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Background
Self-interference in Chains
Cross-chain interaction analysis
Conclusion and future work

How do Wireless Chains Behave? The Impact of MAC Interactions

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RWTH Aachen University, Germany

ACM MSWiM, 2009

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Problem Statement

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

- Analysis and design of systems difficult

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High-level Motivation

Interference in wireless systems are poorly understood

Better understanding and characterizing is necessary
- Design interference-aware protocols
- Redesign complete layering schemes

Interference effects at lower layers has a great impact on higher layers.
- MAC level interactions play a central role in governing performance of a route.

Focus of the paper

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Recently, a new approach for analyzing interference at the CSMA based MAC layer was proposed.

- Several interactions occur between any two links due to effect of interference.

Our contribution: Analyze the interactions that occur in a single multi-hop chain.

- Chain is a sequence of nodes from source to destination.

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CSMA interactions in MHWNs

Two-flows under CSMA/CA

Countable number of interaction patterns:

- 10 categories under SINR model [2]

4 promintent categories.
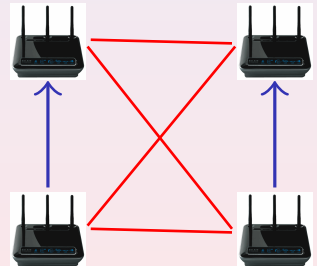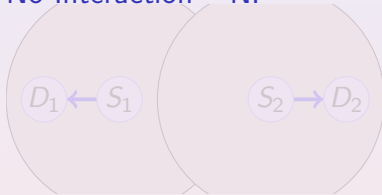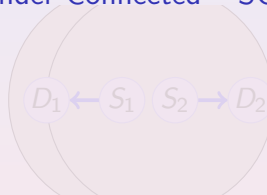
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No Interaction – NI

Sender Connected – SC

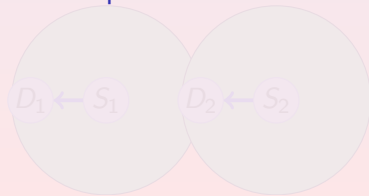## Hidden Terminal – HT (AIS)

HT with Capture – HTC

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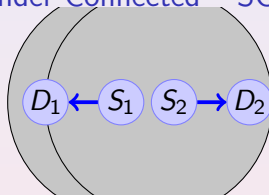

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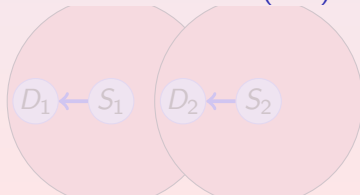

