A Robust Interference Model for Wireless Ad-Hoc Networks

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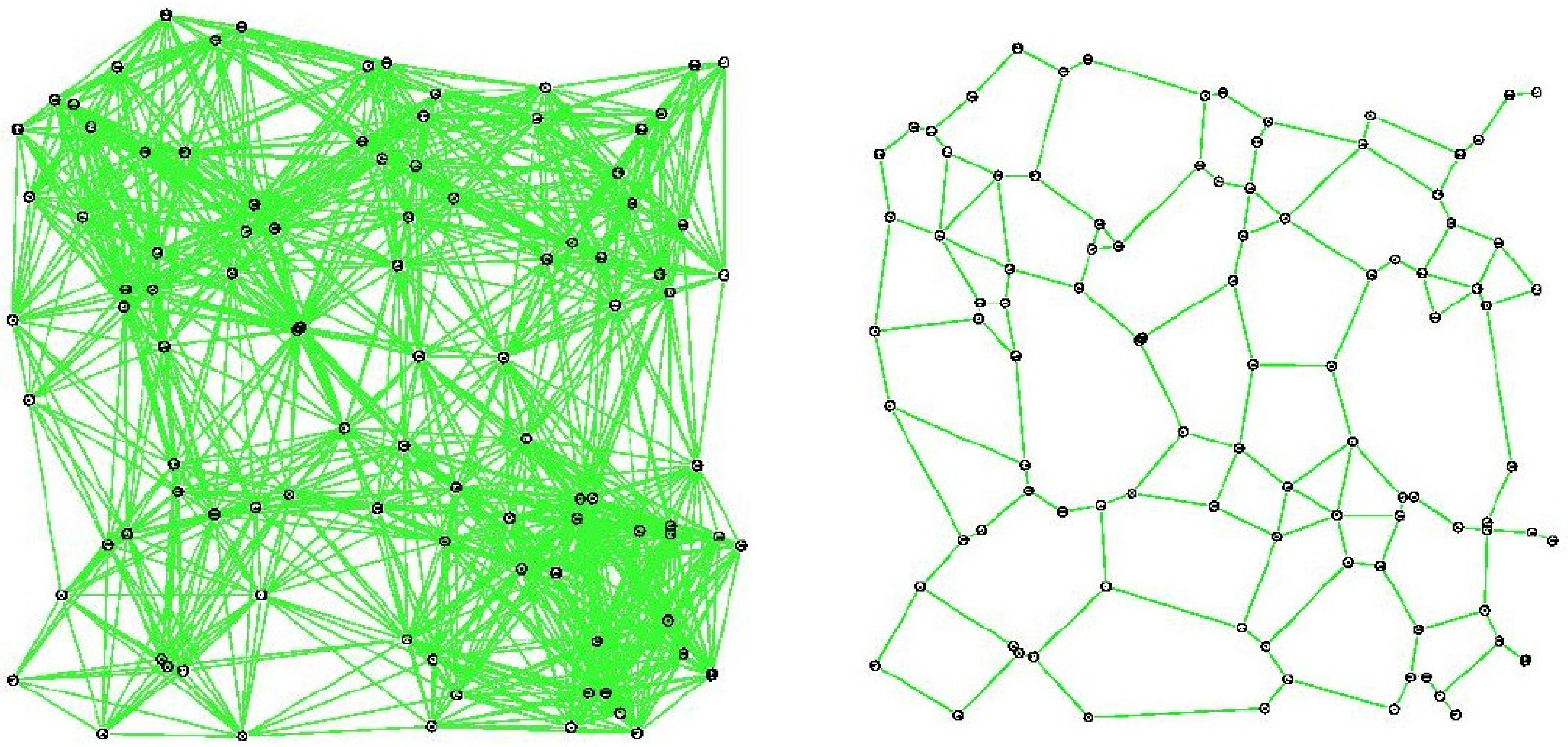
Overview

- What is Topology Control?
- Context – related work
- A robust interference model
- Interference in known topologies
- The highway model
  - Exponential node chain
  - General highway
- Conclusions

