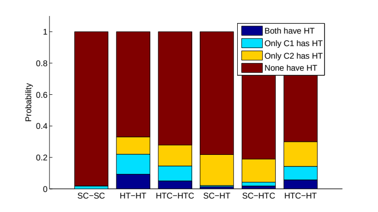


Vulnerability to cross-chain HT & HTC



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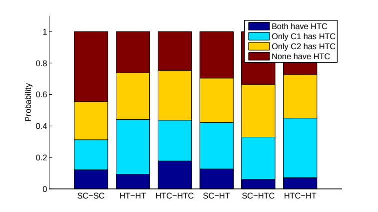

HTC interaction

- SC-Chains: Immune to HT ($\approx$ 0%), but not HTC (up to 55%).
- HTC- and HT-Chains: vulnerable to both HT and HTC.

Cross-chain HTCs is hard to prevent.

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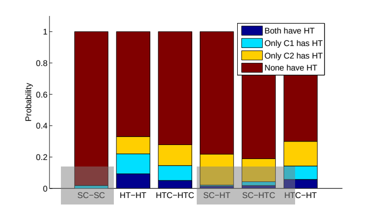

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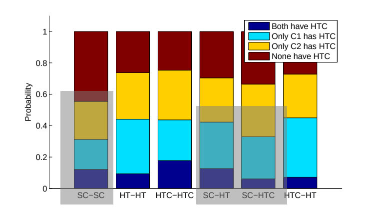

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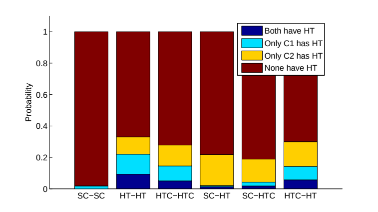

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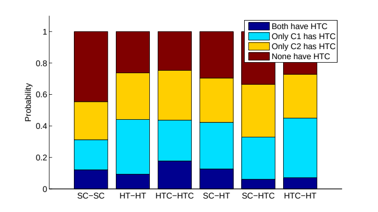

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Link vulnerability to cross-chain HT & HTC

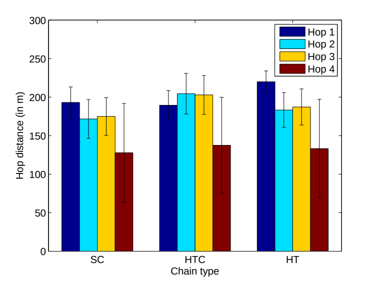
Vulnerability = Probability of link having HT/HTC = $p_c(.)$

Longer links are vulnerable to HT.

- Last hops: $\max(p_c(HT)) = 0.07$
- H_1 of HT-Chain: $p_c(HT) > 0.89$
- H_2 of HTC-Chain: High

HTC weakly depends on hop-distance.

- Most links are vulnerable to HTC.
- H_4s: $0 \leq p_c(HTC) \leq 0.32$
- H_1 of HT-Chain: $0.55 \leq p_c(HTC) \leq 0.9$



Hop-distance

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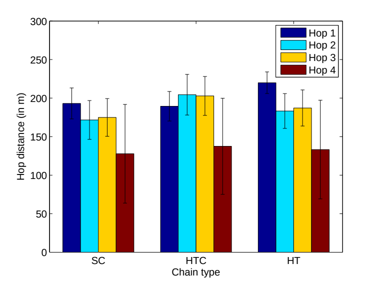


Hop-distance

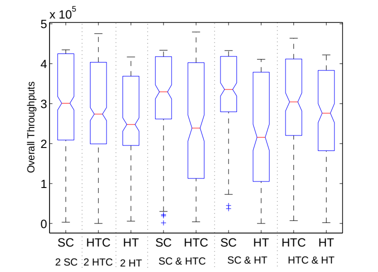
Variability

Probability of occurrence of HT/HTC can be computed

- But performance has large variations

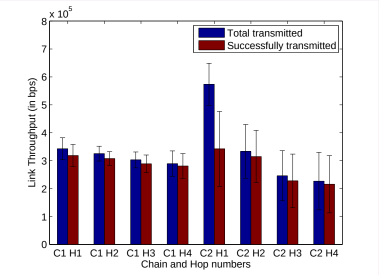
Categorizing cross-chain interactions based on self-interference is insufficient

- Very large combination of link interactions have to be considered

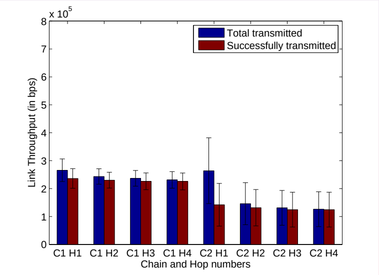


Variation of throughput

Principal metrics for predicting performance



Unconnected H1 of HTC-Chain



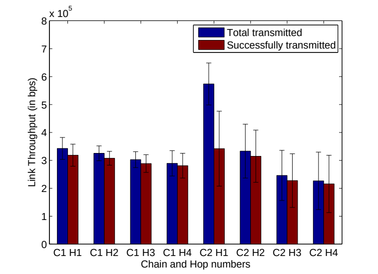
Connected H1s

Throughput under SC- and HT-Chain scenario

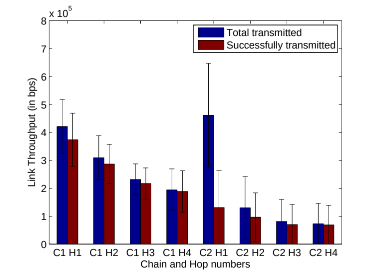
Avoid SC interaction with chain sources

- Sources disconnected to *initial* hops of other chains perform better.

Impact of collisions



Unconnected H1 of HT-Chain



H1 of HT-Chain has HT

Throughput under SC- and HT-Chain scenario

Effect of collisions can be drastic on HT- & HTC-Chains.

- SC- and HTC-Chain scenario: 75% reduction in throughput.

Conclusions

We analyzed the impact of cross-chain interactions on different categories of chain.

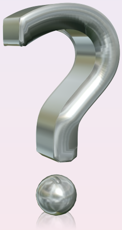
- Link and chain vulnerability to various forms of collisions.
  - Longer hop-distance: Vulnerable to HT.
  - HTC occurs frequently irrespective of hop-distance.
- Performance variability and pipelining.
  - Self-interference metrics insufficient to characterize cross-chain.
  - Avoid contention and HTs from earlier hops of the route.

Our empirical study provides key insight for:

- Understanding the interaction pattern at routing layer.
- Developing interference-aware protocols in wireless networks.

Future Work

- Measurement-based interference estimation.
- Interaction based routing.



Thank you.

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References

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