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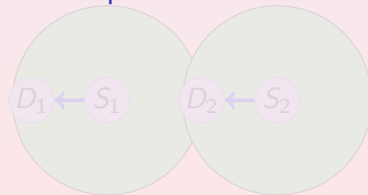
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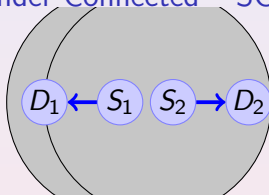Self-interference in Chains
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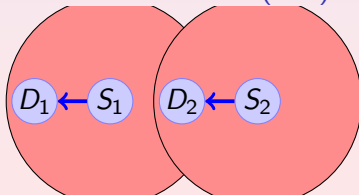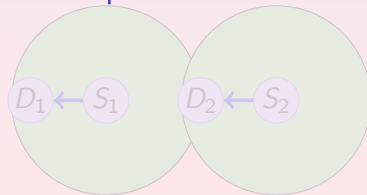
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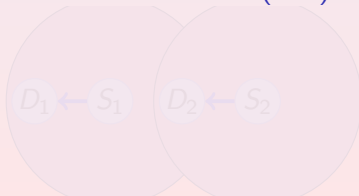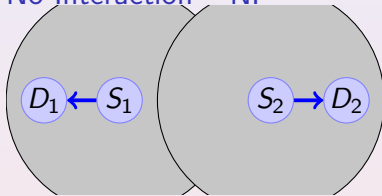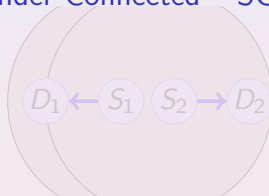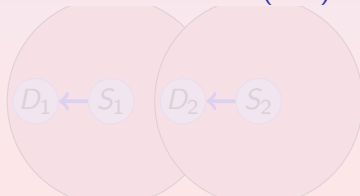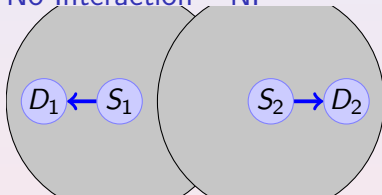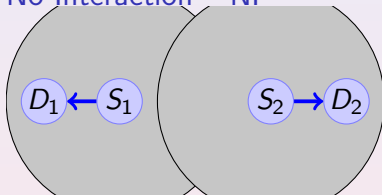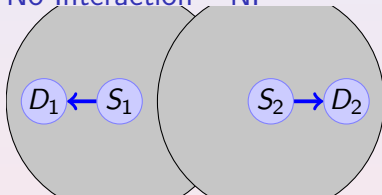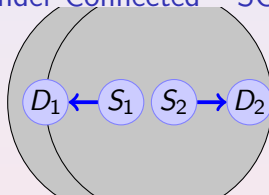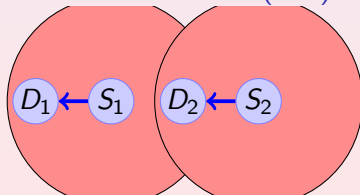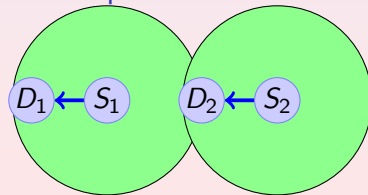
Contributions

- Systematically classify all possible categories of isolated chains based on MAC interactions.
- Examine how frequently each category occurs.
- Evaluate the impact of MAC interactions on performance.
  - Testbed and simulation.
- Cross-chain interaction analysis.
  - Vulnerability of chains to cross-chain hidden terminals.

Factors that affect chain behavior

- MAC level interactions within a chain.
- Cross-chain interactions.
    - Interactions that arise between links of two or more chains.
- Pipelining effect.
- Unfairness due to insufficient channel idle-periods.

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Pipelining

- Traffic on later hops depend on traffic transmitted by earlier hops.
- Implication: Effect of MAC interactions from later hops to earlier hops is controlled.

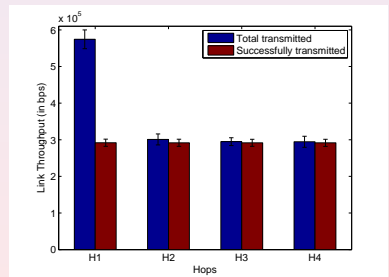Figure: Throughput across chain pipeline

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System description and notations

- We start with analysis of 4-hop chains.
  - Minimum number of hops to observe non-trivial interactions.
  - Extend it to n-hop chains later.

- Link-quality based routing (NADV)

$$S \xrightarrow{H_1} I_1 \xrightarrow{H_2} I_2 \xrightarrow{H_3} I_3 \xrightarrow{H_4} D$$

Three important self-interference interactions

- INT1 – Between $H1$ and $H4$
- INT2 – Between $H1$ and $H3$
- INT3 – Between $H2$ and $H4$

Chain type nomenclature: INT1-INT2-INT3 chain (e.g. HT-SC-SC chain).