Topology Control

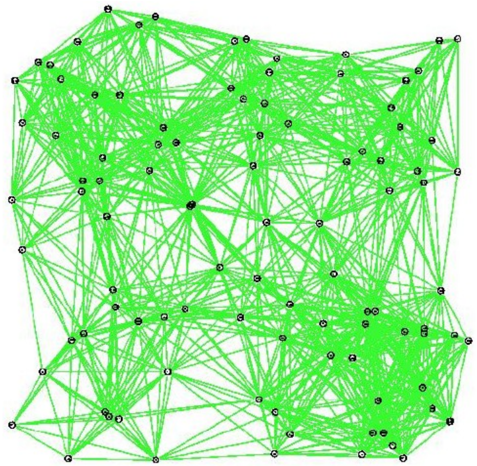


- Drop long-range neighbors: Reduces interference and energy!
- But still stay connected

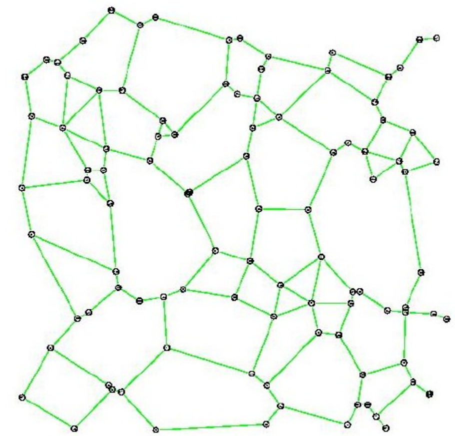
Topology Control as a Trade-Off

Sometimes also clustering, Dominating Set construction

Not in this presentation



Topology Control



Network Connectivity

Conserve Energy
Reduce Interference

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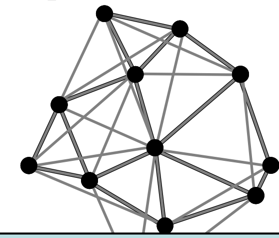
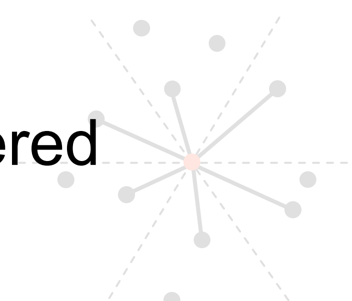
Reducing Interference by Graph Sparseness or Bounded Degree

- Constructions from computational geometry
  - Delaunay Triangulation [Hu 1993]
  - Minimum Spanning Tree [Ramanathan & Rosales-Hain INFOCOM 2000]
  - Gabriel Graph [Rodoplu & Meng J.Sel.Ar.Com 1999]



- Cone-Based Topology Control
  - [Wattenhofer et al. INFOCOM 2000]
  - [Li et al. PODC 2001, Jia et al. SPAA 2003, Li et al. INFOCOM 2002]
  - [Wang & Li DIALM-POMC 2003]

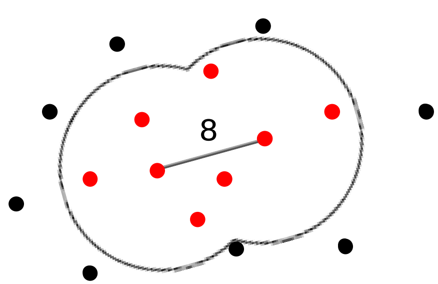
local, planar, distance and energy spanner, constant node degree



Interference is considered only implicitly!