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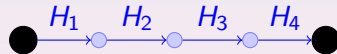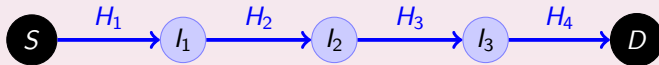
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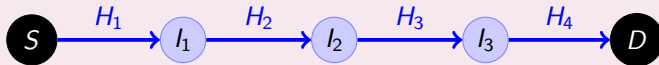- Link-quality based routing (NADV)

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Probability of occurrence
Performance analysis
Generalization for n-hop chains

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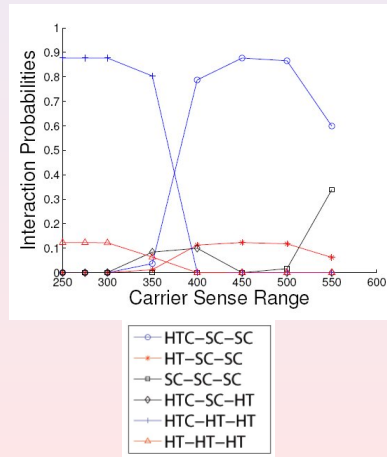# How often does each chain category occur?

Simulations with random 4-hop chains in different node-densities. Vary carrier sensing range and observe interactions.
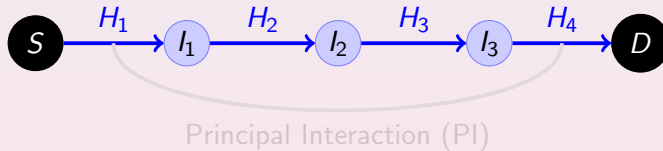
For realistic carrier-sensing ranges:

- INT2 and INT3 are SCs: INT1 is the principal interaction.

- Only 3 type of chains are predominant.

    - HTC/SC/SC chain (HTC-Chains)
    - SC/SC/SC chain (SC-Chain)
    - HT/SC/SC chain (HT-Chain)

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Recap: Categories of isolated chains

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

Principal Interaction (PI)

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

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SC-Chain

HT-Chain

HTC-Chain

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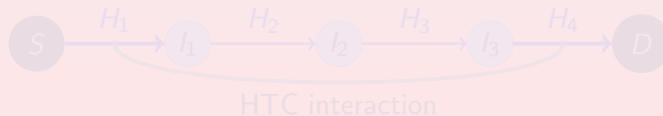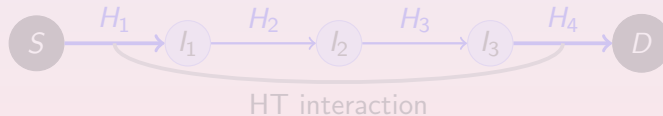
SC-Chain

HT-Chain

HTC-Chain

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SC-Chain

S H_1 I_1 H_2 I_2 H_3 I_3 H_4 D

SC interaction

HT-Chain

S H_1 I_1 H_2 I_2 H_3 I_3 H_4 D

HT interaction

HTC-Chain

S H_1 I_1 H_2 I_2 H_3 I_3 H_4 D

HTC interaction

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Performance analysis: Testbed
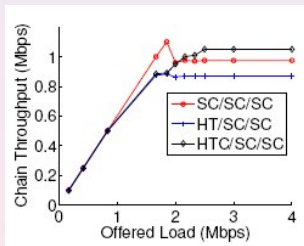
- All chains consume different overall capacity to obtain the same end-throughput.
- Inefficient capacity utilization in HT- and HTC-Chains: Substantial impact on overall consumed bandwidth.

Current routing protocols do not consider MAC interaction based routing.
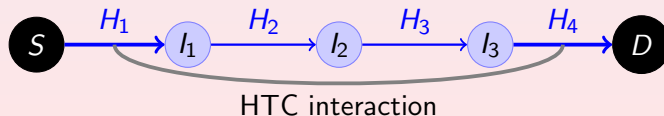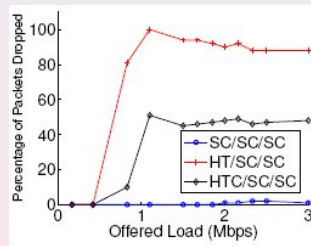
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Generalization to n-hop chains

Number of interactions grow rapidly as n increases ($10^{\frac{n(n-1)}{2}}$)
We eliminate infrequent interactions by following these rules:

- Three prominent MAC interactions (SC, HT, HTC).
- Realistic carrier-sensing ranges eliminate some interactions.
- Node locality constraint: Intermediate hops are along the line from source to destination.