Explicit Interference Definitions

- Diversity as an interference measure [Meyer auf der Heide et al. SPAA 2002]
  - Interference between edges, time-step routing model, congestion
  - Trade-offs: congestion, power consumption, dilation
  - Interference model based on network traffic
- Link-based interference model [Burkhart et al. MobiHoc 2004]
  - „How many nodes are affected by communication over a given link?“
  - Minimize the maximum interference & preserve connectivity
  - Graph sparseness or low node degree $\not\Rightarrow$ low interference



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Sender-centric perspective

- Link-based interference model [Burkhart et al. MobiHoc 2004]
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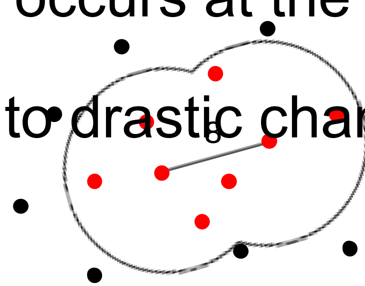
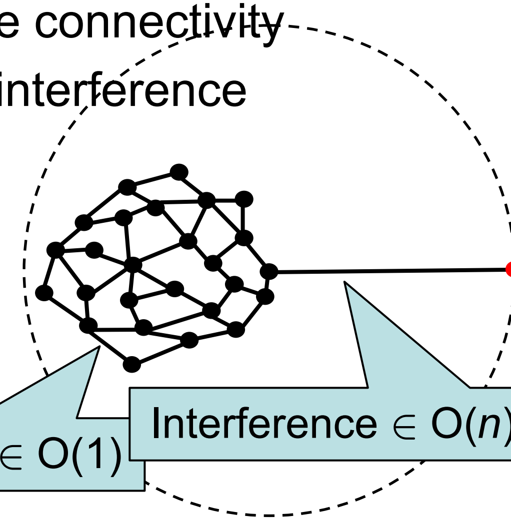
➡ Interference occurs at the receiver

➡ Susceptible to drastic changes





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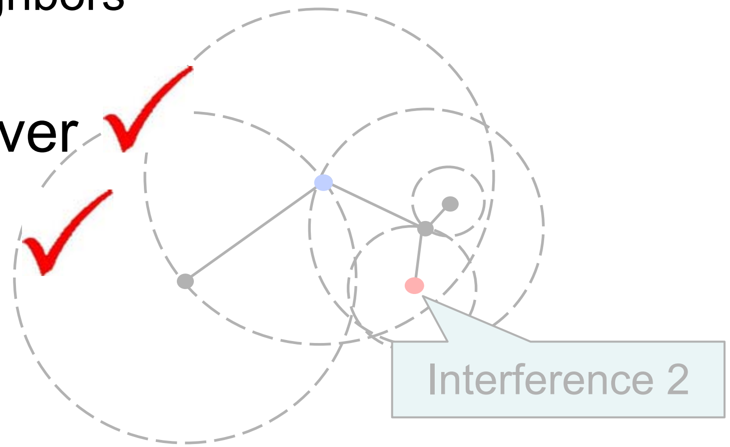
Towards a Robust Interference Model

- Interference model
  - Node *u* disturbs all nodes closer than its farthest neighbor
  - Interference of node *u* =
    #nodes whose distance to *u* is at most the distance to their farthest neighbors

➡ Interference occurs at the receiver ✓

➡ ~~Susceptible to drastic changes~~ ✓



- Problem statement
  - We want to minimize maximum interference
  - At the same time the topology must be connected

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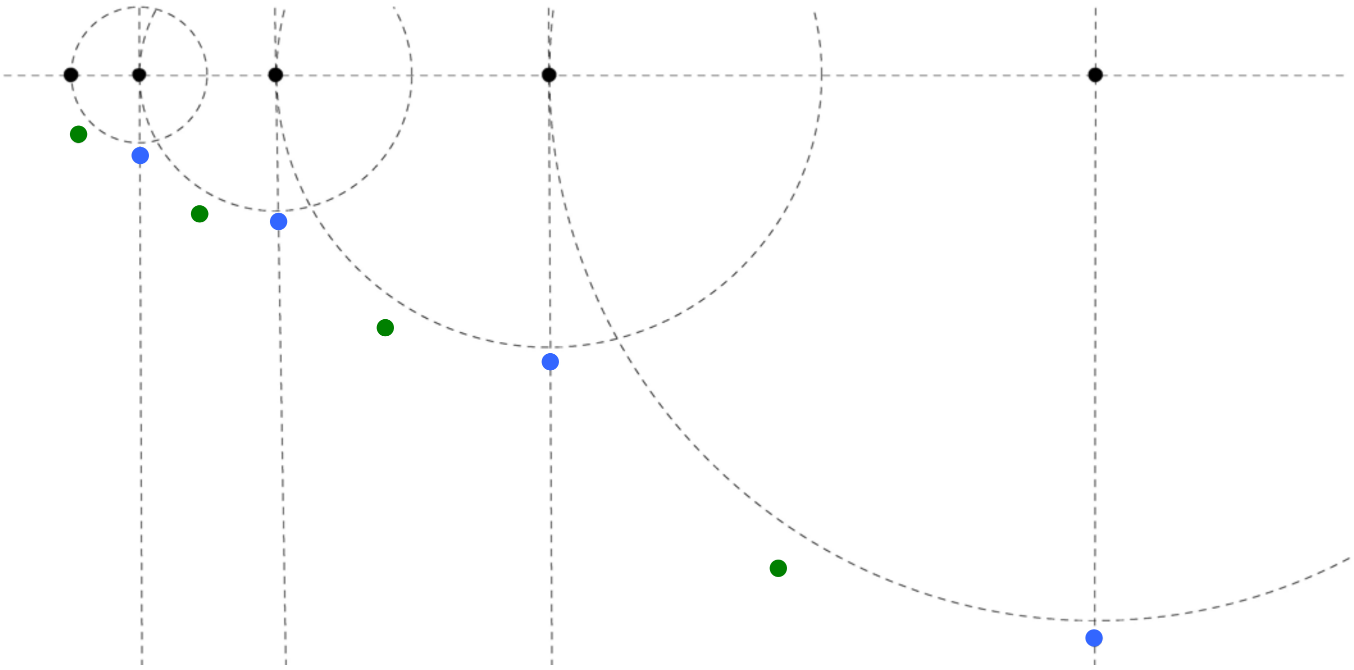
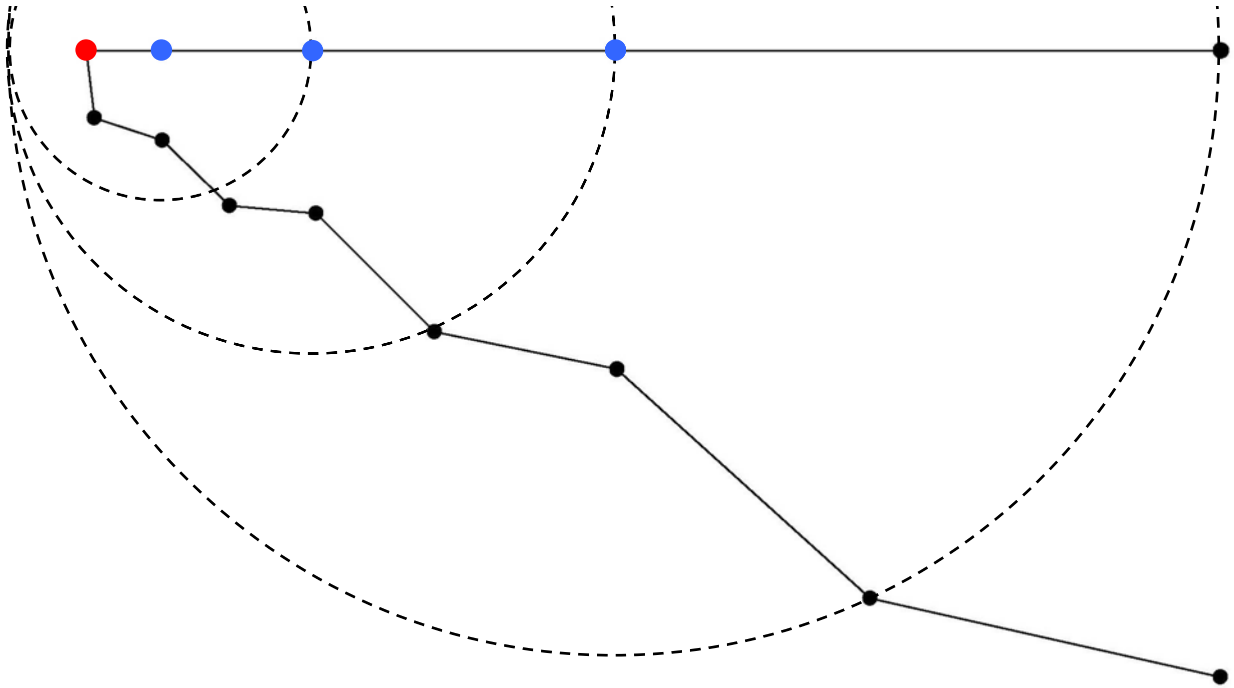
Let’s Study the Following Topology!