Num interactions $= 3^{(n-3)}$

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Performance of n-hop chains

Summary: Performance results follows same trend as in 4-hop scenario.

- All chains have similar overall end-throughput; wasted capacity in chains with HT/HTC.

Observations:

- Throughput of chain is independent of number of SC, HTC or HT interactions.
- Number of dropped packets due to HT/HTC is a function of the hop number.
  - Earlier the hop with HT/HTC, greater is the wasted capacity.
- Chains with only SC perform better than HT- or HTC-Chains

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Cross-chain interaction characteristics

MAC interactions: Independent links.

- Collisions possible at any node.

Isolated chain interactions: Constrained.

- Node-locality.

Cross-chain interactions:

- Independent interactions between chains – Larger number of interactions.

- Constrained self-interference interactions.

Characterizing cross-chain scenarios are harder.

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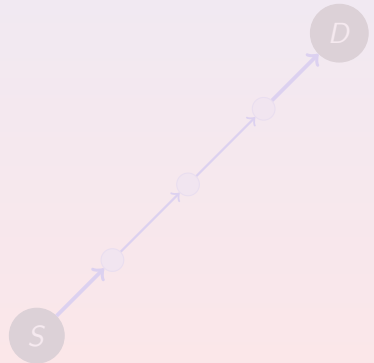MAC interactions: Independent links.

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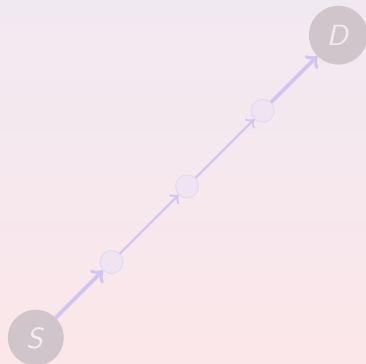MAC interactions: Independent links.

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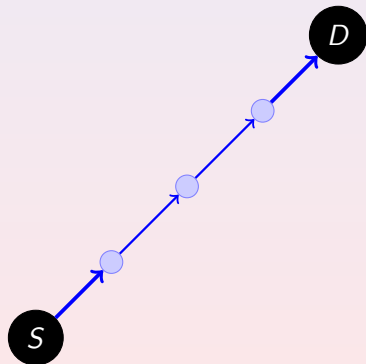MAC interactions: Independent links.

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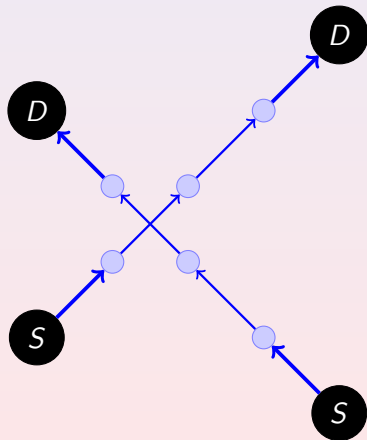MAC interactions: Independent links.

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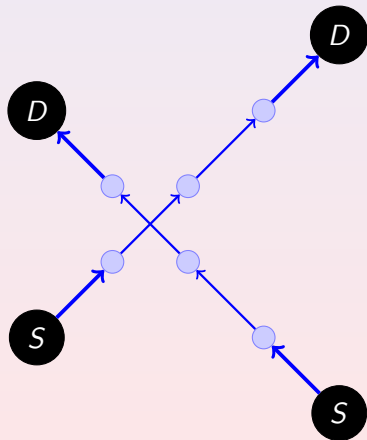MAC interactions: Independent links.