…from a worst-case perspective



Topology Control Algorithms Produce…

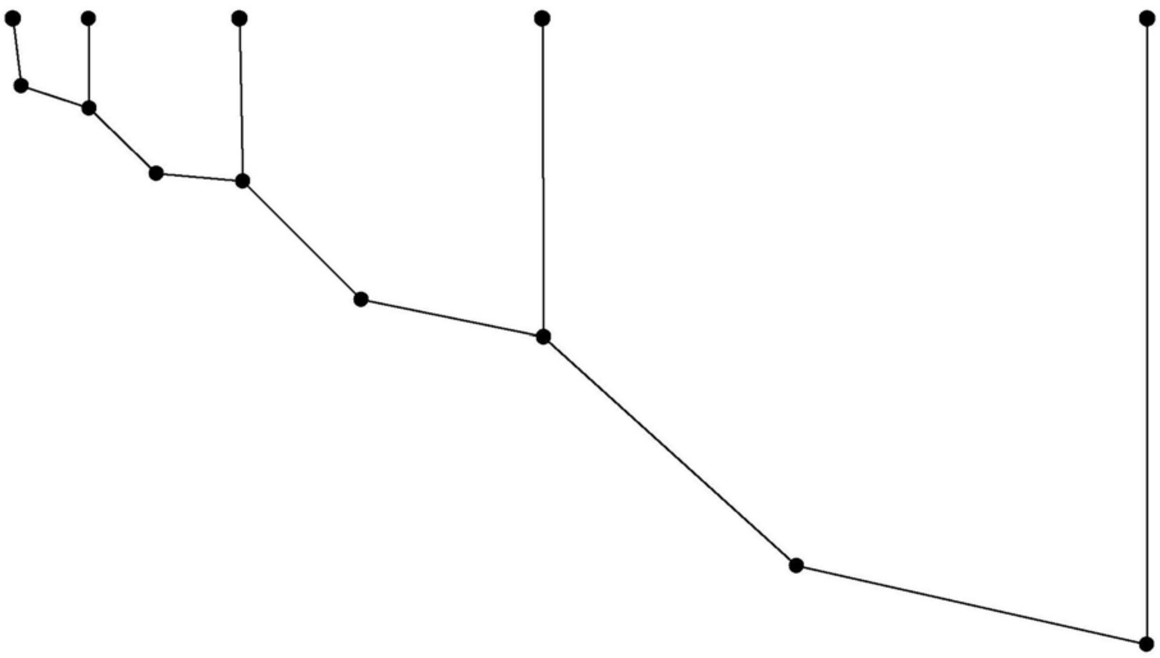
- All known topology control algorithms (with symmetric edges) include the nearest neighbor forest as a subgraph and produce something like this:



➡ The interference of this graph is $\Omega(n)$!

But Interference…

- Interference does not need to be high…



➡ This topology has interference O(1)!!

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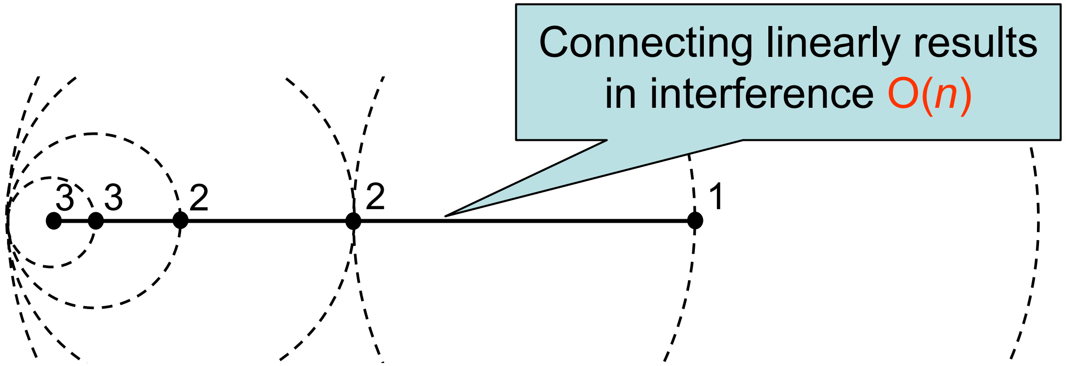
The Highway – a High Interference Topology?

- Already 1-dimensional node distributions seem to yield inherently high interference... [Meyer auf der Heide et al. SPAA 2002]



- ...but the exponential node chain can be connected in a better way

The Highway – a High Interference Topology?

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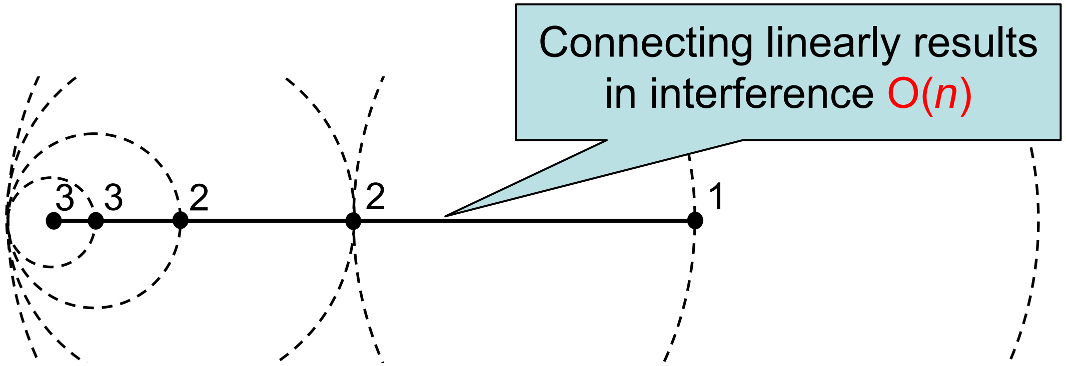

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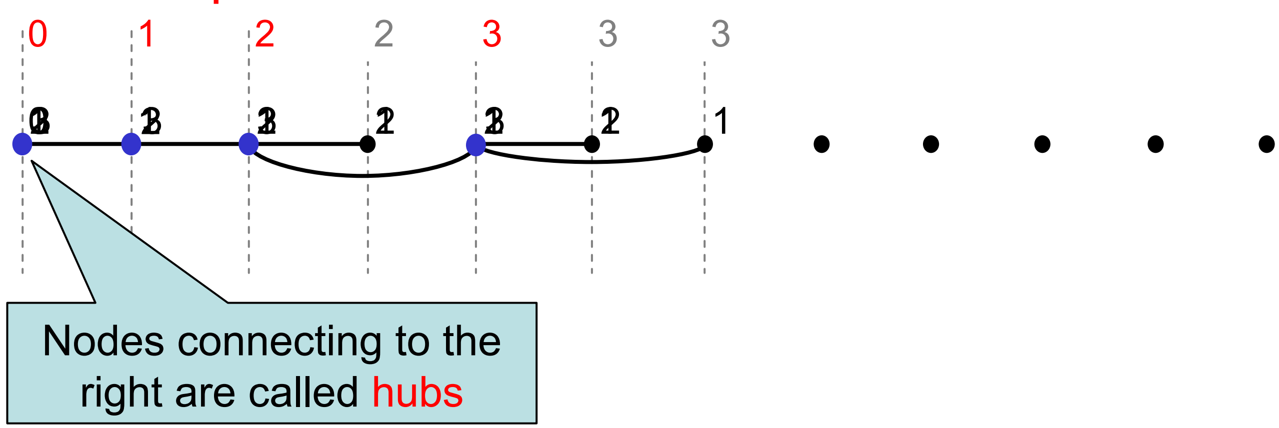