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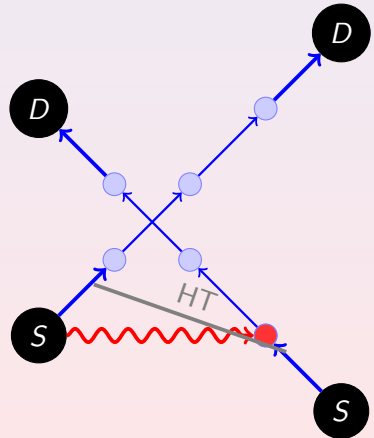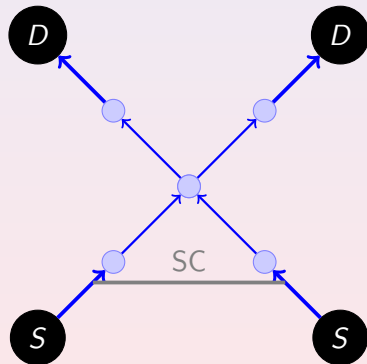MAC interactions: Independent links.

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There are 2 chains interacting with each other; and 3 categories of chains.

Hence, 6 scenarios:

- 2 SC-chains, 2 HT-Chains, 2 HTC-Chains, SC- and HTC-Chains, SC- and HT-Chains, HT- and HTC-Chains

We analyze cross-chain interactions in above scenarios:

- Does the type of chain affect its susceptibility to cross-chain interference?
- Priliminary analysis of the effect of HT and HTC on performance of chains.

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Vulnerability of chains to HT/HTC interactions

HT-Chains and HTC-chains are more vulnerable to cross-chain HT and HTCs.

- 55% for SC-Chains and 80% for HT-/HTC-chains

Routing hint: SC-Chains are more robust in dynamic environment.

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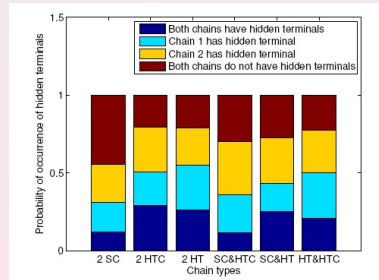
Vulnerability of links to HT/HTC interactions

We calculate the conditional probability that a link has cross-chain HT/HTC interaction, given a certain self-chain interaction.

Links that had HT/HTC in self-chain are more vulnerable to cross-chain HT/HTC interactions.
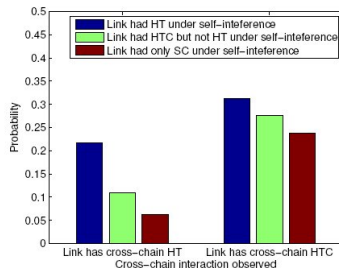
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Conclusion

- We classified the types of isolated chains based on MAC interactions.
- Empirically analyzed the occurrence probability and performance of chains.
  - Testbed and simulation
  - Three type of chains are most common: SC-, HT- and HTC-Chains.
  - All chains have similar end-throughput, but capacity efficiency drastically differs.
- Examined the impact of cross-chain interactions.
  - Stronger categories in self-chain are more robust under cross-chains.

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Future work

- Recently, our paper on in-depth analysis of cross-chain behavior has been accepted [3].
- Measurement-based interference estimation.
- Interaction based routing.

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Thank you.

For further information, please contact:
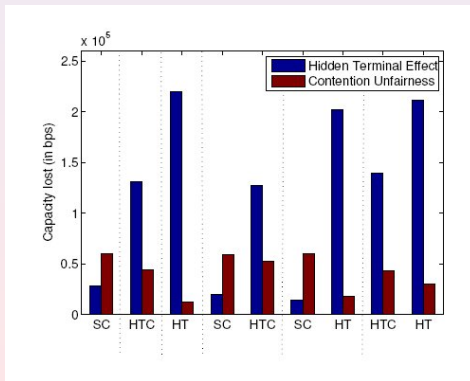Saquib Razak: srazak@cmu.edu
Vinay Kolar: vinkolar@gmail.com

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References

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Problem and Motivation
Background
Self-interference in Chains
Cross-chain interaction analysis
Conclusion and future work

Backup slide: Related work

- Enumerates impact of MAC interactions
- Experimental validation of results
- Studies empirical probability of occurrence of each type of interaction based on routing rules and node density
- n-hop chain
- Two-chain interaction study
- SINR propagation model

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Backup slide: Effect of HT and contention unfairness

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