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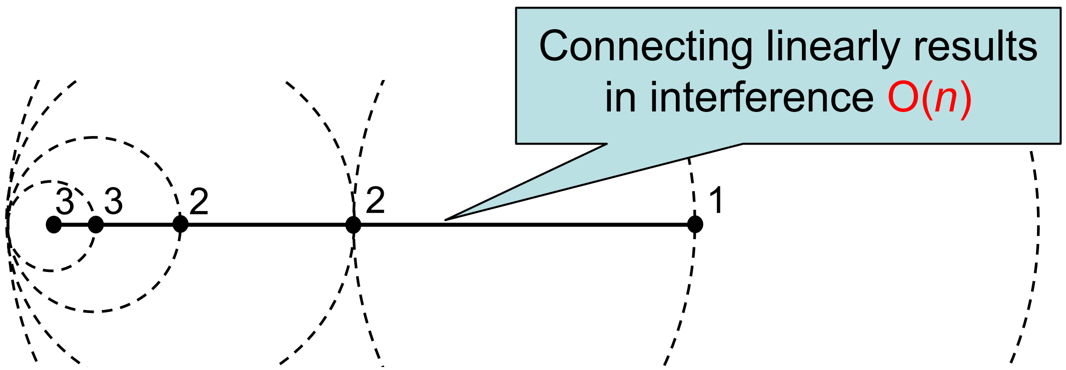

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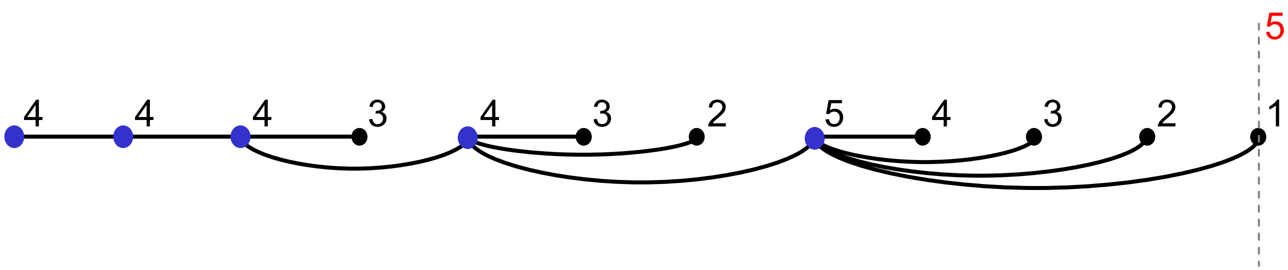
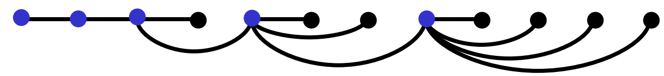


$$\text{Interference} = \left\lfloor \frac{\sqrt{8n-15}+3}{2} \right\rfloor \in O(\sqrt{n})$$

Can We Do Any Better?

- Observations
  - Interference $\geq$ #hubs - 1
  - Interference $\geq$ maximum degree



- Assumption
  - Optimum-interference topology yields interference < $\sqrt{n}$

$\Rightarrow$ #hubs $\leq \sqrt{n}$

$\Rightarrow$ max degree < $\sqrt{n}$

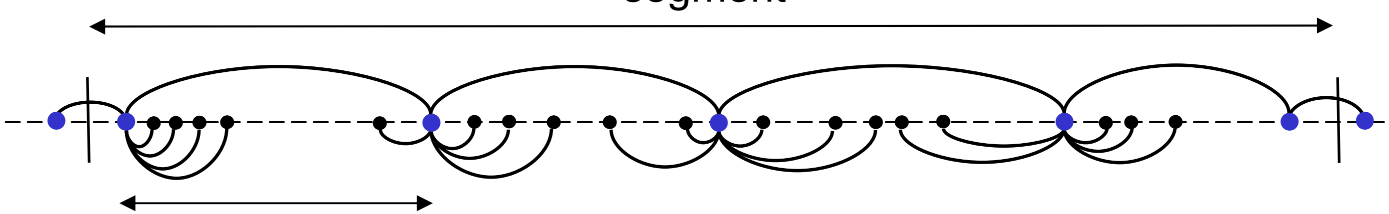
Resulting topology is not connected

$\sqrt{n}$ is a lower bound for the interference in the exponential node chain!

The General Highway Model

Δ = maximum node degree in the UDG

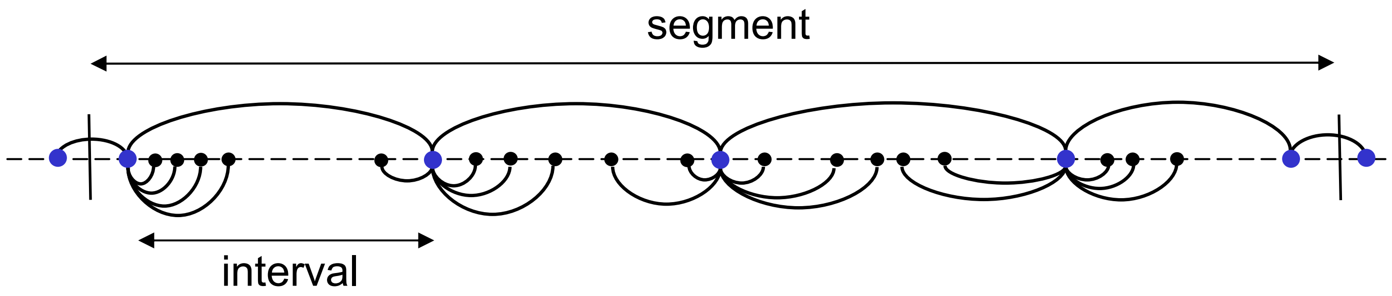
- Arbitrary distributed nodes in one dimension
- Are there instances where a minimum-interference topology exceeds interference $\Omega(\sqrt{\Delta})$?



- Algorithm $\mathcal{A}$
  - Partition the highway into segments of unit length 1
  - Every $\sqrt{\Delta}$-th node in a segment becomes a hub
  - Connect hubs linearly
  - Connect all other nodes to their nearest hub
  - Connect adjacent segments

hub = node with more than one neighbor

On the Highway…



- Observations
  - #hubs in a segment is in $O(\sqrt{\Delta})$
  - Regular nodes only interfere with nodes in the same interval
  - The interference range of a node is limited to adjacent segments

➡ The resulting topology yields interference $O(\sqrt{\Delta})$

➡ Algorithm $\mathcal{A}$ is designed for the worst-case!

Approximation Algorithm

- Idea
  - Only apply Algorithm $\mathcal{A}$ to high interference instances…
  - …else connect nodes linearly

- Algorithm
  - Connect nodes linearly
  - If interference > $\sqrt{\Delta}$ $\Rightarrow$ apply Algorithm $\mathcal{A}$

➡ The resulting topology approximates the optimal interference up to a factor in O($\sqrt[4]{\Delta}$)

- Proof
  - Lower bound also applies to general highway

Conclusions

- Definition of an explicit interference model
  - Receiver-centric
  - Robust with respect to addition/removal of individual nodes

- All currently known topology control algorithms fail to confine interference at a low level

- Focusing on networks in one dimension
  - $\sqrt[4]{\Delta}$-approximation of the optimal connectivity-preserving topology

- Future work

  ➡ Adaptation of our approach to higher dimensions

Questions?

Comments?

Distributed Computing Group